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The relationship between dimensional structure and individual differences in mental ability: A perceptual model of inductive reasoning

Andrist, Charlotte Giovanetti, Ph.D.
Case Western Reserve University, 1991

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THE RELATIONSHIP BETWEEN DIMENSIONAL STRUCTURE AND INDIVIDUAL DIFFERENCES IN MENTAL ABILITY: A PERCEPTUAL MODEL OF INDUCTIVE REASONING

by

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Submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy

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Abstract

by

CHARLOTTE GIOVANETTI ANDRIST

The purpose of the current research was to systematically investigate the relationship between levels of perceptual structure and individual differences in cognitive ability. Two computerized studies were conducted. The first study tested the importance of changing dimensional relationships among novel perceptual stimuli (interstimulus structure) in the prediction of individual differences. The second study further defined two specific parameters of interstimulus structure: amount and form, and tested the relationship among parameters of interstimulus structure, individual stimulus complexity (intrastimulus structure), and individual differences in cognitive ability. The first study was conducted at Lackland Air Force Base with 220 Air Force recruits. The second study was conducted at Cleveland State University with 100 college undergraduates.

Results from the first study indicated that changing dimensional structure between stimuli was an important factor in the prediction of individual differences in intelligence. Study 2 replicated and expanded results from Study 1. Parameters of interstimulus form and amount were identified as independent predictors of individual differences in mental ability in Study 2. Interstimulus form was the most highly related to individual differences in general cognitive ability. Mediating effects were identified for stimulus complexity and the order in which
problems were presented. Basic cognitive processes of discrimination and learning predicted portions of the variance attributed to interstimulus amount and form, respectively. Interstimulus structure was an important predictor of individual differences in cognitive ability after effects of basic cognitive processes were partialed out. In sum, changing dimensional relationships between stimuli were important predictors of individual differences in general cognitive ability. Royer's (1978) structural model of individual differences was supported. Results were consistent with interpretations of Spearman's (1923) qualitative model of mental ability as a model of perceptual processing.
Dedication

This dissertation is dedicated to Martha Eva Giovanetti,
whose words and deeds have shaped my life.
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The difficult part about acknowledgements is that inevitably, someone who has helped in a very special way is left out, not because their help was not appreciated, but just simply because it is impossible to mention everyone. But the good part about acknowledgements is that the many people who have helped in so many important ways are at last recognized. So to all those, mentioned and unmentioned, who have been so supportive during what seems to have been an endless process, I say thank-you.

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Introduction

The purpose of the current research was to investigate the relationship between varying degrees of perceptual structure and individual differences in cognitive ability. Two studies were conducted. The first study tested the importance of interstimulus structure in the study of individual differences. Interstimulus structure is an index of the perceptual relations between two or more multidimensional stimuli as opposed to intrastimulus or individual stimulus complexity. The second study further defined parameters of dimensional structure and tested the relationship among interstimulus structure, intrastimulus structure, and individual differences in cognitive ability.

Background

It is the intelligent person who is often able to impose order on what might appear to be unrelated events. It is this ability to recognize and successfully utilize structure that helps distinguish the intelligent from the unintelligent person (Royer, 1978). Spearman (1923) called it the 'ability to educe relations between objects'. Thurstone (1931) called it 'inductive reasoning'. Performance on inductive reasoning tasks has been shown to be highly correlated with intelligence. In fact, inductive reasoning has been described as the cornerstone of intelligence in many current theories of intelligence (e.g., Pellegrino, 1985; Sternberg & Garner, 1982).

Perceptual processes played a crucial role in Spearman’s (1923) model of intelligence. Consistent with this notion, it has been argued that the ability to perceive stimulus structure should be highly related to individual differences in intelligence (Royer, 1978). But the relationship between individual differences in intelligence and individual differences in the ability to perceive stimulus structure is not clearly understood. For example, results from studies investigating the relationship between measures of perceptual structure and individual differences in intelligence have not consistently supported a relationship between intelligence and the ability to use stimulus structure (e.g., Silverman, 1975). Even studies which have identified a relationship between measures of perceptual structure and individual differences in intelligence
have identified differences in the encoding time of stimuli but not patterns of encoding (e.g., Caruso & Detterman, 1983). The lack of a relationship between intelligence and patterns of stimulus encoding brings the role of stimulus structure in the prediction of individual differences into question.

It will be argued that in order to better understand the relationship between individual differences in intelligence and perceptual structure, a distinction between two types of stimulus structure needs to be made: intrastimulus and interstimulus structure. Intrastimulus structure refers to individual stimulus complexity. Individual stimulus structure is closely aligned with information theory and has been shown to affect information load and encoding of individual stimulus items (e.g., Attneave, 1955; Clement & Varnadoe, 1967; Garner, 1962; 1974). Interstimulus structure, on the other hand, is an index of the structure between stimuli in a multidimensional set.

The lack of a relationship between intelligence and patterns of stimulus encoding may be better understood by examining studies according to the type of perceptual structure (intrastimulus versus interstimulus) being studied. The relationship between intelligence and perceptual structure has generally been investigated by manipulating the role of individual stimulus complexity or intrastimulus structure. These studies have investigated a range of both quantitative and structural perceptual measures which reflect the amount and form of information in individual stimuli. Both quantitative and structural aspects of intrastimulus information have been shown to independently influence the encoding difficulty of individual stimuli (e.g., Chipman, 1977; Garner, 1962; Ichikawa, 1985, Kahana, 1989; Royer, 1966). Intrastimulus parameters have been shown to be sensitive to individual differences in encoding time but not patterns of encoding (e.g., Caruso & Detterman, 1983).

The relationship between interstimulus perceptual structure and individual differences in intelligence, on the other hand, has not generally been explored as such. Although studies which measure individual differences in performance as a function of relationships between stimuli, i.e.,
categorization and reasoning studies, have found a strong relationship between individual differences and patterns of performance, these studies have most often explained performance in terms of strategic and/or control processes (e.g., Belmont & Butterfield, 1971; Borkowski, Carr, & Pressley, 1987; Brown & Campione, 1984; Sternberg & Garner, 1982). The role of interstimulus perceptual structure in studies of individual differences has been almost totally ignored. But it is precisely interstimulus structure or the relationships between stimuli which Spearman first identified as a crucial component in the study of individual differences (Spearman, 1923). Before individual differences in performance can be attributed to higher order conceptual and control processes, the role of changing perceptual structure needs to be better understood.

The following sections attempt to outline an important link between perceptual structure and individual differences in cognitive ability by demonstrating that individual differences in intelligence and the ability to detect perceptual structure are not only logically but empirically connected.

_Historical Overview_

If we lose perspective of the past, we are doomed to repeat the same mistakes in the future. On this note, we begin with a brief historical overview of the relationship between perceptual processes and individual differences in mental ability.

_Individual differences in mental ability_

While the teacher tried to cultivate intelligence, and the psychologist tried to measure intelligence, nobody seemed to know precisely what intelligence [was].

--Ballard, 1920 as found in Spearman, 1923, p. 15

The study of individual differences in intelligence as a function of basic perceptual processes is not new. Tests of perception and discrimination were first used by Galton in 1883 in the study of individual differences research (Spearman, 1904). Galton observed that men of marked ability were able to discriminate unusually fine differences in weight and respond faster than men of lesser ability. Galton was concerned with the establishment of an independent test
of 'man's power' which could be compared to laboratory measures of mental processing. This emphasis on the relationship between performance on basic laboratory tests and an independent ability or 'intelligence' measure marked the beginning of the study of individual differences.

Following Galton, studies of individual differences emphasized the role of basic mental processes in predicting intelligence (see Spearman, 1904 for review). Except for the learning studies of Ebbinghaus (Spearman, 1904), these studies were largely unsuccessful in predicting individual differences in general ability or achievement. Early experimental studies investigating the role of basic perceptual processes as well as other basic mental abilities produced very discouraging results (see Tuddenbaum, 1968 for review).

It is not surprising, therefore, that the use of elementary cognitive tasks and the measurement of basic mental processes gave way to the use of complex mental tasks in the prediction of individual differences in ability. These complex mental tasks, as proposed primarily by Binet (Spearman, 1904; 1923), were designed to sample the range of mental abilities and determine an 'average level of ability'. Spearman (1923) was extremely negative about this approach to the study of individual differences. He compares the pooling or averaging of specific mental abilities through the use of complex test items to the weighing of a pile of baggage and subsequently attempting to tell the weight of a particular piece. He states that 'although such testing does...deal with...diverse processes, it certainly does not measure them all, or even any one of them (Spearman, 1923, p. 351). Spearman was not in favor of using complex mental abilities in order to predict intelligence, rather he was interested in identifying the specific mental processes which were important to individual differences in mental ability.

*General psychological laws and individual differences in mental ability*

A glimpse was then caught by us of what appeared to be the root of all evil...psychology had never yet been provided with it's prime requisite, a genuinely scientific foundation. For this can only be of one kind; it must necessarily be constituted of ultimate laws, and in this sense 'principles'.

--Spearman, 1923; p. 341
Spearman was concerned with two aspects of intelligence, the quantitative and qualitative. The quantitative aspect of intelligence represented the amount or level of intelligence that a person possessed; the qualitative aspect of intelligence represented the mental laws which governed intellectual processes. It was Spearman (1923) who first argued that studies of mental processing must combine the scientific study of psychological laws with the differential study of ability in order to produce a viable model of the intellect. Although Spearman identified ‘g’ as the single best quantitative predictor of individual differences in intelligence, he attempted to understand the qualitative aspects of individual differences in intelligence by developing a process model of the general psychological laws which governed mental processing.

Perceptual processes played a crucial role in Spearman’s (1923) process model of mental ability. Spearman’s model consisted of three basic ‘noegenetic’ principles or qualitative intellectual processes: apprehension of fundamentals, eduction of relations, and eduction of correlates. Apprehension of fundamentals was the initial phase of mental processing which involved the encoding of individual elements. Apprehension was hypothesized to be dependent on the characteristics or complexity of specific fundamentals (elements). The eduction of relations was the ability to infer or ‘educe’ relations between fundamentals. The eduction of correlates was the ability to apply the induced relationship between the first two fundamentals (elements) to another fundament or ‘correlate’. Spearman gave perceptual processes a primary role in the transformation of information from sensation to cognition. Although the perceptual test which Raven and Penrose developed to test Spearman’s process model of intelligence has become touted as one of the best quantitative measures of Spearman’s ‘g’, its perceptual qualities have been virtually ignored. It may be precisely these perceptual or structural relationships between stimuli which make the Raven’s Progressive Matrices a sensitive measure of individual differences in intelligence.

In sum, although Spearman is best known for his factor analytic studies of ‘g’ or the general quantitative factor, he was keenly interested in defining the qualitative nature of
intelligence through general psychological laws. Spearman argued that the nature of the quantitative differences in intelligence could only be understood through the qualitative laws of mental processing.

Current Studies of Inductive Reasoning

Studies investigating the relationship between individual differences in intelligence and reasoning can be characterized by two very different fundamental questions: 1) What are the quantitative aspects of inductive reasoning, and 2) What are the qualitative aspects of inductive reasoning? (Spearman, 1923).

Factor analytic studies have generally been used to investigate the quantitative properties of reasoning and their relationship to individual differences in intelligence. These quantitative studies provide a mathematical description of the variance associated with performance on reasoning tasks and its relationship to individual differences in general intelligence. Factor analytic studies have addressed issues such as whether or not individual differences are best predicted by common variance, specific variance, or some combination of these two solutions (e.g., Cattell, 1971; Horn, 1968; Thurstone, 1931; Vernon, 1950).

Qualitative studies of reasoning, on the other hand, are concerned with the nature of the quantitative index, i.e., why are inductive reasoning tasks so highly ‘g’ loaded? Qualitative models can further be divided into process and structural models. Process models attempt to identify the specific mental processes tapped by reasoning tasks and to identify which of these processes are important in the prediction of individual differences. Structural models, on the other hand, emphasize the relationship between changes in task or perceptual structure and subsequent changes in performance.

Although many qualitative models have incorporated components of same-different comparison processes, memory processes, and higher order cognitive rules or strategies, until very recently, few had attempted to control and/or measure basic components of perceptual structure. This seems surprising since perceptual properties were shown to influence individual
differences in performance on reasoning tasks over a decade ago (e.g., Royer, 1978; 1981). If individual differences in reasoning processes are to be understood, the relationship between perceptual structure and intelligence needs to be understood as well.

The focus of the current review is on structural models of reasoning. Until recently, only two such models had been proposed. The first was one by Rumelhart and Abrahamson (1973) and the second was one by Royer (1978; 1981). In the past few years, however, the interest in the relationship between perceptual structure and performance on both reasoning and categorization tasks has grown considerably (see for example Vosniadou & Ortony, 1989).

Rumelhart and Abrahamson (1973) tested the relationship between similarity structure or the 'psychological distance' between animal characteristics in multidimensional space and performance on an analogical reasoning task. The authors hypothesized that performance on analogy tasks could be explained as a function of differential relationships between object attributes in memory. Royer, on the other hand, used novel visual items rather than semantic labels such as animal names and explained performance as a function of the multidimensional structure of the items without invoking an additional memory component. Royer (1978) constructed a 3x3 matrix task which varied in levels of perceptual structure. Royer demonstrated that performance on analogical reasoning tasks can change as a function of the perceptual structure or dimensional redundancy between components in the task. Royer found that both time and number correct on the task were related to the level of perceptual structure or dimensional redundancy in the matrix.

During this same period, Robert Sternberg (1977) designed his now renowned 'componential model of analogical reasoning' which systematically tested information processing components by varying the structure of analogies (e.g. degenerate, semi-degenerate, and normal). Using a form of the classic subtraction paradigm originally proposed by Donders which he termed componential analyses, Sternberg (1977) studied the contribution of separate information components to individual performance measures and constructed an information
processing model of processes important to analogical reasoning. The Sternberg model was
designed to test the role of different information processes in the prediction of performance on
analogy tasks. Sternberg made no attempt to isolate the structural components important to
analogue reasoning, however. Although the Sternberg model systematically manipulated
number of shared attributes between task elements, he did not address the importance of
changing structural demands or to try to isolate performance differences related to changing task
structure.

Mulholland, Pellegrino, and Glaser (1980) attempted to systematically test the
relationship between varying levels of stimulus structure and analogue reasoning. In order to
directly measure the structural components of element and rule complexity, Mulholland et al.
designed a set of true-false geometric analogies which systematically varied the number of
features present in each analogy element (intrasimulus structure) and the number of
transformations between analogy elements (interstimulus structure). In support of past research
investigating same-different comparison processes (e.g., Egeth, 1966) and spatial transformations
(e.g., Cooper, 1980) the authors found that solution times followed a simple serial and additive
model when either the number of transformations or the number of features were held constant
as the other varied. The additive model broke down, however, when the number of
transformations and number of features varied simultaneously. In this case, solution time was a
nonlinear function of features and transformations.

Mulholland et al. (1980) demonstrated that solution time in an analogy task was a function
of both the number of features contained in each stimulus element and the number of features
which changed across each analogy. This was true even if features remained constant across the
analogy. Although Mulholland et al. did not detail an explanation in terms of perceptual
structure, they attributed this finding to parameters of 'encoding' or stimulus content. The
authors also observed that the number of errors was significantly higher when an increased
number of transformations occurred on the same element. The authors attributed the result to
the difficulty of 'mental bookkeeping' or keeping track of simultaneously changing elements in working memory. The ambiguity of the transformational rules was also identified as a potential problem in the study, i.e., problems had multiple potential rules.

More recently, attempts to understand the relationship between performance on reasoning tasks and working memory have been initiated independently by Kyllonen (Kyllonen & Christal, 1990) and Carpenter (Carpenter, Just, & Shell, 1990). In order to establish a link between reasoning and working memory, Kyllonen tested performance across a series of traditional reasoning and working memory tasks and subsequently applied confirmatory factor analyses to the results. A model was produced in which correlations between the working memory factor and the reasoning factor ranged between .80 and .88. Estimates were robust, and were as high as intercorrelations between measures of reasoning and test-retest reliabilities for reasoning tasks. Kyllonen and Christal argued that the link between working memory and reasoning supports Ackerman's (1988) notions that general ability reflects the availability of attentional resources. But the concept of working memory is not clearly operationalized. In fact, the authors suggest that it cannot be determined from their analyses whether working memory tasks account for performance on reasoning tasks or whether reasoning tasks account for performance on working memory tasks. While the research succeeded in linking the concepts of reasoning and working memory in terms of Spearman's quantitative index of 'g', the operationalization of reasoning/working memory tasks in terms of specific information processes or Spearman's qualitative index of 'g' was left unresolved. Although the authors cite failed attempts at developing process models (e.g., Mulholland et al, 1980; Sternberg, 1977) as evidence that the decomposition of reasoning in terms of specific information processes is not feasible, the role of structural models is not addressed by their arguments.

Carpenter and her colleagues (Carpenter, Just, & Shell, 1990), on the other hand, put together eye-movement data, self-report data, and a computer simulation model to establish the importance of working memory in distinguishing the individual differences in performance on
reasoning tasks. Their data converge to support the conclusion that working memory is the primary component which distinguishes between good and poor performance on the Raven's Advanced Progressive Matrices (APM; Raven, 1962). Although the arguments for a working memory component are convincing, the definition of working memory again has components of 'reasoning' embodied in its definition. The question of exactly what constitutes the process of working memory is unresolved.

In general, studies of inductive reasoning do not attempt to either explain or control the role of the perceptual structure on performance. For example, studies investigating the role of transformations in the prediction of individual differences have typically manipulated either task structure (e.g., display layout) or stimulus complexity (e.g., number of elements in the stimuli, information load). But changes in task structure and stimulus complexity have been shown to affect information load and consequently individual differences in performance (e.g., Caruso & Detterman, 1983). These effects have been shown to affect the encoding and response selection/execution components of a task in nonadditive ways (Mulholland et al., 1980). Even when results strongly implicate the process of encoding which is closely tied to measures of information load (e.g., Mulholland et al., 1980; Sternberg, 1977) issues of perceptual structure have all but been ignored in explaining performance. Yet by the law of parsimony, simple or lower level explanations are preferred over more complex explanations.

For example, although the role of perceptual structure was not directly investigated, changing stimulus complexity levels (number of features for each stimulus) and changing relationships of features between stimuli (transformational rules) can be thought of in terms of changing perceptual relationships. Before the relationship between higher order cognitive and/or control processes and individual differences in intelligence can be understood, the relationship between parameters of perceptual structure and individual differences in intelligence needs to be systematically investigated. The objective of the current study is to identify
components of perceptual structure which are important in the prediction of individual
differences in cognitive ability.

A Perceptual Model of Reasoning

Spearman (1923) proposed that mental processing consisted of three basic laws:
apprehension, eduction of relations, and eduction of correlates. Spearman's three basic
noegenetic laws are defined below in terms of two basic parameters of perceptual structure:
intrasimulus structure and intersimulus structure.

Apprehension: Intrasimulus structure

Apprehension is the encoding of a single item or fundaments. Encoding time has been
directly related to amount of information contained in an item or item complexity (e.g., Attneave,
1954; 1955). Attneave hypothesized that the information load of any given stimulus was a
function of the amount of 'uncertainty' or redundancy contained in the stimulus.

Based on Attneave's work, Garner (1962) devised an objective way to determine stimulus
uncertainty. By reflecting and rotating (R & R) the original stimulus, Garner generated an
'implied' set of stimuli which was a defined as the R & R set or equivalence set size. This set
represented the set of items which were equivalent or easily confused with the original item. The
size of the equivalence set was a function of the amount of symmetry in the original stimulus and
subsequently referred to as equivalence set size (ESS). The larger the ESS, the more uncertainty
in the stimulus and the higher the information load. Information load has been shown to affect
the encoding time of stimuli (e.g., Clement & Varnadoe, 1967; Royer, 1966; 1967).

Both Garner (1962) and Royer (1966) distinguished between the amount and form of
stimulus structure. Later work identified two separate components of individual stimulus
complexity (Chipman, 1977). These components were hypothesized to tap orthogonal
components which measured quantitative and structural aspects of a stimulus. Recent work by
Ichikawa (1985) and Kahana (1989) have supported the role of two orthogonal factors in the
determination of individual stimulus complexity. Information load or item complexity has been
shown to be related to individual differences in encoding time (e.g., Caruso & Detterman, 1983; Royer & Weitzel, 1977).

**Eduction of relations and correlates: Interstimulus structure**

Spearman defined the 'eduction of relations and correlates' as the perception of the relationship between two fundamentals or items. In current studies of inductive reasoning, the eduction of relations and correlates has generally been defined in terms transformational rules (e.g., Evans, 1968; Mulholland et al., 1980; Raven, 1948; Sternberg, 1977). On the most basic level, these rules can be thought of as a series of similarity judgements based on the number of shared dimensions between stimuli in multi-dimensional space (e.g., Holyoak, 1984; Royer, 1978; Rumelhardt & Abrahamson, 1973; Smith, 1989; Whitman & Garner, 1962).

The description of transformational rules in terms of dimensional relationships provides a logical transition between conceptual and perceptual structure. Individual differences in the ability to perceive simple dimensional relationships is a fundamental process which has been studied by many authors in the areas of attention, perception, and cognition (e.g., Gibson, 1969; House, 1979; Tighe & Tighe, 1979; Tversky, 1977; Zeaman, 1978). In fact, the ability to recognize and use simple dimensional relationships is often cited as the primary building block for concept formation, categorization, and reasoning (e.g., Medin, 1983; Offenbach, 1983; Smith, 1989; Rumelhardt, 1989).

The relationships between elements in a set, or interstimulus structure, can also be thought of in terms of two independent components which reflect the amount and form of perceptual structure between stimuli, respectively. The amount of structure is determined by the size of the subset in relationship to the total or implied set of elements. The amount of structure is a function of the number of dimensions which change across the subset of stimuli. The number of changing dimensions or the uncertainty level of the subset of stimuli. The form of interstimulus structure is a function of the level of predictability or correlation between changing dimensions.
Numerous similarity or classification indices have been proposed in order to describe the dimensional relationship between multidimensional objects (e.g., Rumelhardt & Abrahamson, 1973; Tversky, 1977; Whitman & Garner, 1962). These indices can be divided into two broad classes. The first class consists of indices based on the measurement of continuous attributes or dimensions, e.g., similarity scaling or distance measures. These measures have been used extensively in the classic psychophysical literature but only rarely in the concept learning literature (e.g., Rumelhardt & Abrahamson, 1973). The second type of index is based on the number of discrete features or dimensions shared by two or more objects (e.g., Whitman & Garner, 1962; Tversky, 1977). These indices have been used extensively in the classification and concept learning literature (e.g., Medin, 1983; Shepp & Swartz, 1976; Smith & Keimer, 1977), most often in terms of feature analysis (dichotomous attributes that are either present or absent) rather than dimensional analyses (attributes with multiple levels).

The current study is based on the role of changing relationships among dimensions in an inductive reasoning task. The index of dimensional structure used in the current study is based on the number of discrete dimensions which are related in a simple contingent manner. This correlational index of similarity was developed by Whitman and Garner (1962) in order to quantify the dimensional structure between two or more multidimensional stimuli and was subsequently termed 'correlational structure'. This index reflects the form or redundancy of perceptual structure between stimuli while controlling the information load or amount of perceptual structure within individual stimuli.

Applying the index of dimensional structure proposed by Whitman and Garner (1962), inductive processes such as categorization or rule formulation can be defined in terms of the number of correlated or simple contingent dimensional relationships (Royer, 1978; 1981). Royer tested the relationship between the level of correlational structure in a 3x3 matrix of multidimensional stimuli and both time and number correct on the matrix task. Royer found that the degree of correlation between both shared dimensions and spatial position of the stimuli
predicted performance on the matrix task. The predictability or correlational structure among stimuli was an index of matrix difficulty. The less predictable relationships among dimensions were, the more difficult the matrix became to solve.
Research Proposal

The objective of the current research was to determine the relationship between changing levels of interstimulus (dimensional) structure and individual differences in cognitive ability. Two studies were conducted. Study 1 included the development and testing of a computerized matrix task based on changing levels of interstimulus structure in a 3x3 matrix of novel multidimensional perceptual stimuli. In Study 2 perceptual parameters were further defined and measured. Study 2 focused on the development and testing of an adapted matrix task. The adapted task differed from the first in two significant ways: 1) perceptual parameters related to changing dimensional relationships were more specifically defined, and 2) two sets of stimuli (simple/complex) were included in order to test the role of intrastimulus (individual stimulus) complexity. The second study also included measures of basic cognitive abilities including tests of learning, pattern matching, and tachistoscopic threshold. Both Study 1 and Study 2 were computerized.
Study 1

The purpose of study 1 was to construct an inductive reasoning task based on the systematic manipulation of changing relationships between dimensions (interstimulus structure) in a 3x3 perceptual matrix. It was hypothesized that the ability to perceive changing interstimulus dimensional structure was an important cognitive process which would independently predict individual differences in intelligence. This hypothesis was tested by measuring the relationship between performance across levels of the experimental task and performance on both traditional inductive reasoning and general ability tests.

Study 1 had four specific aims: 1) to construct a set of novel multidimensional perceptual stimuli which controlled individual stimulus complexity level as defined by established parameters for information load (Garner, 1974; Royer & Weitzen, 1977), 2) to design a computerized matrix task which varied the degree of perceptual structure in terms of the predictability among dimensions in a 3x3 matrix composed of novel perceptual stimuli as described above, 3) to test the split-half reliability of the task, and 4) to demonstrate the validity of the task by showing that individual differences in performance on standardized inductive reasoning and general ability measures were systematically related to increasing levels of in interstimulus structure.

The experimental task was unique because novel perceptual stimuli were created which held individual stimulus structure or information load constant across decreasing levels of matrix structure. The Raven's Advanced Progressive Matrices (APM) were used as the measure of inductive reasoning. General intelligence was defined as performance on the general ability composite of the Armed Services Vocational Ability Battery (ASVAB). Research was conducted at Brooks Air Force Base with Air Force recruits.

Method

Subjects

Two hundred and twenty Air Force and Air National Guard recruits from Lackland Air Force Base participated in the current study. Participation was coordinated by the Air Force
Human Resources Laboratory at Brooks Air Force Base as an optional part of basic training. The sample was primarily white (80.5%) and male (80.9%). Mean education level was 12.41 years (range 11-18). The Armed Forces Qualification Test (AFQT) composite score from the ASVAB and the Raven's Advanced Progressive Matrices, Set II (APM) were used as measures of general ability and reasoning, respectively.

AFQT data was available for 196 recruits; all recruits were tested on an automated version of the APM. The average AFQT score, as derived from the ASVAB was, 63.8 (SD = 15.02), as compared to a normative youth population with a median of 50. Results are not surprising since Air Force recruits are selected using high cut-off scores on the ASVAB and generally constitute a restricted sample.

Mean number correct on the APM was 16.27 (SD = 5.61) as compared to a technical/commerical mean of 18 (SD = 5.0; Raven, Court, & Raven, 1983). Results seem strange in light of the high AFQT scores. Speed-accuracy tradeoffs may have been partially responsible for the low mean number correct on the APM. Mean time to complete the test was 20.72 minutes (SD = 8.57) compared to the recommended 40 minutes.

Although the testing facilities at Brooks Air Force Base provide an opportunity for the collection of data from unusually large samples of subjects, data may be suspect due to motivational factors (Christal, 1989). For this reason a subgroup of the total sample was selected for participation in the current study according to a task specific performance criterion. The criterion for inclusion was set at 65 percent correct on a simple matching task (6 items or less missed out of 18). Sixteen subjects had scores below 65 percent correct and were dropped from the current study. Mean accuracy on the matching task is usually close to 100 percent.

There was no difference between the mean AFQT score for the valid subgroup and the 16 subjects dropped from the current study, 63.8 versus 63.6, respectively. Therefore, recruits were judged to have been eliminated due to motivational rather than cognitive factors. The subgroup included in the current analyses consisted of 204 recruits, 181 with valid AFQT scores.
Materials

Measures included two psychometric tests and an experimental computerized matrix based on measures of dimensional structure.

Psychometric tests

Psychometric tests administered in the current study included the Raven's Advanced Progressive Matrices, Set II (APM; Raven, 1962) and the Armed Forces Qualification Test (AFQT) score derived from the Armed Services Vocational Abilities Battery (ASVAB).

The Raven's Advanced Progressive Matrices (APM). The Raven's Progressive Matrices (RPM) were designed specifically to test 'the apprehension of fundaments, and the eduction of relations and correlates' (Raven, 1948). The RPM are standardized inductive reasoning tasks which have consistently been shown to be highly 'g' loaded (e.g., Paul, 1985; Jensen, 1987). The APM version of the Raven's Progressive Matrices was designed for above average testees. Since Air Force samples are highly selected on the ASVAB and generally constitute a cognitively restricted sample, the APM was used in the current study in order to avoid ceiling effects on performance.

Armed Forces Qualification Test (AFQT). The AFQT score is formed from three and one-half subtests of the Armed Services Vocational Abilities Battery (ASVAB) and is designed to predict general learning ability and success in the armed services (U.S Department of Defense, 1989).

Computerized Matrix Task (MX)

A computerized matrix task was designed for the current study. The task was constructed by manipulating the relationship between dimensions and spatial position across a 3x3 matrix. Stimulus complexity (information load of individual stimuli) and task structure (number of elements in the matrix and response row) were held constant over changing levels of matrix structure. Changes in performance, therefore, were assumed to be a function of the changing relationships between dimensions in the matrix.
Individual stimuli. Novel perceptual stimuli were identified as optimal for the current study. Novel perceptual stimuli allow better control of both information load and influences of previous learning and memory. Constructing a set of novel multidimensional perceptual stimuli which could be quantified in terms of both classic psychophysical attributes such as symmetry and classic conceptual attributes such as the number of shared dimensions proved to be the most challenging part of initial task construction.

Stimuli were 4x4 grids which varied in the number and position of squares filled. Individual stimuli were constructed from a set of three dimensions which consisted of three levels each as follows: number of cells filled (4, 6, & 8), cohesiveness (# of adjacencies), and degree of rotation (0, 90, & 180) for each stimulus. Two different patterns were chosen for the current task. Total stimulus set size was 3 x 3 x 3 x 2 or 54 possible stimuli, 27 for each pattern. The two sets of 27 stimuli are presented in Appendix A.

In order to verify that the information load or encoding difficulty of individual stimuli remained constant across the levels of the experimental task, the levels of four parameters of stimulus complexity were measured for all six levels of the experimental task. Calculations were made possible through a stimulus complexity program (SCP; Kahana, 1988). Measures included: mean number of cells filled, adjacencies, equivalent set size, and sub-symmetry. The number of adjacencies in a matrix is a quantitative measure of intrastimulus structure which has been shown to be related to the encoding time of stimuli (Caruso & Detterman, 1983). Equivalent set size and sub-symmetry are independent structural measures of stimulus difficulty level which have been shown to influence stimulus encoding difficulty (Caruso & Detterman, 1983; Kahana, 1989).

Mean stimulus complexity or intrastimulus structure as measured by adjacencies, equivalent set size, and sub-symmetry did not differ across the six difficulty levels of matrix structure. Although mean stimulus complexity differed between the two patterns, both patterns were equally represented across all six difficulty levels of the experimental task. Table 1 shows a summary of mean stimulus complexity values.
Matrix structure. Level of matrix structure was based on the relationship between the three stimulus dimensions (number of cells filled, number of adjacencies, and degree of rotation) in the matrix. Six levels of matrix structure were generated. The first level of the experimental task was a simple match-to-sample task with all stimuli in the matrix identical. This simple matching level of the experimental task was included as a baseline measure of encoding and response selection/execution for the novel perceptual stimuli before variability of dimensions was introduced. Matrix structure (spatial position and order of dimensions) systematically decreased from the second to sixth levels.

Mean stimulus complexity defined in terms of the number of cells filled, number of adjacencies, symmetry, and redundancy remained constant across trials for all matrices and exemplar rows. Target positions for the row of exemplar choices were chosen randomly with the constraint that targets appear in all six positions an equal number of times. Matrix difficulty level varied randomly with the constraint that each difficulty level was presented an equal number of times (18). Figure 1 shows an example of the six levels of matrix structure.

Apparatus

The computerized matrix task was administered on an AT-compatible microcomputer with an IBM Enhanced Graphics Adapter (EGA). The matrix task used novel perceptual stimuli presented on a high resolution color monitor. The computer monitor was positioned in the upright position. Mean viewing distance was approximately 43 cm. All stimuli in the computerized matrix task were 4x4 grids of rectangular cells with some of the cells filled. Each stimulus measured approximately 3 cm x 2.5 cm (64 pixels x 56 pixels). Feedback for correct responses
was a two tone beep (1000 HZ/100 msec; 1500 HZ/200 msec). Feedback for incorrect responses was a two tone buzz (100 HZ/200 msec; 50 HZ/300 msec).

Procedure

Information about informed consent and all directions for the current study were read by recruits from the computer monitor. All responses for informed consent, the Raven's Advanced Progressive Matrices, Set II (APM), the computerized matrix task (MX), and demographic data were recorded using the number keys across the top of the computer keyboard. In order to familiarize recruits with the number keys, a practice typing session was administered before the cognitive tasks began.

The APM and MX tasks were administered to all recruits. The tasks were part of a larger 2.5 hour computer battery. Mean administration time for the two tasks used in the current study was approximately 1.25 hours. The ASVAB was administered prior to the computer session to all Air Force Recruits. The ASVAB was not available for National Guard recruits.

*Raven's Advanced Progressive Matrices, Set II (APM).* The APM was administered at the beginning of each computer session to all recruits. The APM is a 36 trial test consisting of 3x3 matrices with the bottom right hand corner piece missing. A row of eight exemplars numbered from 1 to 8 were at the bottom of the page. An automated version of the APM was used. In this version the subject indicated the number of the item that best completed the pattern by typing it into the computer.

Standard APM, Set II test booklets were used to present the items. The first item on the APM, Set II was used as a practice item; this was the only practice item administered. Recruits were given unlimited time to complete the test. Overall time and accuracy were recorded.

*Computerized Matrix Task (MX).* The experimental matrix task measured inductive reasoning as a function of dimensional redundancy in a series of progressive matrices. Each of six matrix complexity levels was randomly tested 18 times. Four practice and 108 test trials were administered. The task was administered in two halves.
Each trial consisted of a 3x3 matrix of stimuli with the bottom right hand corner item missing. Six exemplars appeared in a row at the bottom of the computer screen. A number from 1 to 6 appeared above each exemplar increasing from left to right. The subject’s task was to choose the item which best completed the matrix pattern. Response was indicated by typing the number of the chosen stimulus into the keyboard.

Results

Results are divided into three sections: 1) descriptive statistics and reliabilities for the experimental matrix task (MX), 2) correlation and factor analyses to determine interrelationships among levels of the MX task, and 3) correlation and regression analyses to determine relationships between the MX task, a traditional reasoning task (APM), and a measure of general ability (AFQT).

All data were analyzed for both the total sample and the selected subgroup of recruits. A general nonsignificant trend was found for the selected group to be slower, more accurate, and less variable on the APM and MX task. Data suggest that the sixteen deleted recruits were engaged in extreme speed-accuracy tradeoffs (i.e., ‘goofing off’) during the experimental testing session. Correlation and regression analyses showed trends for a lower relationship between the experimental matrix task and the AFQT in the total group, but trends were not significant. Only results for the selected group are reported.

Basic Statistics for the Experimental Inductive Reasoning Task

Descriptive statistics

Means and standard deviations were computed across difficulty levels of the experimental inductive reasoning task for percent correct, solution time, and the standard deviation of solution time. Patterns of performance reflected a systematic increase in difficulty across levels of matrix structure with percent correct lower, solution time slower, and the standard deviation of solution time higher as matrix structure decreased. Means (SD) across difficulty levels of the experimental inductive reasoning task are shown in Table 2.
Split-half reliabilities

Corrected Spearman-Brown split-half reliabilities were calculated for percent correct, solution time, and the within subject standard deviation of solution time for overall performance on the experimental matrix task. Reliabilities for overall performance were .85, .85, and .82 for percent correct, solution time, and the within subject standard deviation of solution time, respectively. Moderate reliabilities may be due to identified motivational factors in the sample (Crystal, 1989).

Interrelationships among levels of the Matrix Task:

Tests of Simplex Structure

Since both stimulus complexity and task structure were held constant across difficulty levels, performance changes are assumed to be a direct function of decreased matrix structure. In other words, performance on more difficult levels of the experimental task are assumed to entail more processing due to less available interstimulus structure. It was hypothesized that performance would reflect a series of concentric circles with performance on higher levels of task difficulty encompassing performance on lower levels. This type of task structure is referred to as 'simplex structure' after Guttman (Sternberg, 1977).

In order to test the assumption of simplex structure for both percent correct and solution time, correlation and factor analyses were performed as follows: 1) intercorrelations between levels of the experimental matrix task for both percent correct and solution time were computed in order to determine if correlations formed a simplex matrix (correlations decreasing as they move away from the diagonal), and 2) factor analyses were computed to determine if higher levels of the experimental matrix task accounted for performance on lower levels in both combined and independent analyses of percent correct and solution time.
Correlations

Correlations were computed across all levels of task difficulty for both percent correct and solution time. Two separate simplex matrices were formed for the intercorrelations of percent correct and solution time with correlations decreasing monotonically as they moved further away from the diagonal. Intercorrelations between percent correct and solution time formed a reverse simplex, however, with lower levels of percent correct more highly correlated with higher levels of solution time. Correlation patterns between solution time and percent correct suggested that the measures represented two separate constructs. Intercorrelations between difficulty levels and overall performance on the experimental matrix task for both percent correct and solution time are presented in Table 3.

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Insert Table 3 about here

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Factor Analyses

Two principle component analyses using varimax rotation were performed for both percent correct and solution time, respectively.

Factor analyses of the six levels of percent correct indicated slightly increasing loadings on Factor I for the first three levels of percent correct with a slight decrease for levels 4 and 5. Loadings on Factor II also increased as a function of task difficulty with percent correct level 6 loading exclusively on Factor II. Factor loadings for percent correct indicated that percent correct is almost equally loaded across the second through fifth levels of task difficulty with possible ceiling and floor effects for levels 1 and 6, respectively.

Results for factor analyses of solution time indicated increased loadings for Factor I as a function of dimensional redundancy and decreased loadings as a function of dimensional redundancy for Factor II. The pattern of factor loadings for solution time indicated that task difficulty was a function of changing dimensional redundancy. Table 4 shows the factor loadings for both percent correct and solution time across the six levels of matrix structure.
The relationship between the AFQT and the Raven's APM:

Patterns of Individual Differences

Validity of the experimental task was established by testing whether decreasing levels of interstimulus structure were increasingly related to individual differences in performance on traditional inductive reasoning (APM) and general ability tests (AFQT).

Correlation and multiple regression analyses were conducted as follows: 1) correlations between the experimental matrix task and the APM and AFQT were computed both for overall task performance and across difficulty levels of the experimental matrix task, 2) hierarchical multiple regression analyses predicting performance on both the APM and AFQT as a function of decreasing interstimulus structure (increasing difficulty) were computed, and 3) two stepwise multiple regression analyses were conducted in order to determine the best predictors of solution time and percent correct, respectively.

Correlations between the experimental reasoning task (MX), the Raven's APM, and the AFQT

Overall correlations. Correlations were computed between overall performance on the experimental matrix task (MX), the Raven's APM, and the AFQT. Performance on the MX task was measured for percent correct, solution time, and the within subject SD of solution time; performance for the APM was measured for percent correct and solution time. Only the total score was available for the AFQT.

Correlations between overall performance on the experimental matrix task and the APM ranged from .21 to .60. Intercorrelations between APM time and experimental matrix time and SD were .51 and .60, respectively. The intercorrelation between percent correct on the APM and percent correct on the experimental matrix task was .47. The intercorrelation of percent correct
on the experimental matrix task and percent correct on the AFQT was .36; the correlation between percent correct on the APM and the AFQT was .39.

In sum, correlation patterns between the experimental matrix task and both the APM and AFQT were similar. Percent correct on experimental matrix task predicted APM percent correct and the AFQT score as well as the APM and AFQT predicted each other. Table 5 shows the correlations between overall performance on the experimental matrix task and the APM and AFQT.

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Insert Table 5 about here

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*Correlations between the APM and levels of the MX task.* Correlations between the APM and levels of the experimental matrix task increased systematically for both percent correct and solution time with the exception of percent correct on level 6. Unreliability of percent correct level 6 and restricted ranged due to floor effects, may have been contributing factors for the lowered correlation in this condition. Intercorrelations between the APM and percent correct across levels of the experimental matrix task increased from .25 on level 1 to .47 on level 5, $z = 2.54, p < .05$. Intercorrelations between the APM and solution time on the experimental matrix task increased from -.09 to .38 with level 6 more highly related to performance on the APM than level 1, $z = 4.92, p < .001$. Results indicate a relationship between decreasing degrees of interstimulus structure and performance on the APM. Correlations between percent correct on the APM and difficulty levels of the experimental matrix task are shown in Table 6.

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Insert Table 6 about here

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*Correlations between the AFQT and levels of the MX task.* Correlation patterns between levels of the experimental matrix task and performance on the AFQT were similar to patterns of correlations between percent correct on the APM and levels of the experimental matrix task. Correlations between level 1 and level 5 increased systematically from .27 to .37. The increase in
the magnitude of the correlation from level 1 to level 5 was not significant, however. The correlation between percent correct on level 6 and the AFQT was nonsignificant, again due in part, to unreliability and floor effects identified in this condition. A systematic increase in the correlation between solution time across levels of the experimental matrix task and the AFQT was found with correlations ranging from -.10 on level 1 to .28 on level 6, $z = 3.63, p < .001$. Table 6 above shows the correlations between overall performance on the AFQT across difficulty levels of the experimental task.

**Hierarchical multiple regression analyses**

Two hierarchical multiple regression analyses were conducted with percent correct on the APM and overall performance on the AFQT as dependents in order to examine convergent validity of the experimental matrix task. Performance on decreasing levels of interstimulus structure as measured by both percent correct and solution time were entered into the hierarchical equation in 6 sequential steps.

Significant increases in the prediction of performance on the APM were associated with the addition of each level of interstimulus structure from level 1 to level 6 with a squared multiple-R of .08 for level 1, $F(2,201) = 9.13, p < .001$ increasing to .39 after all 6 levels of interstimulus structure had been added into the equation, $F(12,191) = 10.65, p < .001$.

The relationship between decreasing levels of interstimulus structure and the AFQT was similar to the relationship between interstimulus structure and the APM, although not as strong. Significant increases were associated with each squared multiple-R for the first four levels of the experimental matrix task with level 1 accounting for 10 percent of the variance, $F(2,178) = 9.87, p < .001$ and increasing to 22 percent of the variance in performance on the AFQT accounted for by level 4, $F(8,172) = 6.20, p < .001$. The last two levels of the experimental matrix task did not add a significant amount of variance to the prediction of the AFQT.

In sum, hierarchical regression analyses indicated that the relationship between performance on the experimental matrix task and individual differences in mental ability as
measured on both the APM and AFQT were a function of decreasing levels of correlation or dimensional structure. Interstimulus structure predicted performance on both the APM and AFQT; a change in the absolute amount of variance accounted for from level 1 to level 6 of the experimental matrix task was only associated with the APM. Variance accounted for by decreasing levels of interstimulus structure increased across all levels of the experimental matrix task for the APM; changes in variance accounted for were associated with only the first four levels of the experimental matrix task in the prediction of the AFQT. Results for both hierarchical multiple regression equations are reported in Table 7.

Insert Table 7 about here

*Stepwise multiple regression*

In order to better understand the relationship between levels of the experimental matrix task and performance on both the APM and AFQT, two stepwise multiple regression analyses were conducted. In order to find the minimum set of variables which best predicted percent correct on the APM and the AFQT score, all 6 levels of both percent correct and solution time of the experimental task were entered into each stepwise multiple regression equation.

*Stepwise analyses in the prediction of the APM.* Four variables entered into the stepwise solution in the prediction of performance on the APM: percent correct level 5, solution time level 3, solution time level 6, and percent correct level 6 in that order, respectively. Percent correct level 5 predicted 22 percent of the variance in the APM, $F(1, 202) = 57.31, p < .001$. The increases in the squared multiple-R's after the next three variables entered into the equation were .04, $F(2,201) = 9.65, p < .01$; .10, $F(3,200) = 32.06, p < .001$; and .01, $F(4,199) = 4.44, p < .05$. Subsequent analyses indicated that solution time, level 3 acted as a suppressor variable for both percent correct level 5 and time on level 6 in the prediction of performance on the APM. The overall multiple-R squared obtained in the prediction of the APM from the four variables was .37, $F(4,199) = 29.6, p < .001$ as compared to a multiple-R squared of .39, $F(12,191) =$
10.07, \( p < .001 \) when all 12 variables were entered into the equation. Results indicate that the four variables account for nearly all of the variance between the experimental matrix task and percent correct on the APM. A modified simplex structure was identified with solution time level 3 as a suppressor variable.

*Stepwise analyses in the prediction of the AFQT.* Only one variable entered into the stepwise solution in the prediction of performance on the AFQT, percent correct level 5. Percent correct level 5 predicted 14 percent of the variance associated with performance on the AFQT, \( F(1,179) = 29.90, p < .001 \) as compared to 25 percent of the variance, \( F(12,168) = 4.70, p < .001 \) when all 12 variables were entered into the regression equation. In order to better understand the unaccounted variance between the experimental matrix task and AFQT, levels were systematically combined in the search of suppressor variables. A series of regression equations were constructed to predict performance on the AFQT from both percent correct on level 5 and solution time level 6 before and after lower levels of both percent and time were entered. Analyses indicated that solution time, level 3 again had suppressor effects on solution time for level 6 with the multiple-R squared in the prediction of AFQT increasing from .07 to .13 for level 6 after time on level 3 was entered into the regression equation.

The multiple-R squared in the prediction of the AFQT from percent correct, level 5 and solution times from levels 3 and 6 was 18 percent of the variance, \( F(3,177) = 13.32, p < .001 \) as compared to all 12 variables predicting 25 percent of the variance \( F(12,168) = 4.70, p < .001 \). Levels 2 and 4 also had nonsignificant suppressor effects on performance. A simplex model was not supported in the relationship between the AFQT and experimental matrix task.

*Discussion*

A relationship between perceptual structure and performance on both the AFQT and APM was established. A significant relationship was found between the experimental matrix task and both the APM and AFQT tasks with the relationship increasing across decreasing levels
of interstimulus structure for percent correct on the APM; correlations did not increase for the AFQT across levels of interstimulus structure.

It was hypothesized that dimensional redundancy mediated the relationship between the experimental matrix task and measures of higher order or complex mental processing such as performance on inductive reasoning tasks (APM) and measures of general intelligence (AFQT). If dimensional redundancy predicts individual differences in intelligence, a stronger relationship would be predicted between the APM and the experimental task as levels of dimensional structure increased. This prediction was supported.

In sum, a relationship was established between the predictive ability of the experimental matrix task and performance on the APM and AFQT. It was argued that this relationship was mediated by changes in interstimulus dimensional structure across levels of the experimental matrix task. But the exact nature of the relationship between changing interstimulus structure and performance on the APM and AFQT was not clear. In order to better understand the relationship between individual differences in intelligence and interstimulus perceptual structure, however, it is important to identify specific parameters of interstimulus structure which may be most sensitive to individual differences in mental ability. A second study was designed for that purpose. The relationship between interstimulus structure and intrastimulus structure (individual stimulus complexity) in the prediction of individual differences in cognitive ability was also explored in the second study.
Study 2

Study 1 demonstrated that interstimulus dimensional structure between stimuli in a 3x3 matrix was an important factor in the prediction of individual differences in intelligence. The general purpose of Study 2 was to refine the experimental matrix task designed in Study 1 in order to independently define and reliably measure specific parameters of dimensional structure which make matrix task performance an important predictor of individual differences in mental ability. The influence of matrix presentation order was also tested in Study 2.

Two separate components of interstimulus dimensional structure (amount and form) were independently defined and manipulated in the second study. The amount of interstimulus structure was defined as the number of changing dimensions in each 3x3 matrix. The form of interstimulus structure was determined by the number of simple contingent dimensional relationships in the matrix, i.e., the predictability or correlation among matrix dimensions. Amount was the quantitative index of the matrix. Form was the structural index. Amount, as defined, sets a lower limit on the form of interstimulus dimensional structure.

In order to test the relationship between interstimulus dimensional structure and individual stimulus complexity, two sets of stimuli (simple/complex) were also included in Study 2. Object dimensions used in Study 2 were the same three dimensions used in Study 1: number of cells filled, rotation, and adjacencies. Spatial position of stimuli relative to the y-axis was also manipulated and defined as a fourth matrix dimension.

In addition to standardized reasoning and achievement tests such as those used in Study 1, Study 2 measured an expanded set of cognitive abilities including tests of pattern matching, learning, and tachistoscopic threshold. The pattern matching task was used to obtain a baseline measure of encoding, discrimination, and response selection/execution times for each exemplar row in the first half of the experimental task. Pattern matching times for each exemplar row were compared to insure that mean baseline performance times did not differ across levels of interstimulus structure. Tasks of learning and tachistoscopic threshold were included in order to
test the differential effects of different types of perceptual structure on basic measures of
cognitive processing. The pattern matching task was also included in these analyses.

Study 2 had three specific aims: 1) To operationally define and measure two independent
parameters of interstimulus dimensional structure in a 3x3 computerized matrix task: amount
and form, 2) To test the relationship between operationally defined parameters of interstimulus
structure and individual differences in performance on measures of reasoning, standardized
achievement, and basic cognitive processing, and 3) To test the combined influence of
interstimulus and intrastimulus structure on individual differences in matrix task performance.

**Method**

*Subjects*

One-hundred and nine subjects participated in Study 2. All students were attending
classes at Cleveland State University. Participation was part of an optional Psychology course
requirement. Six subjects had incomplete data on the experimental task: three due to technical
difficulties; three failed to show-up for the second testing session. Due to time limitations on the
testing session, the tachistoscopic threshold task was not administered to six subjects and the
learning task was not administered to four subjects. Three subjects with complete data were not
included in the current analysis due to a combination of no sleep and random response on the
second session (judged *a priori*).

Data for one-hundred students between the ages of 18 and 42 (X = 23, SD = 5.9) years
were included in the current analyses. The group was 27.5 percent male and 67.5 percent white
with a mean education level of 13.7 (SD = 1.98) years. Students scored at the national average
on the Composite Score of the American College Test (ACT) with a mean of 18 (SD = 6.7) and
slightly above average on the Standardized Raven's Progressive Matrix Test (Raven, 1958) with a
mean of 47 (SD = 6.4) correct as compared to their normative age sample of 44 correct.
Materials

Measures for Study 2 included two psychometric tests and a set of four computerized cognitive tasks. Computerized tasks included both elementary cognitive tasks and an adapted experimental matrix task which manipulated levels of perceptual structure.

Psychometric tests. Psychometric tests used in Study 2 included the Raven's Standard Progressive Matrices (SPM; Raven, 1958) and the composite score from the American College Test (ACT). The SPM is a standardized paper-pencil test of analogical reasoning. The ACT is a college entrance exam used primarily for admission to state schools.

Adapted experimental matrix task. In order to systematically test the relationship between parameters of perceptual structure and individual differences in mental ability, the original computerized matrix task was adapted for the current study. The adapted matrix task further defined and tested parameters of perceptual structure originally used in Study 1 as follows: 1) Separate components of interstimulus structure were defined by independently manipulating the amount (number of dimensions which varied in the matrix) and form (level of correlation between dimensions). Two aspects of form were also manipulated independently: correlational structure between dimensions and correlational structure between spatial position and object dimensions (testing position as a separate dimension within form), and 2) Individual stimulus complexity (intrasubject complexity) was also manipulated in the adapted matrix task by including both simple and complex sets of stimuli equally represented across all levels of interstimulus (matrix) structure.

Elementary cognitive tasks. Elementary cognitive tasks included three tasks from the Cognitive Abilities Test (CAT; Detterman, 1988) which were designed to test basic cognitive processes. The three elementary tasks included in the current study were: match-to-sample (MS), tachistoscopic threshold (TT), and learning (LR). The MS task measured basic parameters of encoding, discrimination, and response selection/execution. The MS task for the current study was adapted so that each trial was composed of an exemplar row used in the first
half of the experimental matrix task. The TT and LR tasks were included in order to test the 
relationship between parameters of perceptual structure and individual differences in both time 
needed to judge if two stimuli were the same or different (discrimination time) and ability to 
call the position of stimuli, respectively. The LR and TT tasks used the standard set of novel 
perceptual stimuli developed for CAT (Cognitive Abilities Tests; Detterman, 1988).

Apparatus

All computerized tasks were administered on an AT-compatible microcomputer with an 
IBM Enhanced Graphics Adapter (EGA). A high resolution color monitor was used to present 
novel perceptual stimuli. The computer monitor was positioned at a 30 degree angle from 
horizontal with the lower edge of the screen placed at a height of approximately 65 cm.. Mean 
viewing distance was approximately 53 cm. As in Study 1, all stimuli were 4x4 grids of 
rectangular cells with some of the cells filled. Each stimulus measured approximately 3 cm X 2.5 
cm (64 pixels X 56 pixels).

Computer monitors were fitted with a Personal Touch touchscreen. Cognitive tasks had 
the image of a spacebar positioned in the bottom-center of the display. The bar served as a 
response device for trial initiation. Feedback for correct responses on all computerized tasks was 
a two tone beep (1000 HZ/100 msec; 1500 HZ/200 msec). Feedback for incorrect responses was 
a two tone buzz (100 HZ/200 msec; 50 HZ/300 msec).

Design

Two levels of intrastimulus (within stimulus) complexity and twelve levels of interstimulus 
(between stimulus) complexity were tested. All manipulations of perceptual structure were 
defined in terms of the same three object dimensions defined in Study 1: number of cells filled, 
rotation, and adjacencies. Spatial position of stimuli in the matrix (correlated or uncorrelated 
with y-axis) was manipulated as a fourth dimension of interstimulus form.
Intrastimulus structure

In order to choose two sets of stimuli which represented simple and complex levels of intrastimulus structure, respectively, an initial set of 27 items was generated by the experimenter which varied in number (4,6,8) and adjacency of pattern components. The items were then put together in matrix form and rated by 27 students in the Psychology Department at Case Western Reserve University. Students were asked to rate the matrices on a scale of one to five with one being the easiest and five being the hardest. Several students had difficulty using the entire range of numbers, therefore a mean rating was computed using z-scores standardized on each rater's own distribution of ratings. Three stimuli with low mean ratings were chosen as the simple set; the three stimuli with high mean ratings were chosen as the complex set. A t-test demonstrated that ratings on the two sets were significantly different, $t = 8.06, p < .001$. Both the initial set of 27 matrices and the simple and complex sets of stimuli chosen for the current study are presented in Appendices B and C, respectively.

The SCP (Kahana, 1988) was used to calculate measures of intrastimulus structure for the simple and complex set. Intrastimulus measures were identical to those used in Study 1. Symmetry was measured by calculating the number of elements generated if the stimulus was rotated and reflected (ESS) and through a measure of sub-symmetry. Adjacencies were calculated by taking the mean number of horizontal and/or vertical adjacencies. Diagonal adjacencies were not included in the calculations. Changes in adjacencies and symmetry have been shown to independently affect the information load or complexity of individual stimuli (Chipman, 1977; Ichikawa, 1985). Table 8 shows the mean intrastimulus structure values for the simple and complex stimulus sets chosen for the current study.

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Insert Table 8 about here
Interstimulus structure

The 12 levels of interstimulus structure represented an unbalanced manipulation of quantity X form (Garzer, 1974; Royer, 1978). Quantity was represented by the number of object dimensions (1 to 3) which varied in the total matrix. Object dimensions included: number of cells filled, adjacencies, and rotation of the pattern. This quantitative measure of interstimulus structure was defined as the amount of structure present in the matrix. The form of the matrix was represented by the level of correlation between both spatial and object dimensions. Spatial structure refers to the ordered (correlated with the y-axis) versus latin square (uncorrelated with the y-axis) arrangement of dimensions in the matrix. Object structure refers to the level of correlation between dimensions or the number of dimensions (3-0) which are related to each other in a simple contingent manner. Levels of interstimulus form ranged from simple contingent structure (3 dimensions correlated) to complex structure (0 dimensions correlated). The 12 levels of interstimulus structure are presented in Figure 2.

Insert Figure 2 about here

Stimuli from the two levels of stimulus complexity (simple/complex) were randomly tested 5 times within every level of interstimulus complexity, generating 10 trials for each of the 12 levels. Levels of intersimulus complexity (simple/complex) were tested in increasing order of difficulty beginning with the lowest level of amount and simplest, most highly correlated level of form, respectively increasing in difficulty to the highest amount of form and most complex level of structure.

The stimulus pattern remained constant within each matrix problem tested. Mean stimulus complexity of individual matrix problems, i.e., number of cells filled, number of adjacencies, symmetry, and redundancy, did not differ across the 12 levels of interstimulus structure. Target positions for the row of response choices were chosen randomly with the constraint that targets appear in all six positions an equal number of times.
The influence of trial presentation order was tested by dividing trials into two blocks according to spatial position of dimensions in the matrix (ordered versus latin square). Block presentation order was counterbalanced across subjects. See Appendix D for a detailed description of the complete experimental design.

Procedure

Study 2 consisted of six measures: the American College Test (ACT), the Standard Progressive Matrices Test (SPM; Raven, 1958), a computerized matrix task designed for the current study, and three computerized tasks which measured basic cognitive abilities (CAT; Detterman, 1988). The ACT was administered prior to college admission. ACT composite scores were obtained from University files. All other tests were administered to students by the author. After initial efforts to administer the SPM in group format proved inefficient, due to low numbers of subjects in group sessions, all testing was conducted in two individual sessions as described below. Each session lasted an average of 1.5 hours. No differences were found between the scores of students who received the SPM in group versus individual sessions. Total time for each subject to complete the study varied between 2.5 to 4 hours.

Procedures for each of the five measures are described below. Following descriptions of individual task procedures, the structure of the first and second testing sessions are described.

Standard Progressive Matrices (SPM)

The SPM is a 60 trial paper-pencil test consisting of a series of 3x3 matrices with the bottom right hand corner piece missing. A row of eight exemplars numbered from 1 to 8 appear at the bottom of each page. Students were told to fill in the piece of the missing pattern. Each student indicated the number of the item which best completed the pattern by marking it on the answer sheet provided. Standard SPM test booklets were used. No practice items were administered. Standard procedure was followed with one exception. Time was kept separately for each set A - E. In order to counteract any time pressure which might be added by timing individual sets, students were told that time was being measured for each set in order to compare
the difficulty of the sets and that time was not a measure of ability on the test. Students were told that, in fact, time was inversely related to ability and those who rushed simply would get more wrong. Students were encouraged to take as much time as they needed. Time and accuracy were recorded for each set.

*Adapted experimental matrix task (MX2)*

The adapted experimental matrix task was a computerized matrix task which systematically tested performance on three parameters of perceptual structure in a 3x3 matrix of novel perceptual stimuli. Directions were given to students at the start of the experimental matrix task. Directions included both written descriptions identifying the three dimensions (i.e., number of squares filled, number of adjacent blocks, and degree of rotation) and examples of stimuli which varied on the three dimensions. Directions and sample stimuli are presented in Appendix E.

Each trial consisted of a 3x3 matrix of stimuli with the bottom right hand corner item missing. Six exemplars appeared in a row at the bottom of the computer screen. The subject’s task was to choose the item which best completed the matrix pattern. Response was indicated by touching the correct stimulus in the response row.

The computerized matrix task was split into two 120 trial blocks. Six practice trials preceded each block of test trials. Blocks represented one of two spatial conditions: ordered or latin square arrangement of stimulus elements within the matrix. One trial block was administered in each of two testing sessions. Block presentation order was counterbalanced across subjects. One group was presented with simple, spatially correlated matrix problems first. The other group was presented with the more difficult, spatially uncorrelated matrix problems (i.e., latin square arrangement of stimuli) first. Examples of ordered versus latin matrix problems are presented in Figure 2. Total time to complete each block of 120 trials was approximately forty-five minutes.
**Match-to-sample (MS)**

The MS task was a pattern matching task adapted from the cognitive abilities tests (CAT; Detterman, 1988). The CAT consists of eleven tasks designed to test basic abilities. The MS task in the current study was modified so that test trials were identical to the first 60 exemplar rows of each 120 trial block of the adapted experimental matrix task. Correspondingly, probe items in the MS task were the missing items from the 60 matrix trials. The MS task was designed to measure speed and accuracy of encoding, discrimination, and response selection/execution processes.

Each trial had seven stimuli (windows); a row of six stimuli and a probe stimulus centered above the row. The image of a spacebar was displayed at the bottom of the screen. Display size was 13.5 cm X 25 cm. There were four practice trials and a minimum of 120 test trials, 60 tested in each session. Incorrect test trials were reinserted, therefore, the total number of test trials was a function of the number of errors.

At task onset, all stimuli appeared as blank grids. When the image of the spacebar was touched, seven patterns appeared; six different patterns in the row and a probe pattern identical to one of the six patterns. The patterns stayed on the screen as long as the bar was held. Each student indicated a match by lifting their finger from the bar and touching the stimulus identical to the probe. Decision time was the amount of time between the onset of the stimulus display and when a subject lifted their finger from the spacebar. Movement time was the amount of time from the finger lift until the subject touched a stimulus in the response row. Computer record was kep of decision and movement time and accuracy on all test trials.

The matching task was divided into two 60 trial blocks with one block administered in each of two testing sessions. Within each session, the MS task was administered following the first sixty trials of the adapted experimental matrix task as follows: matrix task (first sixty trials), matching task (sixty trials), and matrix task (second sixty trials).
Learning (LR)

The LR task was a probed recall, multtrial task which measured speed and accuracy of recalling the positions of novel perceptual stimuli. Each trial began with a row of blank windows (2, 3, 5, 7, or 9) in the lower portion of the screen. A probe window was centered above the row of blank windows. When the subject touched the bar, one stimulus appeared in each blank grid, consecutively, moving from left to right. Presentation time for each stimulus was 1 second. At the end of the presentation, probe stimuli appeared randomly from the set of stimuli to be learned. The testee was to indicate the position in which that stimulus appeared by touching the position on the screen. Testees had 10 seconds to respond correctly.

Five practice trials were presented which contained two stimulus positions to be learned. Test trial blocks contained 3, 5, 7, or 9 stimuli to be learned, respectively. Each test block contained a maximum of 10 trials. If the testee learned the position of 67% of the stimuli in the set in ten trials or less, the number of elements in the set was increased by two. If the testee did not meet the criterion in ten trials or less, the task was terminated. Time, accuracy, and number of blocks administered were recorded.

Tachistoscopic threshold (TT)

The TT task determined the minimum amount of time required for a testee to decide if two windows, i.e., novel perceptual stimuli, were the same or different. Display size measured 16.75 X 10.9 cm. The initial screen had the image of a spacebar at the bottom. Same (left) and different (right) response choices were above and on either side of the spacebar indicated by two patterns which were either the same or different.

When a testee touched the image of the spacebar, a fixation point appeared. After a variable delay two stimuli appeared. A solid blue mask immediately followed the display for a duration of 250 ms. The subject’s task was to determine whether the two stimuli which appeared were the same or different. Response was indicated by touching either the pattern for same or the pattern for different. Initial duration of the two stimuli was 17 ms. Duration increased by 17
ms each time an incorrect response was made. Test trials were divided into 20 blocks. Testing was terminated when a testee got 5 consecutive correct trials for twenty blocks or 287 trials were administered, which ever came first. There were three practice trials presented for 50 ms each.

Tachistoscopic threshold was the stimulus duration on the last trial administered. Decision time was the time between when the stimulus was flashed and the subject lifted their finger from the spacebar image. Movement time was the time between when a subject lifted their finger and touched the symbols indicating either same or different. Decision time, movement time, threshold, and number of trial blocks completed were recorded.

Session 1

All students were told that they would be taking a series of cognitive tests to aid in understanding the relationship between problem solving abilities and basic perceptual processes. Subjects were asked to read a brief description of the study and to sign the consent form if they choose to participate. Students were also asked to sign a release form which gave the investigator permission to obtain their ACT scores from university files. After obtaining informed consent, the SPM was administered followed by the first blocks of the adapted experimental matrix and matching (MS) tasks, respectively.

Session 2

The second testing session consisted of the remaining blocks of the matrix and matching tasks, and two additional basic cognitive tasks (LR & TT). The two additional tasks were designed to measure memory for position and the threshold needed to determine whether two patterns were the same or different (discrimination time), respectively.

Results

The matrix task constructed for Study 1 was designed to test the relationship between interstimulus dimensional structure and individual differences in cognitive ability. Although a relationship between interstimulus structure and individual differences was demonstrated in Study 1, specific parameters of dimensional structure were not defined. The general purpose of
Study 2 was to refine the computerized matrix task used in Study 1 in order to independently define and reliably measure the effects of specific perceptual parameters on individual differences in performance on measures of cognitive ability.

Measures of individual differences in cognitive ability included two standardized psychometric tests and three tests of more basic processing. Standardized tests were measures of general cognitive ability. They included the composite score for the American College Test (ACT) and number correct on the Raven’s Standardized Progressive Matrices (SPM). The ACT is an achievement test; the SPM as a classic test of inductive reasoning. Basic cognitive tests included measures of learning (LR), tachistoscopic threshold (TT), and decision time on a match-to-sample task (MS).

Results are divided into four major sections: 1) basic statistics for the experimental measures were included in a preliminary section, 2) repeated measures analyses of variance were used to identify mean differences in performance on the adapted matrix task as a function of interstimulus form and amount, 3) correlation and multiple regression analyses were carried out to determine the role of interstimulus form and amount in the prediction of individual differences in cognitive ability, and 4) correlation and multiple regression analyses were done to evaluate the mediating effect of intrastimulus perceptual structure (individual stimulus complexity) on patterns of individual differences. Analyses focus on the prediction of general cognitive ability from parameters of perceptual structure. The effect of block presentation order (simple versus complex matrix problems administered first) on the prediction of individual differences in performance from measures of interstimulus complexity was also investigated.

Distributions for all experimental variables were examined for outliers (values > 3 SD from the mean of individual distributions). Six outliers were identified for the adapted experimental task (MX2); six for the match-to-sample task (MS). Outliers were distributed across both groups of presentation order and were generally found in the initial test condition which was administered. One outlier was identified for the Raven’s Standardized Progressive
Matrices (SPM), three for the learning task (LR), and five for the tachistoscopic threshold task (TT). All analyses were done with and without outliers. Patterns of results were similar for all analyses involving comparison of mean differences in performance. Individual difference analyses, on the other hand, tended to be more sensitive to outliers. The six outliers for the experimental matrix task were deleted from all analyses. Other outliers were deleted only from specific analyses involving that measure. Analyses include results for 94 students on the experimental matrix and SPM tasks, 90 on the MS and LR tasks, 83 on the TT task, and 64 on the ACT.

Preliminary Analyses

Descriptive statistics

Means and standard deviations were computed for all experimental measures without outliers. Mean percent correct on the experimental matrix task was 74% (SD = 11%) with mean time to complete each problem 16.31 (SD = 6.43) seconds. Mean number correct on the SPM was 48 (SD = 5.8) out of 60 total problems with mean time to complete all 60 problems recorded at 21.00 (SD = 7.34) minutes. Mean score on the ACT composite was 18 (SD = 6.6). SPM and ACT scores without outliers were not different than those reported for the total group. Scores for tachistoscopic threshold (TT) and decision time on the match-to-sample task (MS) were .18 (SD = .12) and 2.50 (SD = .48) seconds, respectively. Percent correct on the learning task (LR) was 54% (SD = 10%). Means (SD) for the MS and LR tasks were similar to previously reported means in a normally distributed high school sample (Detterman, 1984). Mean tachistoscopic threshold, however, was much higher than the previously reported threshold for the high school sample, .04 (SD = .03) seconds. Differences may reflect the older mean age of the current sample.

Reliabilities

Reliabilities were reported for all experimental measures included in the current study. Split-half reliabilities for the experimental matrix task were calculated using an alternate-item
procedure. Corrected Spearman-Brown split-half reliabilities for percent correct, solution time and the within-subject standard deviation of solution time were .96, .99, and .98, respectively. Split-half reliabilities for the match-to-sample task were calculated using a first-second half procedure. Corrected split-half reliabilities for decision time and the within subject standard deviation of decision time were .93 and .86, respectively. The corrected Spearman-Brown split-half reliability for tachistoscopic threshold was .72.

Reported test-retest reliabilities on the Raven's SPM for testees under 40 years old ranged from .88 to .93 (Raven, Court, & Raven, 1983). Reported split-half reliability for percent correct on the learning task in the high school sample of 141 seniors was .97 (Detterman, 1984). In sum, all experimental measures used in the current study were moderately to highly reliable ($r_{xy} = .72$ to .99).

*General validity of the experimental matrix task*

General external validity of the adapted experimental matrix task was tested by correlating the adapted matrix task with a set of independent measures of cognitive ability. Measures included both standardized tests of general ability such as number correct on the Raven's Standardized Progressive Matrices (SPM) and the ACT comprehensive score and more basic cognitive measures such as learning (LR), tachistoscopic threshold (TT), and decision time on the match-to-sample task (MS). Correlations between percent correct on the adapted matrix task and accuracy on the SPM, ACT, and LR tasks were expected to be high with the highest correlations expected between accuracy on the adapted matrix task and SPM. Significant correlations with more traditional measures of encoding and discrimination such as tachistoscopic threshold (TT) and decision time on the MS task were not expected to be high.

Significant one-tailed correlations were identified between overall percent correct on the adapted matrix task and measures of accuracy on the SPM, $r = .65$, $p < .001$, ACT, $r = .33$, $p < .01$, and LR, $r = .45$, $p < .001$ tasks. Correlations between accuracy on the SPM and accuracy on the LR and ACT were .40 and .44, respectively, both $p$'s $< .001$. Correlations were not significant
between percent correct on the adapted matrix task and either tachistoscopic threshold (TT) or decision time on the MS task.

Conversely, time on the adapted matrix task was related to both TT, \( r = .28, p < .01 \) and decision time on the MS task, \( r = .45, p < .001 \) but not to measures of accuracy on the SPM, ACT, or LR tasks. Again, patterns of correlations between overall time on the experimental matrix task and measures of cognitive ability were similar to patterns of correlations between time on the Raven's SPM and measures of cognitive ability. Time on the matrix task and time on the SPM were intercorrelated, \( r = .59, p < .001 \).

In sum, patterns of correlations between both time and accuracy on the experimental matrix task and other cognitive measures were similar to patterns of correlations identified for time and accuracy on the Raven's SPM. Correlations supported the validity of the adapted experimental matrix task as a measure of general cognitive ability which tapped processes similar to those measured by the SPM. A summary table of intercorrelations between experimental measures is presented in Table 9.

Insert Table 9 about here

**Components of Interstimulus Dimensional Structure:**

**Tests of Mean Differences between Interstimulus Form and Amount**

For the purpose of the current study, interstimulus amount was operationally defined as the quantitative component of matrix difficulty, i.e., quantity or number of changing dimensions in the matrix. Interstimulus form was operationally defined as the structural component of matrix difficulty, i.e., correlational structure or predictability between matrix dimensions. Within form, separate components of spatial and object dimensional structure were also defined and tested. Spatial structure refers to the ordered versus latin square arrangement of stimuli in the matrix, i.e., correlated or uncorrelated with the y-axis, respectively. Object structure refers to the level of correlational structure between object dimensions, i.e., number of simple contingent
relationships between cells filled, adjacencies, and rotation. Before the relationship between operationally defined parameters of dimensional structure and measures of individual differences in cognitive ability can be investigated, however, the assumption that form and amount tap separate measures of interstimulus structure must be tested.

Patterns of performance were expected to reflect a systematic increase in difficulty across levels of form with percent correct lower and solution time slower as form decreased. Interstimulus amount was expected to interact with interstimulus form with larger mean differences in performance on complex levels of form (low correlational structure among dimensions) as amount increased. Interstimulus amount was not expected to affect mean differences in performance when form was simple (high correlational structure among dimensions).

Repeated measures analyses of variance were used to test the assumption that operationally defined parameters of form and amount measured separate parameters of dimensional structure. Due to an unbalanced overall design, mean differences between form and amount of interstimulus structure were tested across a series of balanced repeated measures designs with both accuracy and solution time as dependents. Results were consistent across all designs. Selected results are presented below.

A 2 (spatial structure: correlated, uncorrelated) X 2 (object structure: correlated, uncorrelated) X 2 (amount: 2-3 matrix dimensions changing) repeated measures analyses of variance with percent correct and solution time each used in turn as the dependent measure was conducted. Main effects for both spatial, $F(1,93) = 66.20$ and 61.59, both $p$'s < .001 and object, $F(1,93) = 476.77$ and 234.67, both $p$'s < .001 matrix structure were identified for percent correct and solution time, respectively with less accurate and slower performance associated with decreasing form for both spatial and object structure. Results were as predicted. Significant main effects for amount on both accuracy, $F(1,93) = 55.51$ and solution time, $F(1,93) = 41.42$, both $p$'s < .001 were also identified. Results support the experimental hypothesis that increasing
amount will negatively affect accuracy of performance independently of form. Results for solution time reflected practice effects, however, with solution time decreasing as amount (number of dimensions) increased.

Significant two-way interactions for accuracy were identified for both amount X spatial structure, $F(1,93) = 19.67, p < .001$ and amount X object structure, $F(1,93) = 45.34, p < .001$, respectively. Results indicate that when form was high (correlated) amount was not associated with differences in performance. When matrix structure was low (uncorrelated), however, increases in levels of amount were related to lower mean accuracy in performance. Again, results were as predicted.

In order to determine whether results for percent correct were due largely to speed-accuracy trade-offs, the analysis was repeated on percent correct with solution time partialed out. This was accomplished by regressing accuracy onto speed and subsequently entering the residuals into the repeated measures analyses of variance. The speed-accuracy adjustment was made in this manner rather than the more conventional manner of partialing out accuracy because percent correct was the primary measure in the current study. Patterns of results supported original findings. Since the regression of speed onto accuracy assumes a linear relationship between the two measures, results must be interpreted with caution. Still, the fact that results remained unchanged even after speed was partialed out, seems to indicate that mean performance differences cannot be primarily attributed to speed-accuracy trade-offs in performance.

In sum, performance on the experimental matrix task was differentially affected by measures of interstimulus form and amount. Types of form (spatial versus object dimensions), although not equivalent, did not interact with each other. Both measures of form also had similar effects on amount of matrix structure. A summary graph of mean percent correct across the eight selected levels of interstimulus form and amount included in the current analyses is presented in Figure 3. See Appendix F for a complete listing of means (SD) across all levels of
form and amount for both percent correct and solution time on the adapted experimental matrix task.

Insert Figure 3 about here

Prediction of Individual Differences in Cognitive Ability:

The Role of Interstimulus Form versus Amount

Two components of interstimulus perceptual structure were defined and measured on the adapted experimental matrix task: form and amount. Repeated measures analyses of variance demonstrated the independent effects of interstimulus form and amount on mean differences in performance. The current set of analyses tested the relationship between operationally defined parameters of interstimulus form and amount and individual differences in cognitive ability.

Patterns of individual differences between interstimulus form and amount and measures of cognitive ability were investigated as follows: 1) correlations between levels of the adapted experimental matrix task and the five measures of cognitive ability were computed in order to identify important relationships between form and amount, 2) hierarchical multiple regression analyses predicting accuracy of performance on both the SPM and ACT as a function of increasing interstimulus complexity (decreasing form and increasing amount) were computed to determine the independent contribution of each component in the prediction of general cognitive ability, 3) hierarchical multiple regression analyses were repeated with basic processing measures of TT, MS, and LR entered on the first step of each equation, in turn, in order to determine the mediating effects of basic processes on the prediction of general cognitive ability from measures of interstimulus structure, and 4) two stepwise multiple regression analyses were conducted in order to identify the best predictors of accuracy on the SPM and ACT.

It was hypothesized that interstimulus dimensional form would be highly related to individual differences in performance on standardized measures of general cognitive ability such as accuracy on tests of reasoning (SPM) and achievement (ACT). Dimensional form was also
expected to be highly related to memory for position (LR). Interstimulus amount was expected to mediate differences between measures of cognitive ability and dimensional form with stronger relationships between measures of cognitive ability and form associated with higher levels of amount (greater number of dimensions) and decreased form (complex relationships between dimensions). Increases in amount were also expected to be associated with measures of stimulus encoding and discrimination (TT and decision time on the MS task) as the number of dimensions which need to be encoded increases. Accuracy on the LR task was expected to play a role in the prediction of individual differences in general cognitive ability with mediating effects between measures of interstimulus form and amount increasing as form decreased and amount increased due to the increased memory load of more complex problems.

Correlations

Correlations between both time and accuracy on the adapted matrix task and independent measures of cognitive ability such as accuracy on the SPM, ACT, and LR tasks and time measures from the TT and MS tasks were computed across changing levels of interstimulus form and amount. Significant one-tailed correlations were identified for form and amount. Significant differences between the magnitude of the correlations were identified with follow-up z-tests.

Correlations between percent correct on the adapted matrix task and accuracy on the SPM, ACT, and LR tasks, ranged from .06 to .65 with significant increases in the magnitude of correlation associated with form of dimensional structure on all three measures. A follow-up z-test was conducted to test the differences in level of correlation. Increases in correlation for the three measures ranged from .38 to .46, all $z's \leq -2.52$, all $p's < .05$ as dimensional form decreased. A significant decrease in the magnitude of correlation between accuracy on the experimental matrix task and decision time on the MS task was also associated with form of dimensional structure, with r's decreasing from .10 to -.22, $z = 2.18$, $p < .05$ as dimensional form decreased. No significant correlations were identified between TT and percent correct on the matrix task.
Significant correlations between solution time on initial levels of the matrix task and measures of tachistoscopic threshold (TT), decision time on the MS task, and accuracy on the LR and SPM tasks were identified, r's = .46, .67, -.44, and -.31, all p's < .01, respectively. Significant decreases in the magnitude of correlation between solution time on the matrix task and decision time on the MS task were associated with decreasing form, r's decreasing from .61 to .17, z = 3.57, p < .001. Correlations between solution time on the adapted matrix task and accuracy on the SPM and LR tasks ranged from -.44 to .31, with significant increases in the magnitude of correlation between solution time on the matrix task and accuracy on the SPM and LR tasks of .62 and .58, respectively, both z's < -3.98, both p's < .001 associated with decreases in dimensional form. No significant increases in the magnitude of correlation were associated with increases in dimensional amount.

In sum, decreasing interstimulus dimensional form was significantly related to general cognitive ability as measured by accuracy on the SPM and ACT. Patterns of correlations also indicated that decreases in interstimulus form were related to basic cognitive processes of recall and encoding, discrimination, and response selection/execution as measured by the accuracy on the LR task and decision time on the MS task, respectively. Results did not support predictions that increases in amount would be associated with increased correlations between measures of encoding and discrimination (TT and decision time on the MS task). Increases in the magnitude of correlation associated with decreases in form and decision time on the MS task, however, suggest that complex (uncorrelated) levels of interstimulus form were more highly related to individual differences in encoding and discrimination times than simple (correlated) levels of interstimulus form.

*Hierarchical multiple regression analyses: Independent contributions of interstimulus form and amount*

The independent contribution of interstimulus form and amount relationship in the prediction of individual differences in general cognitive ability was investigated by predicting
accuracy on the Raven’s Standard Progressive Matrices (SPM) and American College Test (ACT) from both percent correct and solution time on individual levels of interstimulus structure. A total of 10 levels of interstimulus structure representing two levels of amount were included in the current set of analyses. The first level of dimensional amount (2 dimensions changing) contained four levels of dimensional form (2x2 factorial combination of dimension X level of correlation); the second level of amount (3 dimensions changing) contained six levels of form (3x2 factorial combination of dimension X level of correlation).

Three hierarchical multiple regression equations were generated for each dependent. The first two equations tested the effects of decreasing form on general cognitive ability within the first and second levels of amount, respectively. Decreasing levels of dimensional form (increased complexity) were entered into each hierarchical multiple regression equation on successive steps. Four levels of form were entered into the hierarchical equation corresponding to the first level of amount; six levels of form were entered into the hierarchical equation corresponding to the second level of amount. The third equation tested the independent effects of amount on the prediction of individual differences in general ability by entering levels of amount on successive steps of the analyses. The third analysis was conducted as follows: The four levels of form corresponding to the first level of amount were entered on step one of the analyses. The six levels of form corresponding to the second level of amount were then entered using a stepwise procedure. In the stepwise procedure the variable which accounts for the most variance is entered first. Next, variables are entered one at a time in decreasing order of importance until all variables which add a significant amount of variance to the prediction of the dependent are entered. Analyses were reported separately for the two dependent measures.

*Raven’s Standard Progressive Matrices (SPM).* The role of changing interstimulus form in the prediction of accuracy on the SPM was investigated separately within each level of amount. Hierarchical multiple regression analyses corresponding to the first and second levels of amount were conducted as described above. Significant increases in the prediction of performance on
the SPM were associated with the addition of the first three levels of form on the initial level of amount (2 dimensions), with the squared multiple-R increasing from .09, $F(2,91) = 4.49, p < .01$ to .53, $F(6,87) = 16.32, p < .001$ as dimensional form decreased. Results for increased amount (3 dimensions) were similar to results from the first level of amount tested, with significant increases in the prediction of accuracy on the SPM identified with the addition of each of the first four levels of form, $R^2$ increasing from .15, $F(2,91) = 7.78, p < .001$ to .53, $F(8,85) = 12.08, p < .001$ for decreasing levels of form.

The independent contribution of amount in the prediction of individual differences on the SPM was tested by entering levels of amount on two successive steps in the multiple regression analyses as described above. The first level of amount accounted for 53% of the variance in accuracy on the SPM, $F(8,85) = 12.15, p < .001$. A significant increase in the predictability of accuracy on the SPM was associated with increased amount, percent correct on moderately complex (partially correlated) matrix problems adding 3% to the prediction, $F(9,84) = 5.58, p < .05$.

*American College Test (ACT)*. Patterns of predictability for the ACT were assessed separately for each level of amount using the first two hierarchical multiple regression analyses as described above. A significant increase in the prediction of accuracy on the ACT was associated with decreases in form on the initial level of amount tested. The squared multiple-R increased from .01 on the first level to .25, $F(8,55) = 2.25, p < .05$, on the fourth level. Increases in variance associated with decreased form were 3%, 13% and 7% for each level entered, respectively. Only the increase of 13%, $F(6,57) = 4.68, p < .01$ associated with decreased form on complex (uncorrelated) matrix problems was significant, however. Results for the second level of amount reflected similar findings, with significant increases in the prediction of accuracy on the ACT associated with decreases in form, $R^2$ increasing from .11, $F(2,61) = 3.73, p < .05$ to .35, $F(12,51) = 2.25, p < .05$ as form decreased. A significant increase was only identified for the
fifth level of form entered (complex structure among dimensions), $R^2 = .14$, $F(10,53) = 2.50$, $p < .05$, however.

The independent contribution of interstimulus amount on the prediction of performance on the ACT was tested by entering levels of amount on successive steps of the multiple regression equation as described above. The first level of amount accounted for 25% of the variance in accuracy on the ACT, $F(8,55) = 2.25$, $p < .05$. Significant predictability for increased levels of amount were associated with solution time on two the simplest levels of form contributing 12%, $F(9,54) = 10.72$, $p < .01$ and 6%, $F(10,53) = 5.76$, $p < .05$ to the prediction of accuracy on the ACT, respectively.

In sum, hierarchical multiple regression analyses indicated that the relationship between performance on the adapted experimental matrix task and general cognitive ability as measured on both the SPM and ACT were a function of both interstimulus dimensional form and amount with decreasing form the strongest predictor of individual differences in cognitive ability. The prediction of accuracy on the SPM increased systematically across decreasing levels of form on the adapted matrix task. Increased prediction of the ACT were only associated with the more complex levels of form. Results generally support experimental hypotheses with 53% and 25% of the variance on the SPM and ACT tasks predicted by decreases in dimensional form and an additional 3% and 18% predicted by increases in dimensional amount, respectively. Figure 4 shows increases in the prediction of performance on the SPM and ACT tasks as a function of increasing interstimulus complexity (decreasing dimensional form and increasing amount).

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*The role of basic cognitive processes in the prediction of general ability*

In order to determine the relationship between changes in interstimulus amount and form and measures of basic cognitive processing in the prediction of accuracy on the SPM and ACT, hierarchical multiple regression analyses were repeated with accuracy on the LR task, TT, and
decision time on the MS task entered into each regression equation, in turn, on the first step of the analyses. Next, both percent correct and solution time for the adapted matrix task were entered on successive steps of the hierarchical equation in order of increasing complexity for levels of form and amount.

Performance on the LR task was expected to affect the variance accounted for by interstimulus form and amount in the prediction of individual differences in general cognitive ability. Effects were expected to increase as matrix complexity increased, with more variance associated with the LR task on higher levels of amount and lower levels of form (increased memory load). Performance on the TT and MS tasks, on the other hand, were expected to affect variance associated with increased amount (higher number of items to encode) in the prediction of individual differences in general ability.

*Influence of the LR task on the prediction of general cognitive ability: Mediating effects on form.* The LR task measured memory for position. The increasing importance of memory was expected to be reflected in increased variance associated with the LR task as levels of amount increased and form decreased. The relationship between the LR task and the predictability of form were evaluated using hierarchical multiple regression analyses. Separate analyses for each of two levels of amount were conducted predicting accuracy on both the SPM and ACT from levels of decreasing form. Accuracy on the LR task was entered in the first step of each equation. Results indicated that accuracy on the LR task accounted for 16%, $F(1,88) = 17.18$ and 10%, $F(1,60) = 6.92$, both $p's < .01$ of the variance in performance on the SPM and ACT tasks, respectively. Mediating effects of the LR task in the prediction of individual differences in performance on both tasks were identified on simple (highly correlated) levels of the matrix task, with decreases of 6-8% in the variance associated with increases in complexity (decreases in dimensional form). No mediating effects were identified on matrix problems with simple contingent structure. Mediating effects were not identified for amount with the addition of the
LR task to the equation. Overall variance accounted for by the adapted matrix task did not increase for either the SPM or ACT tasks.

Influence of the TT and MS tasks on the prediction of general cognitive ability: Mediating effects on amount. The TT and MS tasks were included in the current study as measures of stimulus encoding and discrimination. Decision time on the MS task also taps processes of response selection/execution. The influence of TT and MS on the predictability of increased interstimulus amount was tested by repeating the hierarchical analyses for amount described above and entering TT and MS, in turn, on the first step of each equation. The TT task accounted for 1% and 3% of the variance in performance on the SPM and ACT tasks; decision time on the MS task accounted for 4% and 1% of the variance in performance, respectively. Only the increase in variance for the SPM task identified for decision time on the MS task was significant, $F(1,88) = 4.02, p < .05$. Variance associated with increased amount was eliminated when either TT or decision time on the MS task were entered into the hierarchical equation for the SPM task. Decision time on the MS task did not affect the predictability of the ACT. The TT task, on the other hand, had suppressor effects on the ACT task with the variance accounted for in the prediction of performance on the ACT task increasing from 43%, $F(10,58) = 4.05$ to 62%, $F(13,42) = 5.23$, both $p$'s < .01 after the TT task was entered.

Prediction of SPM and ACT from basic tasks: Independence of interstimulus amount and form. A hierarchical multiple regression analysis was conducted predicting each dependent, in turn, from the performance on the matrix task after basic cognitive processes as measured by accuracy on the LR task, tachistoscopic threshold (TT), and decision time on the MS task were entered into the equation on the first step. Basic processes accounted for 15%, $F(3,75) = 4.27$ and 21%, $F(3,50) = 4.32$, both $p$'s < .01 of the variance in the prediction of performance on the SPM and ACT tasks, respectively. Individual differences in performance on the adapted matrix task accounted for an additional 40%, $F(6,72) = 14.83$ and 12%, $F(6,47) = 5.83$, both $p$'s < .001 in predictability of accuracy on the SPM and ACT tasks, respectively.
In sum, experimental hypotheses were supported. Performance on the TT and MS tasks accounted for a portion of the variance associated with amount; performance on the LR task accounted for a portion of the variance associated with form on highly uncorrelated levels of the matrix task. Performance on the adapted matrix task was also highly predictive of individual differences in general cognitive ability as measured by accuracy on the SPM and ACT tasks above measures of basic cognitive processing such as recall (LR), and encoding and discrimination (TT and MS). The independence of the adapted matrix task from measures of basic cognitive processing in the prediction of accuracy on the SPM and ACT tasks indicates the important role of changing interstimulus dimensional structure in the prediction of individual differences in general cognitive ability above measures of encoding, discrimination, and recall. Contrary to experimental predictions, the LR task was not associated with increased levels of amount.

Stepwise multiple regression analyses: Identification of the best predictors of performance on the SPM and ACT

Two multiple regression analyses were conducted to determine whether higher levels of interstimulus form and amount were the best predictors of accuracy on the Raven’s Standard Progressive Matrices (SPM) and American College Test (ACT), respectively. Both percent correct and solution time from all 12 levels of the experimental task were entered into each multiple regression equation using a stepwise procedure. Analyses were reported separately for the SPM and ACT, respectively.

Raven’s Standard Progressive Matrices (SPM). Three variables entered into the stepwise solution in the prediction of accuracy on the SPM: two measuring percent correct on complex (uncorrelated) levels of dimensional form and one measuring solution time on a simple (correlated) level, in that order. Percent correct on the two uncorrelated levels of form predicted 50% of the variance in the SPM, \( F(2,91) = 44.88, p < .001 \). The increase in variance associated with solution time on the highly correlated level of form was 4%, \( F(3,90) = 7.65, p < .01 \). Total
variance accounted for by the three variables was 54%, $F(3,90) = 34.65, p < .001$ as compared to 64%, $F(24,69) = 5.11, p < .001$ when all 24 variables were entered.

*American College Test (ACT)*. Five variables entered into the stepwise solution for performance on the ACT. The single best predictor of the ACT task was solution time on the most complex (uncorrelated) level of the matrix task, $R^2 = .14$, $F(1,62) = 10.29, p < .001$. Percent correct on the two simplest (highly correlated) levels of form entered the equation next, accounting for 8%, $F(2,61) = 6.59$ and 7%, $F(3,60) = 5.74$ of the variance, both $p$'s < .05. The last two variables to enter the equation were, again, solution time measures on uncorrelated levels of the matrix task, accounting for an additional 7%, $F(4,59) = 8.43$ and 8%, $F(5,58) = 9.29$, both $p$'s < .01. Total variance accounted for by the five matrix task variables in the prediction of accuracy on the ACT was $R^2 = .44$ with $F(5,58) = 9.29, p < .001$ as compared to an $R^2 = .59$, $F(24,39) = 2.33, p < .01$ when all 24 variables were entered into the equation. The absolute increase in variance accounted for by the set of 24 variables was not significant.

In order to test the independence of each set of variables in the prediction of their respective dependents, analyses were repeated. First, the respective sets were reversed, i.e., the five variables which predicted performance on the ACT were used to predict performance on the SPM and vice versa. The set of five variables including time on uncorrelated problems and percent correct on correlated problems predicted 18% of the variance in performance on the SPM as compared to 59% from the set including three variables representing percent correct on uncorrelated problems and time on simple problems. When the sets were reversed, 12% of the variance in the ACT was predicted as compared to the 44% predicted by the original set. Follow-up $z$-tests indicated that differences between the absolute amount of variance predicted for both the SPM and ACT when the respective sets of variables were switched were significant, both $z$'s <= -2.02, both $p$'s < .05.

In sum, results supported general experimental hypotheses with performance on uncorrelated matrix problems predicting individual differences in general cognitive ability as
measured by accuracy on the SPM and ACT tasks. Performance on the SPM was predicted by
accuracy on complex matrix problems and time on simple problems. The ACT, on the other
hand, was predicted by time on complex problems and accuracy on simple problems.

The Relationship between Interstimulus and Intrastimulus Structure:

The Role of Stimulus Complexity

Interstimulus structure refers to the complexity of relationships among stimuli in the
matrix. Intrastimulus structure refers to the complexity of individual stimulus items. Although
the study of individual stimulus complexity has occupied much of the perceptual literature, the
relationship between intrastimulus complexity and interstimulus complexity has been virtually
ignored. The relationship between individual differences in the performance on adapted matrix
task as a function of intrastimulus structure was tested in two sets of multiple regression analyses.
The first set determined the role of increased stimulus complexity on overall prediction of
general cognitive ability. The second set of analyses examined the role of increased stimulus
complexity on individual levels of amount and form.

Overall role of increasing intrastimulus structure on the prediction of the general cognitive
ability. Two hierarchical multiple regression analyses were conducted with accuracy on the SPM
and ACT each as dependent variables in order to determine the overall effect of increased
stimulus complexity on the prediction of general cognitive ability. All 12 levels of percent correct
and solution time for simple stimuli were entered on the first step of the analyses using a
stepwise procedure. Next, in order to determine if increased stimulus complexity added to the
prediction of general cognitive ability, all 12 levels of percent correct and solution time for
complex stimuli were added into the equation using a stepwise procedure.

Five and three variables from the simple set were entered in each multiple regression
equation accounting for 57%, $F(5, 88) = 23.05$ and 31%, $F(3, 60) = 8.96$ both $p's < .001$ in the
prediction of accuracy on the SPM and ACT, respectively. Results indicated that percent correct
on uncorrelated problems and time on correlated problems were the best predictors of
performance on the SPM. Time on uncorrelated problems and percent correct on correlated problems were the best predictors of performance on the ACT. Results were consistent with overall analyses reported above. Increased stimulus difficulty added 4% and 11% to the amount of variance accounted for by the SPM and ACT, respectively increasing the respective squared multiple-R's to .61, $F(7,86) = 19.12$ and $F(5,58) = 8.25$, both $p$'s < .001.

*Role of increased intrastimulus structure on individual levels of amount and form.* A series of hierarchical multiple regression analyses were conducted in order to determine the amount of variance accounted for by changes in stimulus complexity on individual levels of the adapted matrix task. Regressions were conducted, in turn, with accuracy on the SPM and ACT as dependent measures. Levels of stimulus complexity were entered on two successive steps across all levels of the matrix task for each dependent measure.

Increases in the predictability of percent correct on the adapted matrix task were associated with accuracy on both the SPM and ACT tasks with changes in stimulus complexity accounting for between 5 and 10 percent of the variance, all $p$'s < .05 on both simple and uncorrelated matrix problems. Significant increases in predictability of performance on the SPM and ACT tasks across levels of stimulus complexity were also associated with solution time on the most complex (uncorrelated) levels of the matrix task. Increases in the prediction of performance on the SPM task, ranged from .07 to .21 for all measures of time associated with uncorrelated trials, all $p$'s < .01.

In sum, although the amount of variance associated with the matrix task increased as stimulus complexity increased, the absolute amount of variance accounted for in the prediction of either the SPM and ACT tasks did not increase significantly. Analyses of individual levels of the matrix task indicated that increases in the predictability of percent correct on the adapted matrix task associated with increased stimulus complexity were stable across levels of amount and form on both the SPM and ACT with increases in variance between 5-10%. Changes in the predictability of solution time associated with increased stimulus difficulty, on the other hand,
were only identified for uncorrelated matrix problems. Increases in stimulus difficulty associated with solution on uncorrelated problems indicated an interaction between complex (highly uncorrelated) matrix problems and individual differences in encoding and discrimination time with more difficult stimuli having an increasing effect on response time on highly uncorrelated levels of the matrix task.

Matrix Presentation Order

Both mean group and individual difference analysis were conducted to assess the effects of trial presentation order on components of perceptual structure. A mixed analysis of variance was conducted to test mean group differences. Both correlation and multiple regression analyses were conducted to identify patterns of individual differences associated with presentation order.

The experimental matrix task was expected to be a stronger predictor of individual differences in general ability when simple matrix problems were presented first. It was hypothesized that groups receiving simple trials first would have a greater opportunity to gradually develop a perceptual strategy and would therefore be faster and more accurate on more difficult matrix problems. Expectations were based on informal observations in pilot sessions conducted by the author and notes concerning task construction for the Raven’s Progressive Matrices (Raven et al., 1983).

Mean group differences: Analysis of variance

In order to test the overall effects of matrix presentation order on mean performance, a series of analyses of variance were conducted separately for solution time and percent correct with block presentation order as the group factor and form (spatial/object dimension correlative level), amount (number of dimensions, 1-3), and stimulus difficulty (simple, complex) as within subjects factors.

No significant main effects were associated with presentation order for either percent correct or solution time for any of the components of perceptual structure. A significant interaction between block presentation order and spatial structure was identified for both percent
correct, \( F(1,92) = 6.47, p < .05 \), and solution time, \( F(1,92) = 100.67, p < .001 \). Follow-up results indicated that students who received more difficult trials first were more accurate on those problems and faster on simpler problems than students who received simple problems first.

**Correlations**

Significant one-tailed correlations within group of presentation order indicated that students who received difficult (uncorrelated spatial trials) matrix problems first tended to exhibit higher correlations between percent correct on simple (high form/low amount) trials of the experimental task and the SPM and ACT. Students who received simpler (spatially correlated) matrix problems first, on the other hand, tended to exhibit higher correlations between percent correct on difficult matrix problems and the SPM, ACT, and MS task. Due to the small number of students in each group \((n < 47)\), however, only the differences between correlations for the match-to-sample task were significant, \( z = 2.33, p < .05 \). Students who received difficult problems first also exhibited significantly higher correlations between solution time on the matrix task and percent correct on the Raven's, \( z = 1.98, p < .05 \).

Results suggest that the order in which problems are administered affects patterns of individual differences with correlations between accuracy on simple problems higher when students receive difficult problems first and correlations with difficult problems higher in groups receiving simple problems first. Correlations with time were also affected. Students who received difficult problems first exhibited higher correlations between time on the matrix task and percent correct on the reasoning task.

**Stepwise multiple regression analyses**

Stepwise multiple regression analyses were conducted within each group of presentation order. Accuracy on the SPM and ACT were each used, in turn, as dependents. All 12 levels of both percent correct and solution time on the adapted experimental task were entered into the regression equation. Results were reported separately for each dependent.
Raven's Standard Progressive Matrices (SPM). Results for accuracy on the SPM indicated higher predictability for the adapted matrix task when students received simple (spatially correlated) matrix problems first, $R^2 = .76, F(4,42) = 32.58$ as compared to an $R^2$ of .49, $F(3,43) = 13.54$ when students received uncorrelated (spatially uncorrelated) trials first, both $p$'s < .001. Measures of percent correct on the adapted matrix task were primarily responsible for the increased predictability of the experimental task in the two groups with percent correct on uncorrelated problems accounting for 31% more variance when students received simple matrix problems first.

American College Test (ACT). Results for the ACT reflected similar differences in the predictability of the adapted matrix task associated with the type of matrix problems which were administered first with multiple-$R^2$'s of .62, $F(3,24) = 13.27$ and .43, $F(2,33) = 12.43$ for students who received simple versus uncorrelated matrix trials first, respectively. Predictors for the two groups were different. The best predictors of performance on the ACT for students who received simple matrix problems first were percent correct on both complex (uncorrelated) and simple (correlated) problems accounting for 29%, $F(1,26) = 10.39$ and 22%, $F(2,25) = 13.01$ percent of the variance in the prediction of performance on the ACT, respectively. The best predictors of performance on the ACT for students who received complex trials first, on the other hand, were all measures of solution time. Due to the small number of students in each group, the increased magnitude of the prediction associated with students who received simple problems first was not significant, however.

In sum, experimental hypotheses were supported. Stepwise multiple regression analyses for accuracy on both the SPM and ACT indicated increased predictability of the adapted matrix task for students who received simple (spatially correlated) matrix problems first. Performance in the group of students who received simple matrix problems first was predicted primarily by measures of accuracy on the experimental matrix task. Performance on measures of general ability for students who received complex matrix problems first, on the other hand, was predicted
by measures of solution time on the matrix task. Results suggest that the order in which problems are administered affects patterns of individual differences. Patterns of results seem to indicate that accuracy on the experimental task increases as a predictor of individual differences with practice. A summary graph of differences in the predictability of the adapted matrix task as a function of group of presentation order is presented in Figure 5.

Discussion

The general purpose of Study 2 was to adapt the computerized matrix task designed and tested in Study 1 in order to independently define and reliably measure the role of specific components of interstimulus dimensional structure in the prediction of individual differences in cognitive ability. Two parameters of interstimulus structure were operationally defined and tested: form and amount. Within interstimulus form, separate components of spatial and object dimensional structure were also defined and tested.

Preliminary results indicated that the experimental task was a highly reliable and valid measure of general cognitive ability which tapped processes similar to those measured by the Raven’s Standardized Progressive Matrices (SPM). Tests of mean differences in performance on the adapted matrix task indicated that defined parameters of interstimulus dimensional form and amount both had the anticipated effects on matrix task performance with mean accuracy on matrix problems decreasing as the level of interstimulus structure increased. Solution time on the matrix task was confounded with practice effects, however, decreasing as the level of interstimulus structure increased. Effects were attributed to the fact that matrix problems were administered in order of increasing difficulty, i.e., increasing interstimulus dimensional structure. Results indicate that measures of time are extremely sensitive to practice effects while measures of accuracy do not appear to be affected by practice.
Analyses also indicated that parameters of interstimulus amount and form had differential effects on matrix task performance. Mean differences in accuracy associated with increases in interstimulus amount decreased in a very systematic, additive way. Changes in form affected mean differences in performance on the matrix task in a nonadditive way, however, with exponential decreases in accuracy observed as form decreased. Types of form (spatial versus object dimensions), although not equivalent, did not interact with each other. Both measures of form also had similar effects on amount of matrix structure. Results were interpreted as evidence that operationally defined parameters of interstimulus amount and form tapped separate measures of interstimulus structure. Results also indicated that spatial and object dimensional structure were both measures of interstimulus dimensional form with stronger effects on mean matrix task performance associated with object structure.

It was hypothesized that changing interstimulus amount and form would be highly sensitive to measures of individual differences in general ability. Form, as the relational component of interstimulus matrix structure was expected to be the most highly predictive measure of individual differences in mental ability. Changes in amount, as the quantitative measure of interstimulus structure, were expected to be more highly related to time on the matrix task and time dependent measures of encoding and discrimination. Interstimulus amount was also expected to mediate the relationship between more complex levels of interstimulus form and measures of learning, reasoning, and achievement.

General experimental hypotheses were supported with performance on the adapted matrix task predicting general cognitive ability as a function of both interstimulus dimensional form and amount. Decreasing form was the strongest predictor of individual differences in cognitive ability. Performance on the SPM was predicted by accuracy on complex matrix problems. The ACT, on the other hand, was predicted by time on complex problems and accuracy on simple problems.
Differential relationships between components of interstimulus dimensional structure and measures of general cognitive ability were very enlightening. Performance on the ACT task was more sensitive to measures of both time and quantity than the SPM task. The best predictors of individual differences in performance on the ACT task were measures of solution time on the matrix task. Individual differences in performance on the SPM, on the other hand, were predicted primarily by accuracy on uncorrelated levels of form. Changes in interstimulus amount on adapted matrix task had little or no effect on SPM performance. Proportions of variance accounted for associated with form versus amount in the prediction of performance on each measure of general ability were also informative with 53% and 25% of the variance on the SPM and ACT tasks predicted by decreases in dimensional form and an additional 3% and 18% predicted by increases in dimensional amount, respectively. Results indicate that the SPM task was more strongly related to measures of form and the ACT task was related to both amount and form. The fact that the SPM is more strongly related to form comes as no surprise, since both the operational definition for form and the SPM are based on Spearman's model of cognitive processing. The fact that the adapted matrix task predicts both measures of general ability equally well, but predictions are based on different measures is very intriguing, and may reflect the classic difference between measures of fluid and crystallized intelligence with fluid intelligence more dependent on measures of form and crystallized intelligence more dependent on amount.

As the quantitative component, interstimulus amount was hypothesized to measure processes similar to the process of 'apprehension' described by Spearman (1923) in his model of cognitive processing and, as such, to be highly sensitive to measures of encoding and discrimination. Interstimulus form, on the other hand, was hypothesized to measure the 'eduction of relations and correlates' or the component of cognitive processing which Spearman identified as the most important predictor of individual differences in ability.
Since the SPM was constructed to measure Spearman's model of cognitive processing, the strong relationship between form and performance on the SPM seems to indicate that the changing dimensional form is highly related to what Spearman termed 'eduction of correlates'. Performance on the ACT, on the other hand, is also heavily influenced by the quantitative component of perceptual structure and measures of time. Results support the experimental hypothesis that individual differences in cognitive ability are a function of interstimulus dimensional structure, with changes in interstimulus form highly related to performance on the SPM.

Although on one level 'task specific' variance could be an explanation for the increased relationship between the SPM and accuracy on the form, the type of task specific variance must be considered. If differences in variance accounted for were related to task specific demands such as superficial similarity of task format and/or basic demands of stimulus encoding and matching processes, then why would the proportion of variance attributed to interstimulus amount be so much higher for the ACT task than for the SPM task? This is an important question which needs to be pursued in further studies.

Performance on the tachistoscopic threshold and match-to-sample tasks were expected to mediate increases in prediction of the matrix task associated with amount, i.e., increases in encoding and discrimination time. Predictions were supported. Measures of matrix quantity were related to performance on the TT and MS tasks. Results support the validity of amount as a quantitative measure of interstimulus structure with measures of amount highly sensitive to measures of encoding and discrimination. The current study was conducted at too global a level, however, to investigate the interaction between patterns of stimulus encoding and discrimination and accuracy on uncorrelated matrix problems (see for example Betheil-Fox et al., 1984 and Carpenter et al., 1990 for other methods).

Performance on the LR task was expected to have mediating affects on the predictability of ability from interstimulus form and amount with effects increasing for higher levels of amount
and more complex levels of form (increased memory load). The LR task had mediating effects on form but not on amount. Results seem to indicate that the LR task is highly sensitive to the relational rather than the quantitative component of matrix structure. Patterns of results between performance on the learning (LR) task and interstimulus amount are surprising. Amount is a quantitative measure which reflects the increasing number of dimensions changing in a matrix. The LR task measures recall of position for novel perceptual stimuli.

Increases in the number of elements in inductive reasoning tasks have been associated with performance differences (e.g., Mulholland et al., 1980; Carpenter et al., 1990). Changes in task performance as the number of elements in a problem increases, have been linked to increased 'working memory' load. Indeed, reasoning and working memory have recently been equated (Kyllonen & Christal, 1990). If increased memory load predicts individual differences in performance on reasoning tasks, then it seems logical that memory for position (LR) would be related to increased amount. This prediction was not upheld in the current set of analyses. Instead, memory for position was related to decreases in form, i.e., relationship between elements. Results seem to indicate that increasing the number of elements (increased amount) in a reasoning task does not directly affect performance by increasing the memory load per se. Rather the association between working memory and performance on inductive reasoning tasks seems to be directly related to the increased difficulty of identifying relationships between elements (decreased form) as the number of elements in the problem increases.

Stimulus complexity was also expected to interact with both interstimulus form and amount with stronger performance deficits associated with more complex stimuli as levels of interstimulus complexity increased. Again, general predictions were supported with changes in the predictability of solution time associated with increased stimulus difficulty on the matrix task in more complex (uncorrelated) matrix problems. Changes in stimulus complexity did not affect performance on simple matrix problems. Increases in stimulus complexity associated with solution on uncorrelated problems seems to indicate an interaction between complex matrix
problems and individual differences in encoding and discrimination time with more complex stimuli having an increasing effect on response time in highly complex (uncorrelated) matrix problems. The larger mediating effects of stimulus complexity on uncorrelated problems seems to indicate that encoding, discrimination, and response selection/execution times play a larger role in the accuracy of uncorrelated matrix problems than they play in simple (correlated) matrix problems.

The effect of trial presentation order (simple versus complex matrix problems administered first) on individual differences in performance on the adapted matrix task was also investigated. Results suggest that the order in which problems are administered affects patterns of individual differences with higher predictability of the adapted matrix task associated found when simple matrix problems are administered first.

Many tests, including the Raven's Progressive Matrices, have been designed beginning with the easiest trials and progressing in order of increasing difficulty. Beginning with the easiest problems first seems to allow the test taker the opportunity to develop a strategy, thus increasing the predictability of the test. The relationship between the prediction of individual differences in cognitive ability from perceptual factors must therefore be questioned when matrix problems are presented in increasing order of difficulty. The enhanced 'validity' of the adapted matrix task in the current study may be due to factors which are not necessarily 'perceptual' in nature. The question of why different presentation orders interact with task performance to either enhance or reduce the relationship with measures of cognitive ability is not clear. Although these observations were only exploratory, general findings may have important implications for testing cognitive abilities and should to be systematically explored in future studies.

In sum, interstimulus form and amount were sensitive measures of individual differences in mental ability with form the best predictor of individual differences in general cognitive ability. Mediating effects were identified for stimulus complexity and matrix presentation order. Basic cognitive processes of encoding, discrimination, and recall were also shown to be important
predictors of individual differences in general ability and to have mediating effects on the predictability of interstimulus form and amount.
General Discussion

The purpose of the current research was to investigate the relationship between varying degrees of perceptual structure and individual differences in cognitive ability. Two computerized matrix tasks were constructed and tested using a structural model of inductive reasoning. The current structural model was based on one proposed by Royer (1978) which argued for the important role of complex 'correlational structure' in the predication of individual differences in intelligence. Parallel's were drawn between Royer's structural model and Spearman's qualitative model of cognitive processing in the prediction of individual differences in cognitive ability through changing levels of perceptual structure.

The first task operationally defined decreasing interstimulus dimensional structure by systematically increasing the difficulty of dimensional relationships between stimuli in a 3x3 matrix task. The second task further refined the initial matrix task by defining two individual parameters of interstimulus dimensional structure: amount and form. Two levels of stimulus complexity (intrastimulus structure) were also included in the adapted matrix task.

Tasks were tested in two successive studies. The first study tested the importance of interstimulus dimensional structure in the prediction of individual differences in general cognitive ability. The second study tested the relationship among parameters of intrastimulus structure, interstimulus structure, and individual differences in cognitive ability.

Both tasks were identified as reliable and valid predictors of individual differences in general ability. Results from the first study indicated that changing dimensional structure between stimuli was an important factor in the prediction of individual differences in intelligence. The experimental task predicted performance on the Raven's Progressive Matrices better it predicted than performance on the AFQT.

Study 2 replicated and expanded results from Study 1. Parameters of interstimulus form and amount were identified as independent predictors of individual differences in mental ability in Study 2. Interstimulus form was the most highly related to individual differences in general
cognitive ability. No difference in the magnitude of the prediction was identified for the two measures of general ability. Measures of general ability, i.e., SPM versus ACT, were predicted by different parameters of the adapted matrix task, however. The SPM was predicted by percent correct on complex (uncorrelated) problems of the matrix task and solution time on simple (correlated) problems of the matrix task. The ACT, on the other hand, was predicted by solution time on highly uncorrelated levels of the matrix task and percent correct on correlated levels. Results also indicated that interstimulus form was a better predictor of performance on the SPM; amount, on the other hand, was a better predictor of the ACT. It was suggested that the differential predictive validity of measures of percent correct versus solution time and form versus amount for the SPM and ACT, respectively, may reflect the classic distinction between measures of fluid and crystallized intelligence (Cattell, 1971). Fluid measures of ability are highly related to measures of inductive reasoning; crystallized measures of ability have generally been defined in terms of past knowledge. The current study suggests distinctions between these two types of measures in terms of basic processing components. The distinction may be an important link between psychometric and information processing measures of intelligence.

Both mean group and individual difference analyses indicated that measures of amount and stimulus complexity had similar effects on performance and that form had differential effects. Results support the experimental hypothesis that interstimulus amount and intrastimulus (individual stimulus) complexity are both quantitative measures which reflect the information load of the matrix and stimuli, respectively. Interstimulus form, on the other hand, seems to be measuring a process more closely associated with measures of learning or what has been described by Spearman as the 'eduction of relations and correlates'. This process, rather than being a complex cognitive process based on 'higher order processing' has been defined, in the current study, as a basic process based on the systematic manipulation of relationships between dimensions in a matrix. Royer's (1978) structural model of intelligence was supported.
In sum, the classic measures of stimulus encoding and discrimination were sensitive to quantitative measures of both individual stimulus and matrix information. The relational component of form extends the same-different comparison to ask, 'How are these two stimuli different?' The current model is an attempt to bridge the gap between 'perceptual' and 'conceptual' processing by operationally defined processes on an inductive reasoning task in terms of perceptual structure. Results point to the importance of perceptual processing in the eventual understanding of individual differences in cognitive ability.

Problems in the studies, however, make it difficult to isolate the exact role of interstimulus structure in the prediction of individual differences in intelligence. The first study tested a sample cognitively restricted of Air Force Recruits. Motivational problems were also identified in the first study. In the second study, although the matrix task was a more valid predictor of individual differences, the relationship between parameters of changing interstimulus dimensional structure were confounded with 'strategic' effects, i.e., the blocking of trials enabled students to learn a perceptual 'strategy'. When trials are blocked according to increased difficulty, the effects of changing interstimulus structure cannot be separated from the effects of learning a perceptual 'strategy'.

But although a portion of the increased validity of the adapted matrix task may be the result of presentation order, results from the first study, even in a cognitively restricted sample, still indicate that interstimulus dimensional structure is an important independent predictor of individual differences in cognitive ability. The exact nature of the relationship, however, needs to be further pursued by systematically manipulating the order in which trials are presented in a sample of subjects with a wider range of individual differences in cognitive ability. In this manner, the effects of developing a perceptual 'strategy' versus the specific effects associated with changing interstimulus dimensional structure may be better understood.

In conclusion, changing dimensional relationships between stimuli were identified as important, independent predictors of individual differences in general cognitive ability. Results
are interpreted as evidence of the importance of perceptual structure in the prediction of individual differences in intelligence. Results are consistent with Spearman's qualitative model of mental ability.
Bibliography


American university population and an examination of the relationship with Spearman's g. *Journal of Experimental Education, 54*, 95-100.


Table 1: Stimulus Complexity Parameters for the Experimental Matrix Task

<table>
<thead>
<tr>
<th></th>
<th>Number of Squares Filled</th>
<th>Number of Adjacencies</th>
<th>Equivalent Set Size</th>
<th>Sub-Symmetry</th>
<th>Number of Turns</th>
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<td>4.7</td>
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<td>4.6</td>
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<td>176.5</td>
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<td>119.4*</td>
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<td>229.4*</td>
<td>6.9*</td>
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<td>4.6</td>
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<td>7.4</td>
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*Although Pattern 2 was less symmetrical, it was equally represented across difficulty levels.
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<th>Solution Time</th>
<th>SD of Time</th>
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<td>5.11 (1.24)</td>
<td>2.19 (1.02)</td>
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<td>Difficulty Level 3</td>
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<td>4.63 (2.14)</td>
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<td>Difficulty Level 4</td>
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<td>11.02 (3.52)</td>
<td>5.14 (2.30)</td>
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<td>Difficulty Level 5</td>
<td>.72 (.18)</td>
<td>12.64 (4.34)</td>
<td>6.59 (3.35)</td>
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<td>Difficulty Level 6</td>
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<td>8.49 (4.44)</td>
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<td>Pattern</td>
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<td>7.57 (3.67)</td>
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<td>2.</td>
<td>3.</td>
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<td>---------------------</td>
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<td>.231*</td>
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<td>.251**</td>
<td>.227*</td>
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<td>.282**</td>
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<td>.557**</td>
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<td>Totals</td>
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<td>.894**</td>
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<td>.558**</td>
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* p < .01
** p < .001
Table 4: Principle Component Analysis with Varimax Rotation

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<td>.209</td>
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<td>1. Exp. Task-%correct</td>
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<td>3. Exp. task-SD time</td>
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<td>4. APM-%correct</td>
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<td>5. APM-time</td>
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<td>6. AFQT score</td>
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*p < .01

**p < .001
Table 6: Correlations between Difficulty Levels of the Experimental Matrix Task and the Raven’s Progressive Matrix Task and AFQT

<table>
<thead>
<tr>
<th>Percent Correct</th>
<th>Raven's % Correct</th>
<th>Raven's Time</th>
<th>AFQT Score</th>
<th>Solution Time</th>
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<td>.250**</td>
<td>.273**</td>
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<td>Level 2</td>
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<td>.195*</td>
<td>.253**</td>
<td>Level 2</td>
</tr>
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<td>.395**</td>
<td>.273**</td>
<td>.312**</td>
<td>Level 3</td>
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<td>Level 4</td>
<td>.413**</td>
<td>.182*</td>
<td>.350**</td>
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<tr>
<td>Level 5</td>
<td>.470**</td>
<td>.244**</td>
<td>.367**</td>
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<td>Level 6</td>
<td>.337**</td>
<td>.136</td>
<td>.150</td>
<td>Level 6</td>
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<tr>
<td>Overall</td>
<td>.469**</td>
<td>.265**</td>
<td>.363**</td>
<td>Overall</td>
</tr>
<tr>
<td>Raven's % Correct</td>
<td>.092</td>
<td>.195*</td>
<td>.098</td>
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<tr>
<td>Raven's Time</td>
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<td>.179*</td>
<td>.083</td>
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<td>AFQT Score</td>
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<td>.390**</td>
<td>.017</td>
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</tr>
<tr>
<td>Solution Time</td>
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<td>.389**</td>
<td>.153</td>
<td></td>
</tr>
<tr>
<td>Level 5</td>
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<td>.468**</td>
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<td></td>
</tr>
<tr>
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<td>.576**</td>
<td>.279**</td>
<td></td>
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<tr>
<td>Overall</td>
<td>.214*</td>
<td>.513**</td>
<td>.191*</td>
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* $p < .01$

** $p < .001$
Table 7: Hierarchical Multiple Regression  
Predicting Performance on the Raven’s and AFQT  
across Levels of the Experimental Matrix Task

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<tr>
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<th>Change R-sq</th>
<th>F(df)</th>
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<td></td>
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<td>Step 1 level 1</td>
<td>.289</td>
<td>.083</td>
<td>.083</td>
<td>9.13 (2, 201)</td>
<td>p &lt; .001</td>
</tr>
<tr>
<td>Step 2 level 2</td>
<td>.354</td>
<td>.125</td>
<td>.042</td>
<td>4.78 (4, 199)</td>
<td>p &lt; .01</td>
</tr>
<tr>
<td>Step 3 level 3</td>
<td>.454</td>
<td>.206</td>
<td>.081</td>
<td>10.05 (6, 197)</td>
<td>p &lt; .001</td>
</tr>
<tr>
<td>Step 4 level 4</td>
<td>.479</td>
<td>.230</td>
<td>.023</td>
<td>2.96 (8, 195)</td>
<td>NS</td>
</tr>
<tr>
<td>Step 5 level 5</td>
<td>.566</td>
<td>.320</td>
<td>.091</td>
<td>12.87 (10, 193)</td>
<td>p &lt; .001</td>
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<tr>
<td>Step 6 level 6</td>
<td>.622</td>
<td>.387</td>
<td>.067</td>
<td>10.45 (12, 191)</td>
<td>p &lt; .001</td>
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<tr>
<td><strong>Dependent: AFQT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 1 level 1</td>
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<td>.100</td>
<td>.100</td>
<td>9.87 (2, 178)</td>
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<tr>
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<td>.056</td>
<td>5.84 (4, 176)</td>
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<td>3.27 (6, 174)</td>
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<td>4.15 (8, 172)</td>
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<td>.251</td>
<td>.017</td>
<td>1.87 (12, 168)</td>
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Table 8: Means (SD) for Stimulus Complexity Parameters for the Simple and Complex Stimulus Sets of the Experimental Task, Study 2

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<th>Equivalent Set Size</th>
<th>Sub-Symmetry</th>
<th>Number of Turns</th>
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<tbody>
<tr>
<td>Simple Set</td>
<td>6.0 (1.6)</td>
<td>4.8 (2.3)</td>
<td>4.9 (1.9)</td>
<td>184.9 (110.0)</td>
<td>7.3 (1.8)</td>
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<tr>
<td>Complex Set</td>
<td>6.0 (1.6)</td>
<td>2.9 (2.6)</td>
<td>5.0 (2.0)</td>
<td>118.3 (50.9)</td>
<td>14.2 (2.7)</td>
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Table 9: Intercorrelations between the Adapted Experimental Matrix Task and Measures of Cognitive Ability, Study 2

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<td>2. Matrix Task - Time</td>
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<td></td>
<td></td>
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<td>3. Learning - Correct</td>
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<td>-0.06</td>
<td>1.00</td>
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<td>4. Matching DT</td>
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<td>5. Tachistoscopic Thres.</td>
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<td>0.28*</td>
<td>-0.25</td>
<td>0.32**</td>
<td>1.00</td>
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</tr>
<tr>
<td>6. ACT Score</td>
<td>0.33*</td>
<td>0.11</td>
<td>0.32*</td>
<td>0.10</td>
<td>0.17</td>
<td>1.00</td>
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</tr>
<tr>
<td>7. Raven's Correct</td>
<td>0.65**</td>
<td>0.08</td>
<td>0.40**</td>
<td>0.21</td>
<td>0.12</td>
<td>0.44**</td>
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<td>8. Raven's Time</td>
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<td>0.31*</td>
<td>0.17</td>
<td>0.32**</td>
<td>1.00</td>
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Minimum pairwise N of cases: 58
1-tailed Signif: * - .01  ** - .001
Figure 1: Six Levels of Difficulty for the Experimental Matrix Task, Study 1
Figure 2: Twelve Levels of Interstimulus Structure, Study 2

LATIN SQUARE ARRANGEMENTS
Figure 3: Accuracy on the Adapted Matrix Task as a Function of Interstimulus Form and Amount

Percent Correct

Interstimulus Dimensional Structure

2 dimensions

3 dimensions

Spatial-correlated
Object-correlated
Spatial-uncorrelated
Object-uncorrelated
Figure 4: Prediction of the SPM and ACT as a Function of Interstimulus Form and Amount.

![Figure 4: Prediction of the SPM and ACT as a Function of Interstimulus Form and Amount.](image)
Figure 5: Predictability of the Adapted Matrix Task as a Function of Presentation Order
Appendix A: Set of 27 Stimuli used in the Experimental Matrix Task, Study 1

Pattern 1

Pattern 2
Appendix B: Complete Set of Stimuli from which the Simple and Complex Sets were Chosen

We are trying to rate the relative ease versus difficulty of the following patterns. Please fill in the pattern if it is clear to you.
Then circle a number 1-5 indicating the relative difficulty (1=easiest; 5=hariest). PLEASE MAKE SURE TO USE ALL 5 NUMBERS.

PLEASE GO ON TO NEXT PAGE
Please fill in the missing pattern. Then rate the ease or difficulty of the pattern on a scale from 1-5 (1=easiest; 5=most difficult).

[Grids of patterns with numbers 1 to 5 for each section]

PLEASE GO ON TO NEXT PAGE.
Please fill in the missing pattern. Then rate the ease or difficulty of the pattern on a scale from 1-5 (1=easiest; 5=most difficult).

THANK YOU FOR YOUR TIME!
Appendix C: Mean Difficulty Ratings for Simple and Complex Stimulus Sets for the Adapted Experimental Matrix Task, Study 2

Easy set: Mean difficulty rating = -.76 (SD = .35)

Hard set: Mean difficulty rating = 1.39 (SD = .49)

Only the first nine items from each set are shown. Remaining items include rotations of shown items at 90° and 180°.
APPENDIX D: Experimental Design for Study 2

Two measures of perceptual structure were manipulated: intrastimulus and interstimulus structure. Within interstimulus dimensional structure two separate components, matrix amount and form, representing the quantity and structure of the matrix, respectively, were also manipulated. Amount of matrix structure was the information load or number of dimensions (1-3) which varied in the total matrix; form was measured according to the number of dimensions which predicted each other in a simple contingent manner, i.e., level of correlational structure. Intrastimulus structure was represented by simple and complex sets of stimuli, respectively.

Conditions of Interstimulus structure

The twelve levels of interstimulus structure were as follows:

1= 1 dimension changing
2= 2 dimensions changing; correlated
3= 2 dimensions changing; uncorrelated
4= 3 dimensions changing; correlated
5= 3 dimensions changing; partially correlated
6= 3 dimensions changing; uncorrelated

Stimuli in orders 7-12 were identical to 1-6, but in were spatially rearranged in a latin square arrangement, i.e., uncorrelated with the y-axis. Trials were blocked within spatial condition, i.e., ordered versus latin square arrangement and tested in increasing order of difficulty. Block presentation order was counterbalanced across subjects. Intrastimulus structure (simple versus complex) was randomized within each block.
Order of matrix presentation (simple versus complex trials first) was a between subject measure. Parameters of perceptual structure were all tested within subject. Trials were blocked within two spatial conditions (ordered versus latin square arrangement). Trials were tested within two equal halves. Five trials were presented within each half (10 trials for each condition of perceptual structure).

**KEY**: O = order of presentation, S = subject,  
  p = level of spatial correlation (ordered versus latin square),  
  a = amount (number of dimensions changed in the matrix),  
  d = level of object dimensional correlation,  
  i = individual stimulus complexity (simple versus complex)
Appendix E: Task Directions and Sample Problems for Study 2

DIRECTIONS

The following task uses novel perceptual stimuli which vary in three ways: the number of blocks filled, the distance between the blocks, and the rotation of the pattern of blocks. For example, the following stimuli vary on levels of the three dimensions.

Number of blocks filled:
Distance between blocks:

Rotation of the pattern of blocks:
### Appendix F: Means (SD) across Difficulty Levels of the Adapted Experimental Matrix Task, Study 2

<table>
<thead>
<tr>
<th></th>
<th>Percent Correct</th>
<th>Reaction Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Min</td>
</tr>
<tr>
<td><strong>Amount: One dimension varied</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial Form: Correlated</td>
<td>.94 (.07)</td>
<td>.70</td>
</tr>
<tr>
<td>Spatial Form: Uncorrelated</td>
<td>.86 (.13)</td>
<td>.50</td>
</tr>
<tr>
<td><strong>Amount: Two dimensions varied</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimensional Form: Correlated</td>
<td>.75 (.06)</td>
<td>.80</td>
</tr>
<tr>
<td>Spatial Form: Uncorrelated</td>
<td>.87 (.16)</td>
<td>.40</td>
</tr>
<tr>
<td>Dimensional Form: Uncorrelated</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial Form: Correlated</td>
<td>.71 (.18)</td>
<td>.20</td>
</tr>
<tr>
<td>Spatial Form: Uncorrelated</td>
<td>.66 (.18)</td>
<td>.20</td>
</tr>
<tr>
<td><strong>Amount: Three dimensions varied</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dimensional Form: Correlated</td>
<td>.96 (.06)</td>
<td>.70</td>
</tr>
<tr>
<td>Spatial Form: Uncorrelated</td>
<td>.85 (.15)</td>
<td>.40</td>
</tr>
<tr>
<td>Dimensional Form: Partially Correlated</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial Form: Correlated</td>
<td>.67 (.18)</td>
<td>.20</td>
</tr>
<tr>
<td>Spatial Form: Uncorrelated</td>
<td>.53 (.22)</td>
<td>.15</td>
</tr>
<tr>
<td>Dimensional Form: Uncorrelated</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spatial Form: Correlated</td>
<td>.48 (.21)</td>
<td>.10</td>
</tr>
<tr>
<td>Spatial Form: Uncorrelated</td>
<td>.35 (.25)</td>
<td>.00</td>
</tr>
</tbody>
</table>

**Overall means**

<table>
<thead>
<tr>
<th></th>
<th>Percent Correct Mean (SD)</th>
<th>Reaction Time Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Total</td>
<td>.74 (.11)</td>
<td>.42 .93</td>
</tr>
<tr>
<td></td>
<td>15.85 (6.20)</td>
<td>4.22 35.61</td>
</tr>
<tr>
<td>Total Spatial Form: Correlated</td>
<td>.78 (.10)</td>
<td>.47 .97</td>
</tr>
<tr>
<td>Total Spatially Uncorrelated</td>
<td>.69 (.15)</td>
<td>.36 .95</td>
</tr>
</tbody>
</table>