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AN APPLICATION OF COMPUTATIONAL THEORY TO THE PREDICTION OF CREATIVITY IN COLLEGE STUDENTS

By

Michael James Finton

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ABSTRACT

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THE PREDICTION OF CREATIVITY IN COLLEGE STUDENTS

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Empirical investigations of creativity have typically examined single variables. The predictive and explanatory value of this approach is limited, because creativity is a variable which is likely multiply determined. Computational theories assume that the central components of a cognitive process can be identified and the relative importance of each variable can be assessed. In this study, a computational model was used to determine whether scores on tests of mental imagery, cognitive flexibility, abstract reasoning, and personality were correlated to scores on the Figural battery of the Torrance Tests of Creative Thinking. Twenty-seven male subjects and 81 female subjects were tested, for a total sample of 108 subjects. Results indicated that, when analyzed separately, personality traits and the ability to form mental images were not related to creative ability. For male subjects, the ability to embellish drawings with detail was related to personality traits and the ability to benefit from corrective feedback. Whereas no combination of variables successfully predicted overall creative ability, two equations were found that predicted scores on some of the component tests of creative ability for male subjects and analyses involving the entire sample. These results are discussed in terms of the shortcomings of computational models.

Great is Your faithfulness.

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Five and one-half years after I began, I am now near the end of my graduate training in clinical psychology and neuropsychology. As I look back over the past year, I am particularly struck by the number of individuals who have supported me emotionally and helped me grow both personally and professionally as I worked on my dissertation.

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INTRODUCTION

Imagery has long been considered to be a major component of thought (Glasgow & Papadias, 1992). Furthermore, many researchers have suggested that imagery is important to creativity. Rothenberg (1988) has argued that creative individuals are dependent upon imagery and can only create new ideas by actively manipulating visual images. In contrast, some (e.g., Harpaz, 1990) have suggested that creativity and imagery can only be understood in the context of neuropsychological variables; still others (e.g., Alter, 1989) have indicated that examination of personality traits apart from imagery will lead to a richer understanding of the creative process.

This divergence of opinion in the appropriate variable to examine in creativity has led to the study of a range of factors whose relative contribution to the creative process is unknown. Computational theories are intended to improve predictive accuracy by identifying multiple variables. These theories assume that complex cognitive processes can be broken down into their component parts. Individual modules are thought to ultimately correspond directly to cerebral structures; moreover, sequential movement between modules is assumed to represent the rich cortical and subcortical interconnection of cerebral processes. Once identified, these processes are translated into elaborate computer programs, which in turn are used to validate and extend theories of cerebral processing. If computational modeling is a valid tool for investigating complex cognitive activities, then it could potentially be applied to creativity, a process which has engendered much debate as to its nature.

Review of the Literature

Creativity

The creative process has been described for hundreds of years (Shaw & DeMers, 1986; Shaw & DeMers, 1987). The most universally accepted definition of the creative process was forwarded by Wallas (Shaw, 1987), who described creative thought as occurring within four stages: preparation, in which information is gathered about the problem to be solved; incubation, in which conscious effort to solve the problem is replaced by unconscious work; illumination, which is characterized by insight into a potential solution of the problem; and verification, a period of conscious work in which the viability of the solution is evaluated. Later writers attempted to delineate the specific process by which creative solutions were formulated. For example, Mednick (1962) believed that creativity was characterized by " . . . the forming of associative elements into new combinations which either meet specified requirements or are in some way useful. The more mutually remote the elements of the new combination, the more creative the process or solution" (p. 221). However, the process by which associations were developed (i.e., conscious or unconscious) was not specified. Simon (Csikszentmihalyi, 1988) has argued that such solutions are made possible by the presence of a large and diverse knowledge base. Because this information can be programmed into a computer and programs can be written which analyze this data, he has argued that creativity is nothing more than problem solving ability. In contrast, others (Smilansky & Halberstadt, 1986) have suggested that the ability to formulate problems underlies the process of creativity, since "until a question is posed, no problem exists to be solved" (p. 183). These authors believe that individuals who are able to approach a field of study without dependence upon existing solutions will manifest higher levels of creative ability. Torrance (1990) has defined creativity as

> a process of becoming sensitive to problems, deficiencies, gaps in knowledge, missing elements, disharmonies, and so on; identifying the difficulty; searching for solutions; making guesses or formulating hypotheses about deficiencies; testing and retesting hypotheses and possibly modifying and retesting them; and finally communicating the results (p. 8).

The lack of consensus in defining creativity has had enormous ramifications for empirical research. Because measurement of any variable is shaped by theoretical assumptions, the absence of an accepted definition means that creativity will be measured in a variety of ways. Indeed, a number of creativity measures have been developed. Some (e.g., Remote Associates Test; Shaw & DeMers, 1986) assess the ability to generate numerous and unusual associations to diverse stimuli; others (e.g., Regression in the Service of the Ego Scale; in Barron & Harrington, 1981) attempt to access unconscious mechanisms; still others (e.g., Symbol Equivalents Test; in Barron & Harrington, 1981) examine the role of metaphorical thinking in creativity. Perhaps the most widely used tests evaluate the ability to generate multiple solutions to stimuli. Several authors (i.e., Barron & Harrington, 1981; Feldhusen & Clinkenbeard, 1986) have noted that, of these tests, the Torrance Tests of Creative Thinking (TTCT; Torrance, 1990) are employed most frequently.

When questionnaires are used without reference to assumptions about the nature of creativity, inconsistent results should be expected both within and between studies, since investigators may not be investigating identical constructs (Shaw & DeMers, 1985). The TTCT was used in this study, both because it has relatively robust psychometric properties and its extensive use in previous research maximizes the number of comparisons that can be made between studies.

In developing his test, Torrance was influenced by Burnham (1892; in Torrance, 1990), who believed that imagination was the act or power of forming a mental image when the stimulus was no longer physically present.

Imagination could be dichotomized into reproductive and creative productive forms: The former involved recall and reproduction of previously learned information, whereas the latter involved the recombination of previously learned information into new wholes. Torrance was also influenced by Spearman (1930; in Torrance, 1990), who argued that new ideas could be created not only from abstract representations of concepts, but from sensory impressions such as sight, smell, and touch. Like Burnham, Spearman believed that new ideas were created by transforming previously learned information. Because imagery is implicit in Torrance's definition of creativity and in the theory which underlies the TTCT, further examination of this variable appears to be warranted.

Imagery

Imagery has been cited by a number of authors (e.g., Isaksen, Dorval, & Kaufmann, 1991; Goldschmidt, 1991) as preeminent in the creative process. Indeed, anecdotal accounts of the powerful influence imagery has in attaining creative insights are numerous. However, the results from empirical investigations of the interrelationship of imagery and creativity have been inconclusive (Parrott & Strongman, 1985). Like creativity, these contradictory findings may reflect the difficulties inherent in operationalizing imagery (Shaw & DeMers, 1986).

Imagery is typically defined as sensory or perceptual experiences which exist in the absence of a sensory or physical stimulus (Richardson, 1977). A number of methodologies have been developed for the investigation of mental imagery. Because most individuals are able to report details of their subjective experiences (Kosslyn & Jolicoeur, 1981), one of the oldest techniques for evaluating imagery ability has been self-report.

Fechner (1860; in Kosslyn & Jolicoeur, 1981) and Galton (1883; in Kosslyn & Jolicoeur, 1981) were among the first to study imagery quantitatively. Subjects were asked to generate images of objects; both investigators found that individuals differed in the vividness of their images. Later researchers (Betts, 1909; in Kosslyn & Jolicoeur, 1981; Marks, 1977) constructed scales to quantify the subjective amount of vividness experienced. However, because it is impossible to ascertain whether all subjects report their experience of the same construct, use the same criteria to assess images, or are influenced by demand characteristics or response biases, use of these scales warrants caution in interpretation (Kosslyn & Jolicoeur, 1981; Parrott & Strongman, 1985).

Objective tests of imagery ability were developed partly in response to the methodological inadequacies of self-report measures. Construction of these tests is usually based less upon a theoretical rationale than upon a belief that the experimental task requires imagery. Results are later correlated with behavior in other areas (Kosslyn & Jolicoeur, 1981).

Several objective tests have been used in the study of mental imagery. For example, in what has come to be known as the Hebb test (Hebb, 1968), subjects are read words and then asked to spell them backwards. In other tests, subjects are required to arrange series of letters or numbers into a matrix, and then name items in rows, columns, and diagonals. The ability to perform at high levels on both tests was assumed to be a consequence of the static and unchanging nature of images, which were thought to be much like photographs. Those subjects high in imagery ability would therefore be able to simply 'read' the letters from their images. However, investigators (e.g., Woodworth, 1938; in Kosslyn & Jolicoeur, 1981) have found that subjects are unable to maintain static images, suggesting that the nature of mental imagery is somewhat more complex. Furthermore, skill in this task may be related to relatively well developed abilities in visual organization.

Kosslyn and Jolicoeur (1981) argued that, in general, objective tests of imagery have displayed scant predictive ability. This failure is due to both the lack of demonstrated validity of the constructs purported to be measured by such tasks and the tendency to develop imagery tests within a theoretical vacuum. In order to remedy these deficiencies, a model of mental imagery was developed, primarily by Kosslyn, which encompasses how images are represented and processed internally. Using a computational model, Kosslyn and Jolicoeur (1981) proposed that image processes can be split into generation, inspection, and transformation components.

In the generation module, images are derived from information stored in long-term memory. Activation of this representation retrieves this information for display in a visual buffer, utilizing a quasi-pictorial format. Evidence for this format accrued over a series of experiments. First, images appeared to be spatial rather than abstract representations of concepts, as evidenced by the greater amounts of time necessary to scan between increasingly distant points on a visual image of a map (Kosslyn, Ball, & Reiser, 1978). Furthermore, the visual perspective of imaged objects appeared to be the same as that for actual objects. That is, smaller objects appeared larger than larger objects if imaged in the foreground (Kosslyn, 1978). The finding that subjects take longer to inspect smaller images for details than larger images was interpreted by Kosslyn (1975) as further evidence that images were spatial representations which were similar to those involved in the perception of nonimaginal objects.

In addition to the manner in which images are represented and generated, Kosslyn has argued that images are constructed sequentially, in part because the component parts are encoded separately. Kosslyn, Reiser, Farah, and Fliegel (1983) demonstrated that the time necessary to construct images increases when additional objects are included in an imaged scene. Kosslyn, Cave, Provost, and von Gierke (1988) also demonstrated that images of simple patterns are generated sequentially. Subjects were shown a blank grid and a lowercase letter. They were required to state whether two 'x' marks would fall into cells on a grid that were to be occupied by the uppercase version of the letter. Kosslyn, Cave, Provost, and von Gierke found that reaction times increased with the complexity of letters. Significantly, the response times for probes that were nearer to the beginning of the path along which the letter is typically drawn were faster than response times to probes that were farther. The same pattern of results held for novel patterns which were taught to the subjects.

Activities carried out in the inspection module are made possible by the vividness of images. Indeed, vividness of imagery has been hypothesized to be one of the most important components in the imagery process (i.e., Kosslyn & Jolicoeur, 1981). Kosslyn (1980, 1988) suggested that images have limited resolution, and must be "refreshed" periodically to maintain their vividness. In addition, Kosslyn, Cave, Provost, and von Gierke (1988) suggested that inspecting images in order to make decisions regarding content is dependent upon the accuracy with which distinct perceptual units of the overall image are encoded. Thus, decisions about images are quickest when the information required corresponds to units inherent in the image.

Transformation of mental images, like vividness, has been hypothesized to be an important component of the imagery process (i.e., Kosslyn & Jolicoeur, 1981). Gordon (1949) stated that the ability to manipulate images is necessary to create meaning and structure for the individual. As stated by Shaw and DeMers (1986), "the implication is that manipulation and control of images would be very important to the individual's ability to understand and cope with the environment" (p. 67). The essence of this position has been captured by Johnson-Laird (1983), who suggested that individuals construct mental models of their environment. Thought is postulated to be a consequence of the manipulation of these internal representations. The ramifications of this position for creativity will be more extensively addressed in the discussion section.

The ability to manipulate mental images has been studied in a variety of contexts. Shepard and Feng (in Finke, Pinker, & Farah, 1989) tested the ability to transform letters. For example, when subjects were told to rotate a letter 90 degrees and were subsequently given the letter 'N', they were quickly able to identify the new letter as a 'Z'. More complex tasks have also been used. Finke and Slayton (1988) demonstrated that subjects can discover patterns in images when instructed to combine a set of geometric figures, lines, or alphanumeric characters. Palmer (1977) instructed subjects to superimpose two connected line segments and compare the resultant image to visual probes. Subjects were successful both when the subpatterns constituted geometric figures and when the subpatterns were disconnected line segments, suggesting that the ability to manipulate images is a robust phenomenon.

Nonetheless, Lezak (1983) noted that the efficiency of such mental processes is dependent upon the presence of other variables. The ability to manipulate single or combined images is undoubtedly influenced by attentional factors. R. A. Cohen (1993) has postulated that attention is influenced by at least four factors. First, the appropriate features of stimuli must be selected. Higher-order systems subsequently select and focus on subsets of these characteristics; attention can shift to other areas as a consequence of expectancies or new information. Second, a large number of responses are generated in response to the requirements of a given task. Potential responses are selected from this set, after which specific answers are chosen through the mediation of executive supervisory control. Cohen noted that the structures necessary for these functions are located primarily in premotor and prefrontal cortex. Third, the capacity of attention is influenced by both structural and energistic factors. Structural factors include the constraints of memory, the speed of neural processing, and the nature of representation. Energistic factors refer to the general arousal and motivational state of the individual. Fourth, the ability to sustain attention, defined as the variability in performance over time, is influenced by both the degree to which an individual is susceptible to fatigue and by the frequency of available targets to be detected. However, despite the importance of these variables to mental imagery, the contribution of visual attention has not yet been assessed in empirical studies.

The ability to manipulate images also seems to be related to the integrity of functions normally ascribed to the frontal lobes. Activity in prefrontal cortex has been noted by a number of researchers to be crucial for creative behavior (e.g., Arieti, 1976; Loye, 1988). As previously mentioned, the frontal lobes exert a significant influence on attentional processes. Moreover, inherent in virtually all definitions of creativity is the concept that the creative process is characterized by planned or intentional activity; these functions have repeatedly been ascribed to areas of the frontal lobe (Lezak, 1983). Elliott (1986) argued that creative behavior is a consequence of activation of prefrontal areas, but added that these areas regulate brain regions by synchronizing activity on a physiological level, both vertically (up the neuraxis) and horizontally (across the hemispheres). Although the relationship between frontal lobe functions and imagery has yet to be established empirically, Richardson (1969; in Shaw & DeMers, 1987) suggested that skillful manipulation of vivid imagery may facilitate problem solving by creating alternative mental sets. If true, this would implicate variables such as abstract reasoning ability and the ability to shift mental set.

Imagery and Creativity

Imagery and creativity have been repeatedly paired in anecdotal literature. However, the strength of the relationship between these variables has been less clear in empirical research. For example, Shaw and DeMers (1987) found that vividness and manipulation of imagery was strongly associated with creativity. Parrot and Strongman (1985) reported that vividness of imagery was associated with lower Fluency scores and higher Elaboration scores on the TTCT; moreover, vivid imagery appeared to interact with the ability to manipulate imagery to produce ideas which were higher in number and quality. In contrast, Campos and Gonzalez (1993) found that spatial imagery accounted for less than 3% of the variance in creativity in a combined sample of geography, history, mathematics, and fine arts students, suggesting that imagery and creativity were not closely related.

Contradictions between studies are also evident when attempts are made to control for subject variables. Forisha (1978) found that imagery and creativity were significantly correlated for women but not for men. In contrast, Forisha (1975; 1980, in Shaw & DeMers, 1987) reported that imagery and creativity were significantly correlated for men but not women. Sheehan, McConkey, & Law (1978) reported that creative imagination and manipulation of imagery were significantly related for women, whereas creative imagination was correlated only with imagery vividness in men. It is possible that much of the apparent contradictions between studies could have been reconciled if additional variables were controlled. Indeed, Parrot and Strongman (1985) hypothesized that inconsistencies in results between studies were due to variables which affected the awareness and utilization of imagery, such as sex differences, personality variables, and cognitive variables (e.g., intelligence).

In addition to research correlating performance on imagery tasks with creativity, other investigators have examined the process of imagery in order to support contentions that the ability to perceive new patterns in mental images is a hallmark of creativity, and characterizes work by both artists and scientists (Shepard, 1978). An interesting theory has been developed by Rothenberg (1976, 1980, 1986, 1988), who conducted a series of interviews with individuals in the arts and sciences who had performed significant creative achievements. He found that these individuals frequently conceived two or more discrete entities within the same mental space during the creative process. Rothenberg argued that superimposition of stimuli, whether auditory, tactile, gustatory, olfactory, kinesthetic, or visual, activates tangential or unrelated associations, whereas reference to visual stimuli which are separated spatially activates associations which are more ordinary. Stimuli are thought to be consciously and intentionally selected by the individual, and representative of different ideas or themes. Rothenberg termed this process "homospatial".

The question of whether new interpretations can be given to mental images after the components have been manipulated has been hotly debated (Anderson & Helstrup, 1993). Chambers and Reisberg (1985) presented ambiguous figures (e.g., a picture which could be construed as a duck and a rabbit) to subjects and then required them to scan their image and detect the reversal. The failure of all subjects in this task was interpreted as evidence that reconstruals are evident only when images are paired with conceptual or symbolic representations of the new image. However, Finke, Pinker, and Farah (1989) demonstrated that reconstruals of images are possible on a task which required subjects to manipulate images of letters and add other components. Anderson and Helstrup (1993) attempted to reconcile the contradictions in these results by suggesting that reconstrual difficulties occur primarily when whole patterns are initially presented to subjects. When subgroupings are evident within the whole pattern, subjects appear able to compose and decompose patterns.

Although Rothenberg (1976, 1980, 1986, 1988) claimed that the ability to superimpose stimuli and inspect the composite image for novel features is strongly related to higher scores on creativity measures, he never adequately tested his hypothesis. That is, in each of his studies, he provided experimental groups with stimuli which were already superimposed (e.g., a double-exposure of a horserace and nuns). As such, the issue of whether or not creativity is associated with the ability of subjects to manipulate images which are internally generated and superimposed remains untested and unknown.

Personality and Creativity

The earliest known attempts to understand the nature of creativity were recorded by Socrates (Andreasen, 1978) and focused on psychological variables. This line of research was built primarily upon behavioral observations rather than structured interviews or objective measures, and indicated that psychological dysfunction was associated with creative ability. This conclusion was echoed by later philosophers; more recent investigations have attempted to quantify distinct constellations of personality traits associated with creativity.

Several studies have indicated that creativity is associated with affective disorders. Insofar as affective symptoms are related to overt behavior, these studies provide important information regarding personality traits associated with creativity. Andreasen (1987) found that 43% of her sample of eminent writers suffered from bipolar disorder. Richards, Kinney, Lunde, Benet, and Merzel (1988) concluded that higher levels of creativity were directly associated with levels of bipolar disorder. Notably, Schuldberg (1990) reported that subsyndromal forms of mania in his creative subjects were manifested as impulsive behavior.

The connection between personality traits and creativity has been assessed by other researchers. Maslow (in Yau,

1991) stated that the personality characteristics of creative individuals listed by Torrance corresponded to characteristics of self-actualizing people. Using the Eysenck Personality Questionnaire, Kundu (1987) found that both low and high levels of creativity in high school students were associated with high levels of extroversion. Likewise, Alter (1989), using scores from the Adjective Check List, suggested that music students were more creative, energetic, autonomous, and aggressive than nonartistic control subjects.

Other evidence has suggested that a relationship exists between openness and creativity. In this context, openness has been defined in various ways, including the ability to symbolize in awareness all aspects of experience (Rogers, 1961), open-mindedness (Rokeach, 1960; in McCrae & Costa, 1980), and preference for new experience (Zuckerman, 1978; in McCrae & Costa, 1980). Parsons, Tittler, and Cook (1984) suggested that the ability to consider several divergent possibilities and focus them into an integrated product was characteristic of creative individuals. McCrae (1987) noted that scores on the Openness scale of the NEO Personality Inventory (Costa & McCrae, 1992) were significantly related to levels of divergent thinking, as indicated by self reports, peer ratings, and spouse ratings. Scores on the Openness scale were also correlated with scores on the Creative Personality Scale, which has been shown to accurately characterize creative individuals.

A Comprehensive Model of Creativity

Creativity is a construct which has largely been studied in terms of single rather than interrelated variables. Personality traits and the ability to generate and manipulate images have repeatedly been demonstrated to be related to creativity. Performance on imagery tasks is undergirded by the assumption that these images can be maintained in working memory long enough to be examined and/or modified to meet the demands of a given cognitive task. In addition, both abstract reasoning and the ability to shift set appear to be related to creativity, at least on a theoretical level. Significantly, no research has been conducted to assess the importance of visual attention to imagery or the influence of cognitive variables to imagery and creativity. Furthermore, the relative influence of all four variables in creativity has not yet been assessed. Models of creativity thus need to be much more sophisticated, incorporating a range of variables, such as (1) the ability to generate mental images, (2) the ability to superimpose mental images, (3) the role of attentional processes, (4) the role of abstract reasoning and cognitive flexibility, and (5) the role of personality variables.

The model tested here will examine the role of each of these variables in the creative process. Those subjects who are better to generate, manipulate, or make decisions about images would be expected to have more raw material available for use in creative acts than those subjects whose abilities were less efficient. Abstract reasoning abilities and the ability to shift set would be expected to enable subjects to reconceptualize stimuli, thereby increasing the number of potential answers. Lastly, those who are more creative will be expected to demonstrate an interest in novel ideas and unconventional values.

In this study, creativity was defined as the ability to produce a number of original ideas which are conceptually distinct within a given timespan, and was assessed with the Figural battery of the Torrance Tests of Creative Thinking (TTCT; Torrance, 1990). Because this definition is cognitively based, the possibility that scores on this measure will not reflect the influence of personality variables should not be discounted. Nevertheless, research by Kundu (1987) and Kabanoff (1991) has demonstrated that levels of creative ability can be associated with specific personality variables, suggesting that the TTCT is sensitive to both cognitive and personality factors.

Notwithstanding claims made by Kosslyn and Jolicoeur (1981), the status of vividness as a necessary component of mental imagery is questionable. The conflicting results endemic to this literature are likely a consequence of difficulties in quantifying and verifying the existence of this variable. Because of these inherent conceptual ambiguities, the decision was made to not use imagery vividness as a variable in the current study.

Hypotheses

Hypothesis I

If creative individuals are able to generate and manipulate visual images more easily than noncreative individuals, then subjects who score higher on the Creativity Index and individual subtests of the TTCT will be more accurate and consistent on an image generation task than other subjects.

Hypothesis II

The ability to focus attention may be central to mental imagery, since manipulation and inspection of images may be dependent upon repeatedly generating the initial stimuli. If true, then scores on the Symbol Digit Modalities Test (SDMT; Smith, 1973), a test of attentional capacity, will be significantly correlated with performance on all imagery tasks.

Hypothesis III

Previous research has suggested that cognitive flexibility and abstract reasoning may be important variables for mental imagery, primarily because these abilities can be used to break up unproductive mental sets. If this is true, then scores on the Wisconsin Card Sorting Test (WCST; Heaton, 1981) will be significantly related to accuracy and consistency of mental imagery.

Hypothesis IV

If cognitive flexibility and abstract reasoning can be used to break up unproductive mental sets and generate novel solutions to imagery tasks, then these abilities may also be related to scores on measures of creativity. If true, then overall scores on the figural subtests of the TTCT will be significantly related to scores on the WCST.

Hypothesis V

Past research has indicated that creativity is associated with a distinctive pattern of personality traits. In particular, both extroversion and a tendency to seek new experiences have been associated with creativity. If true, then scores on the Extroversion and Openness scales of the NEO-FFI and scores on the TTCT Creativity Index will reach statistical significance.

Hypothesis VI

Several variables appear to be related to creativity. Although there is disagreement regarding the variables which are most salient to the creative process, evidence has been presented that image generation and manipulation, cognitive variables, and personality variables are important to creativity. If combinations of these variables predict creativity better than single variables, then the best predictor of the TTCT Creativity Index will be a combination of scores from tests of image generation and manipulation, the NEO-FFI, and the WCST, rather than scores from single dependent measures.

Method

Subjects

One hundred and twenty-three subjects, most of whom were underclassmen, were recruited from psychology classes at Michigan State University. Because neuropsychological research has indicated that strength of hand preference is directly related to the degree of cerebral lateralization for mental processes (Lezak, 1983), lateralization of abilities is an important variable in studies examining creativity and imagery. In this study, the decision was made to include only right-handed subjects in order to control for this issue. Only subjects with high right-handedness scores on the Edinburgh Handedness Inventory were selected to participate. In exchange for their participation, these subjects were given extra-credit points which were later added to their final course grade.

Sixteen subjects were unable to complete the experiment because they had scheduling conflicts, forgot to attend their appointment time, or no longer wished to participate in the experiment. The final number of subjects was 107 and included 27 males and 81 females. Because of missing data, statistical comparisons using the WCST were based upon 24 males and 77 females, for a total of 101 subjects. Males ($\bar{X} = 24.4$, $SD = 7.69$) were significantly older ($t = 2.28$, $p < .02$) than females ($\bar{X} = 21.7$, $SD = 4.33$).

Materials

The Edinburgh Handedness Inventory (EHI; Oldfield, 1971) was developed to provide a quantitative assessment of handedness for use in neuropsychological work, because handedness is considered a marker for hemispheric asymmetry of function (Bryden, 1977). A shortened version of this measure was developed by Bryden (1977). The revised EHI consists of 5 questions which are presented to the subject in a written format. Subjects are required to indicate their preferred hand for the task represented in each item, including the strength of preference in their rating. Scores range from 5 to 25, with the former representing strong left handedness and the latter representing strong right handedness. The reliability of this test was calculated to be .85; the correlation of this test with known handedness was also .85. Subjects who scored less than 15 on this measure were not selected to participate in the experiment.

Levels of creativity were measured by the Figural battery of the Torrance Tests of Creative Thinking (TTCT; Torrance, 1990). The Figural battery of the TTCT consists of 3 subtests. Subjects are required to draw pictures using a pre-printed shape, incomplete figures, and parallel lines. Each subtest is scored by assessing ideational fluency, flexibility, originality, and elaboration, the ability to forestall closure of geometric figures, and the ability to generate abstract titles for drawings. Raw scores on each TTCT subtest are subsequently converted to a distribution with a mean of 100 and a standard deviation of 15 in order to make them comparable to IQ scores. The five subtests are combined along with criterion-related indices (e.g., use of humor) to produce a general Creativity Index, also with a mean of 100 and a standard deviation of 15.

Data pertaining to the reliability and validity of the TTCT are adequate, although somewhat sparse. The TTCT was normed on over 125,000 records of students ranging in grade from kindergarten through college (Torrance, 1990). Of immediate interest to the current study, 2126 records of college-age students were used in the development of normative data. With the exception of the relationship between the Fluency and Originality subtests ($r = .86$), the Fluency and Closure subtests ($r = .64$), and the Originality and Resistance to Premature Closure subtests ($r = .66$), intercorrelations between subtests are less than .40. Both Holland (1968) and Wallach (1972) noted that test-retest reliabilities ranging from 1 week to 3 years typically exceed .70 and inter-scorer reliability is usually above .90.

Treffinger (1985) noted that performance on the TTCT was significantly and positively correlated with later creative achievement from periods as short as 9 months to 22 years. In a factor analysis, Mourad (1976; in Torrance, 1990) found that scores of college students on the TTCT were related to visual processing and creativity variables. Torrance (1982, in Torrance, 1990) found that the scores of graduate students on the TTCT reached statistical significance when compared to scores on the Creative Motivation Scale, the Similes Test, and various indices of the Rorschach Inkblot Test. Torrance & Wu (1981) analyzed data from subjects who were originally tested in high school in 1959, and correlated these scores with adult creative achievement. The Creativity Index consistently predicted future achievement, as did the Abstractness of Titles, Elaboration, and Resistance to Premature Closure subtests.

The NEO-Five Factor Inventory (NEO-FFI) is a shortened version of the NEO-Personality Inventory. It contains 60 items which comprise five 12-item scales; these scales were developed to test the five-factor model of personality (i.e., neuroticism, extroversion, openness, agreeableness, conscientiousness). These factors are purported to represent the five basic traits found in other objective tests of personality and in natural language. Responses to test items are made by subjects along a 5-point scale which ranges from "strongly disagree" to "strongly agree".

Costa and McCrae (1992) reported that correlations between the NEO-FFI scales and adjective self-reports appeared to be adequate. Convergent correlations ranged from .56 to .62; the highest divergent correlation was .20. McCrae (1991; in Costa & McCrae, 1992) found that peer ratings using Form R of the NEO Personality Inventory-Revised were correlated with NEO-FFI self-reports. Convergent correlations ranged from .33 to .48; the highest divergent correlation was .17.

Cognitive flexibility and abstract reasoning were assessed by the Wisconsin Card Sorting Test (WCST; Heaton, 1993). The general procedure used in the WCST requires the subject to match individual cards taken sequentially from two packs of 64 response cards to one of four sample cards placed in front of the examiner. Each of these key cards contains a specific shape and color: the first has a red triangle, the second has two green stars, the third has three yellow crosses, and the fourth has four blue circles. All response cards have designs similar to those on the stimulus cards but vary with color, geometric form, and number. The subject is first required to sort according to color of the stimuli. After ten consecutive correct responses, the sorting principle is changed without the subject's knowledge to the shape of stimuli; after ten consecutive correct responses, the sorting principle is changed again to the number of shapes represented on cards. This procedure is continued until six categories have been completed (i.e., color, form, number, color, form, number) or all 128 cards have been used. Subjects must implement corrective feedback (i.e., whether the match was "right" or "wrong") given by the examiner on individual items in order to determine the principle to which cards must be matched.

The WCST has been demonstrated to be sensitive to a number of variables. Drewe (1974) indicated that performance on the WCST is particularly sensitive to frontal lobe functioning. Milner (1963) found that the number of categories correctly sorted was related to the ability to both shift and maintain set. Both intrascorer and interscorer reliabilities are impressive, and range from .88 to .96 (Heaton, 1993).

Because performance on the WCST is affected by intellectual level (Heaton, 1993), estimates of general cognitive functioning were assessed with the Vocabulary and Block Design subtests of the Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981), and were used to correct WCST scores for the influence of intellectual ability. These subtests were cited by Silverstein (1982) as providing the best short-form estimate of general mental ability. The Vocabulary subtest consists of 35 words arranged in increasing difficulty. Subjects are required to define words in response to the examiner's query, "What does ____ mean?" Administration continues until subjects fail five consecutive words or reach the end of the word list. In the Block Design subtest, subjects are required to use colored blocks to reproduce the geometric design depicted on a card. Testing continues until three consecutive designs have not been completed within the time limits.

Silverstein (1982) reported that the combination of Vocabulary and Block Design subtests correlated .91 with Full Scale IQ scores. Reliability was calculated at .94. Similarly, Thompson, Howard, & Anderson (1986) found that correlations between the Vocabulary - Block Design short form and Full Scale IQ scores ranged from .91 to .94.

Stimuli used for the superimposition and imagery task were 16 letter pairs. The letters were first printed in black Avant Garde font at 18-point size and were then transferred to photographic slides. Each letter pair was printed in lowercase and uppercase; the order in which the letter pairs appeared in the experimental task was determined by a random number table. They were presented with a slide projector placed on a table 6 feet from a screen. When projected, the letters appeared directly in front of the subjects at a distance of 7 feet and were 12 inches tall. Examples of the stimuli can be found in Appendix A.

Subjects were trained how to perform the task before testing was allowed to continue. The specific instructions are included in Appendix B. The letter pairs were presented in two trials. For each trial, each pair of letters was presented for 2 seconds, after which the slide projector was advanced to a blank screen. The subjects were given up to 40 seconds to name the letters that they were able to form by superimposing individual letter pairs.

The equation

$$\frac{((\text{N Cor} - \text{N Incor}) - \text{N Omit})}{\text{N Possible}},$$

where "N Cor" equaled the number answered correctly, "N Incor" equaled the number answered incorrectly, "N Omit" equaled the number of correct responses that were omitted, and "N Possible" equaled the total number of possible correct responses, was used to score each item. The uppercase scale consisted of items in which subjects were presented uppercase letters and required to superimpose mental images of the lowercase letters. The lowercase scale consisted of items in which subjects were presented lowercase letters and required to superimpose these letters. Because the superimposition task for both scales was identical, the ability to manipulate mental images did not differentially affect performance. An efficiency score was calculated for items of both the uppercase and lowercase scales by summing all relevant items and calculating an average. Because the items of the lowercase and uppercase scales differed only in whether imagery was required, the lowercase efficiency score was subtracted from the uppercase efficiency score to isolate the imagery component and create the final imagery index.

Because performance on the imagery tasks may be influenced by attentional capacity, the Symbol Digit Modalities Test (SDMT; Smith, 1973) was administered. In this test, subjects are given an answer sheet which contains several rows of blank squares. Each blank square is paired with a symbol. By referring to a key at the top of the page where numbers are paired with symbols, subjects are required to fill in as many blank squares as possible in 90 seconds with the appropriate number. In the first trial, responses are made in a written format. Responses in the second trial are given orally.

Reliabilities for the SDMT are adequate, and range from .78 for the oral version to .82 for the written version

(Smith, 1973). The SDMT has been found to be sensitive to cerebral dysfunction from a variety of neurological disorders, including chronic brain lesions, dementia, and cerebrovascular disease (Bornstein & Suga, 1982). The substrate common to each of these conditions and tested by the SDMT appears to be attention (Spreen, 1991).

Procedure

Subjects were administered the EHI, NEO-FFI, and TTCT Figural battery in small groups ranging from 2 to 14 members in size. Subjects were administered the remaining measures individually in a second testing session according to the following paradigm. Subjects were first given the Symbol Digit Modalities Test. After completion of both written and oral portions, they were given instructions and examples of the letter superimposition task. To ensure that all subjects utilized the same font when generating mental images, they were required to copy the alphabet, which was printed in the same font as stimulus items. Subjects were not allowed to begin the imagery task until they had demonstrated that they could reproduce this font accurately. Following administration of the letter superimposition task, subjects were administered the WCST, followed by the Vocabulary and Block Design subtests.

The subjects were debriefed about the purposes of the experiment after all data was collected. Subjects were encouraged to keep their knowledge of the experiment confidential until all subjects were tested.

Results

A small minority (e.g., Shaw & DeMers, 1987) have argued that creativity is directly correlated with intellectual functioning below IQ levels of approximately 115. However, because the evidence supporting this relationship was necessarily based on dichotomized variables, these results are likely to be statistical artifacts. As a consequence, scores on the TTCT were not corrected for the influence of intellectual ability in the present study. In contrast, since cognitive ability has been found to moderate performance on the WCST (Heaton, 1993), partial correlation coefficients which corrected for the influence of IQ were used for all analyses involving the WCST. Furthermore, because males were significantly older than females, partial correlations which corrected for the influence of age were used for all analyses of gender differences.

Multiple analyses on the same groups of data may have increased the probability of a Type I error. As a consequence, the criteria for statistical significance used in individual t-tests and in multiple regression equations were made more stringent by dividing the alpha level of .05 by the number of tests that were conducted. In all instances, this resulted in an alpha level of .01.

Group means, standard deviations, and t-tests for gender differences are reported in Table 1 for dependent and independent variables. These results indicate that males achieved significantly lower scores than females on the

Elaboration scale of the TTCT. No other findings reached statistical significance.

Intercorrelations of subsets of items from the imagery task are presented in Table 2. Because the extent to which imagery abilities are distributed in the population is unknown, the imagery index was analyzed as a cognitive task, rather than as an individual difference variable. The decrease in correlations over time between subsets of the index suggests that subjects developed a strategy that was independent of imagery ability. This trend appeared to develop quickest in females; accordingly, the first 8 items of the imagery index were used for females, males, and the total sample in subsequent analyses as the best indication of the ability to form, manipulate, and make decisions regarding mental images. This group of items will hereafter be referred to as the imagery scale. Although use of the first 16 or 24 items may have resulted in a more robust scale for analyses involving males and the entire sample, these items were also utilized for them in subsequent analyses because of concerns that use of a shorter imagery scale for females alone would bias statistical comparisons.

Table 1

Means, Standard Deviations, and t-tests of Gender Differences for Independent and Dependent Variables

	Males (N = 27)		Females (N = 81)		Total (N = 108)		
Variable	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	t
IQ	107	10.5	103	10.8	104	10.8	0.72
CIndex	103	18.4	106	13.8	105	15.0	- 0.72
Closure	83	21.1	86	17.7	85	18.5	- 0.63
Elaboration	90	17.4	100	18.9	98	19.0	- 2.58*
Fluency	97	22.2	99	16.2	99	17.8	- 0.56
Originality	96	17.9	93	17.6	94	17.6	0.68
Titles	100	26.0	104	21.5	103	22.6	- 0.87
Imagery	- .07	1.04	- .03	0.46	- .04	0.65	- 0.46
CAT	5.4	1.28	5.4	1.22	5.4	1.23	- 0.13
NPE	13.5	12.3	11.5	8.10	12.0	9.31	0.97
PE	11.8	9.28	12.0	8.45	12.0	8.62	- 0.12
TE	25.3	20.5	23.6	15.6	24.0	16.9	0.47
SD Oral	67.5	9.02	70.8	10.2	70.0	10.0	- 1.49
SD Written	58.3	7.44	61.1	7.64	60.4	7.67	- 1.69

(table continues)

Table 1 (cont'd)

	Males (N = 27)		Females (N = 81)		Total (N = 108)		
Variable	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	t
A	30.7	5.29	32.0	6.11	31.7	5.92	- 1.01
C	31.2	6.47	32.8	7.16	32.4	7.00	- 1.02
E	30.4	6.15	31.8	6.41	31.4	6.34	- 0.98
N	19.3	7.93	22.0	8.35	21.3	8.29	- 1.45
O	32.6	6.51	31.2	5.99	31.6	6.12	0.98

Note. CIndex = Creativity Index; Closure = Resistance to Premature Closure; Titles = Abstractness of Titles; CAT = Number of WCST Categories Achieved; NPE = Number of WCST Non-Perseverative Errors; PE = Number of WCST Perseverative Errors; TE = Total Errors; SD Oral = Symbol Digit Modalities Test - Oral Version; SD Written = Symbol Digit Modalities Test - Written Version; A = Agreeableness; C = Conscientiousness; E = Extroversion; N = Neuroticism; O = Openness to New Experience.

* $p < .01$

Table 2

Correlations Between the First 8 Items of the Imagery Scale and Subsets of the Imagery Scale for Males, Females, and All Subjects

	First 8 Items		
Imagery Scale	Males	Females	Total
Items 9 - 16	.97**	.85**	.90**
Items 17 - 24	.87**	.67**	.80**
Items 25 - 32	.11	.66**	.80**
Items 33 - 40	.14	.51**	.61**
Items 41 - 48	.16	.11	.40*
Items 49 - 56	.02	- .14	- .13
Items 57 - 64	.12	.05	.06

Note. Twenty-seven male subjects and 81 female subjects were included in these comparisons, for a total sample of 108 subjects.

* $p < .01$

** $p < .001$

Hypothesis I

Correlations between the TTCT Creativity Index and the imagery scale are reported in Table 3, as are correlations between the figural subtests of the TTCT and the imagery scale. Contrary to the hypothesis, no correlations reached statistical significance. The statistical power of these comparisons (J. Cohen, 1988) ranged from approximately .02 to .16 for males and approximately .02 to .20 for females. The statistical power of the correlations for the entire sample was .09.

Hypothesis II

Correlations between scores on the Oral and Written versions of the SDMT and the imagery scale are presented in Table 4 for males, females, and all subjects. Contrary to the hypothesis, visual attention was not significantly correlated to the ability to form, manipulate, or make decisions about mental images. The statistical power of these comparisons (J. Cohen, 1988) was not greater than .03 for males, .08 for females, and .09 for the entire sample.

Hypothesis III

Correlations between scores on the imagery task and the WCST are reported in Table 5 for males, females, and all subjects. Contrary to the hypothesis, the ability to form, manipulate, or make decisions about mental images was not related to cognitive flexibility or abstract reasoning for males, females, or the total sample. The statistical power

Table 3

Correlations Between Scores on the Figural Subtests of the Torrance Tests of Creative Thinking and the Imagery Scale for Males, Females, and All Subjects.

	Imagery		
TTCT	Males	Females	Total
CIndex	.02	- .16	- .12
Closure	- .04	- .13	- .11
Elaboration	.25	- .15	- .08
Fluency	- .20	- .01	- .06
Originality	- .02	- .10	- .08
Titles	.07	- .14	- .09

Note. CIndex = Creativity Index; Titles = Abstractness of Titles; Closure = Resistance to Premature Closure. Twenty-seven male subjects and 81 female subjects were included in these comparisons, for a total sample of 108 subjects.

Table 4

<u>Correlations Between Scores on the Written and Oral Versions of the Symbol Digit Modalities Test and the Imagery Scale for Males, Females, and All Subjects.</u>

SDMT	Males	Females	Total
Oral	- .06	.10	.08
Written	- .07	.12	.06

Note. Twenty-seven male subjects and 81 female subjects were included in these comparisons, for a total sample of 108 subjects.

Table 5

Correlations Between Scores on the Wisconsin Card Sorting Test and the Imagery Scale for Males, Females, and All Subjects.

	Imagery		
WCST	Males	Females	Total
CAT	-.15	-.02	-.02
NPE	.20	.12	.16
PE	.20	.04	.08
TE	.22	.08	.12

Note. CAT = Number of Categories Achieved; NPE = Non-Perseverative Errors; PE = Perseverative Errors; TE = Total Errors. Twenty-four male subjects and 77 female subjects were included in these comparisons, for a total sample of 101 subjects.

of these comparisons (J. Cohen, 1988) was not greater than .09 for males, females, or the entire sample.

<u>Hypothesis IV</u>

Correlations between scores on the TTCT Creativity Index and scores on the WCST are reported in Table 6 for males, females, and all subjects, as are correlations between the figural subtests of the TTCT and scores on the WCST. Contrary to the hypothesis, no statistically significant correlations were found. The statistical power (J. Cohen, 1988) of these comparisons ranged from .03 to .41 for males, from approximately .02 to .29 for females, and from .02 to .37 for correlations involving the entire sample.

<u>Hypothesis V</u>

Correlations between scales of the NEO-FFI and the TTCT Creativity Index are recorded in Table 7 for males, females, and all subjects, as are correlations between the scales of the NEO-FFI and figural subtests of the TTCT. Only the correlation between the Fluency subtest and the Extroversion domain reached statistical significance. The statistical power of this correlation was .41 (J. Cohen, 1988).

<u>Hypothesis VI</u>

All scales of the dependent variable (TTCT) were normally distributed. No instances of multi-collinearity were found, and the results of the multiple regression analysis are thus thought to be unaffected by the strength of correlations between independent variables. Using forced entry, independent variables were entered into a multiple

Table 6

Correlations Between Scores on the Wisconsin Card Sorting Test and the Figural Subtests of the Torrance Tests of Creative Thinking for Males, Females, and All Subjects.

TTCT	CAT	NPE	PE	TE
CIndex				
Males	-.17	.15	.19	.18
Females	-.16	.10	.09	.10
Total	-.16	.12	.13	.13
Closure				
Males	-.02	-.10	.04	-.03
Females	.06	.02	-.09	-.04
Total	.04	-.02	-.04	-.04
Elaboration				
Males	-.45	.25	.42	.34
Females	-.15	.04	.10	.08
Total	-.21	.08	.18	.13
Fluency				
Males	-.02	.27	.10	.21
Females	-.15	.16	.12	.15
Total	-.11	.20	.11	.17

(table continues)

Table 6 (cont'd)

TTCT	CAT	NPE	PE	TE
Originality				
Males	-.04	.34	.12	.26
Females	.00	-.02	-.10	-.06
Total	-.01	.10	-.05	.03
Titles				
Males	-.18	.19	.14	.18
Females	-.19	.06	.10	.09
Total	-.18	.09	.11	.11

Note. CIndex = Creativity Index; Closure = Resistance to Premature Closure; Titles = Abstractness of Titles; CAT = Number of Categories Achieved; NPE = Non-Perseverative Errors; PE = Perseverative Errors; TE = Total Errors. Twenty-four male subjects and 77 female subjects were included in these comparisons, for a total sample of 101 subjects.

Table 7

Correlations Between Scales of the NEO-Five Factor Inventory and the Figural Subtests of the Torrance Tests of Creative Thinking for Males, Females, and All Subjects.

TTCT	A	C	E	N	O
CIndex					
Males	-.25	-.12	.26	-.14	-.38
Females	.09	.07	.01	.05	.03
Total	.01	.02	.09	-.01	-.10
Closure					
Males	-.25	-.15	.14	.09	-.20
Females	-.03	.02	-.09	-.08	.09
Total	-.08	-.02	-.02	-.02	.00
Elaboration					
Males	.04	-.41	-.07	.13	-.31
Females	.08	.07	.01	.16	.04
Total	.09	-.01	.01	.18	-.07
Fluency					
Males	-.22	.10	.46*	-.24	-.25
Females	.06	.08	.10	-.02	-.14
Total	-.01	.09	.21	-.07	-.18

(table continues)

Table 7 (cont'd)

TTCT	A	C	E	N	O
Originality					
Males	- .38	.03	.17	- .21	- .20
Females	.12	- .03	.10	- .02	.12
Total	.00	- .02	.11	- .08	.04
Titles					
Males	- .17	- .14	.11	- .14	- .06
Females	.19	.16	.04	.10	- .02
Total	.10	.09	.06	.04	- .03

Note. CIndex = Creativity Index; Closure = Resistance to Premature Closure; Titles = Abstractness of Titles; A = Agreeableness; C = Conscientiousness; E = Extroversion; N = Neuroticism; O = Openness to New Experience. Twenty-seven male subjects and 81 female subjects were included in these comparisons, for a total sample of 108 subjects.

* p = .01

regression equation in the order of the imagery scale, the SDMT, the NEO-FFI, and the WCST, with the Creativity Index and the scales of the TTCT used as the criterion variable. All possible permutations of independent variables were entered into this equation; contrary to the hypothesis, no variables met minimum entry criteria.

When multiple regression equations were generated using stepwise entry of independent variables, only two equations reached statistical significance. These equations are presented in Tables 8 and 9. For males, scores on the Conscientiousness and Openness to New Experience domains of the NEO-FFI and the number of WCST categories completed predicted the number of drawings that were completed. The statistical power (J. Cohen, 1988) of these data ranged from .53 to .98. For the entire sample, scores on the oral version of the SDMT, the Neuroticism domain of the NEO-FFI, and the number of WCST categories completed predicted the amount of detail in drawings. The statistical power of these comparisons ranged from .90 to .99.

Table 8

Multiple Regression Equation for the Elaboration Subtest of the Torrance Tests of Creative Thinking for All Subjects.

Variable	B	SE B	Beta	R^2	p
N	.470	.209	.20	.14	.03
CAT	- 3.50	1.40	- .227	.32	.01
SD Oral	.483	.173	.255	.30	.01
(Constant)	72.9	15.0			.00

Note. CAT = Number of WCST Categories; SD Oral = Symbol Digit Modalities Test - Oral Version; N = NEO-FFI Neuroticism domain. Twenty-seven male subjects and 81 female subjects were included in these comparisons, for a total sample of 108 subjects.

Table 9

Multiple Regression Equation for the Elaboration Subtest of the Torrance Tests of Creative Thinking for Males.

Variable	B	SE B	Beta	Adj. R^2	p
CAT	- 6.32	7.08	- .46	.21	.02
O	- 1.08	0.40	- .40	.36	.01
C	- 0.99	0.41	- .37	.49	.005
(Constant)	190.1	22.0			.00

Note. CAT = Number of WCST Categories; C = Conscientiousness Scale of the NEO-FFI; O = Openness to New Experience Scale of the NEO-FFI. Twenty-seven male subjects and 81 female subjects were included in these comparisons, for a total sample of 108 subjects.

Discussion

The available evidence at the outset of this study indicated that the effect sizes between individual variables and creativity would be moderate. The subsequent power analysis (J. Cohen, 1988) showed that statistical power of .80 could be achieved for correlations significant at the .01 level by testing 101 subjects if the size of the correlations was approximately .30. Similarly, the equivalent statistical power for a multiple regression equation using three independent variables and with statistical significance at the .01 level required 108 subjects.

Unfortunately, the number of subjects that participated in all phases of this study was lower than expected. In fact, a significant limitation of this study was the relatively low level of participation by males and the consequent impact upon statistical power. Difficulties in recruiting males for this experiment may have been a consequence of several factors, including a smaller pool of available subjects, a reluctance of male subjects to utilize extra-curricular activities to gain course credit, and a tendency for them to view creativity as a topic outside the purview of traditional male interests. Although women participated at a much higher rate, interpretation of results for them also was limited by issues of statistical power.

In addition to difficulties in recruiting the necessary number of subjects to ensure adequate statistical power, a marked disparity in the magnitude of the expected and actual effect sizes was evident in this study between individual variables and the TTCT. The overwhelming majority of these effect sizes were smaller than predicted, and could be interpreted as a consequence of the .20 (β) risk of making a Type II error. Alternatively, if a Type II error was not made, these effect sizes could be interpreted as representative of the true relationship between the independent variables and creativity. In this instance, issues of sample size become particularly important, since more subjects would be necessary to reliably detect small effect sizes. These issues become particularly salient when considering the statistical power of analyses conducted on groups in this study that were created based upon gender differences. The dangerously low levels of power endemic to these analyses make the probability of committing a Type II error quite high. Accordingly, the data from analyses based upon gender differences should be considered as exploratory in nature.

Imagery

The intent of this study was not to develop a test of mental imagery, but rather to examine the contribution of imagery to the creative process. The ability to generate, manipulate, and make decisions about mental images was assessed by requiring subjects to decide if letter pairs presented on a screen would form additional lowercase letters when superimposed. Clearly, to be performed successfully, the initial items of this task required the formation of mental images. Nonetheless, there is no psychometric information concerning the reliability or validity of individual test items or the scale that was used to measure imagery ability.

Sergent (1990) implied that the veridicality of imagery tasks could be objectively evaluated, since performance on such tasks was dependent upon the ability

> (1) to understand the instructions, (2) to access, from a given clue, information stored in long-term memories, (3) to have properly stored memories about the object to be imaged, (4) to establish a correspondence between semantic information about an object and its visual appearance, (5) to generate the visual image, (6) to have appropriate perceptual mechanisms for its visualization and inspection so as to perform a specific decision or verbally report the content of the image (p. 99).

These criteria will be utilized as a starting point for evaluating the pattern of scores on the imagery task.

A precursor to the first of these criteria was the ability of subjects to attend to the visual presentation of stimuli. Of the potential factors that comprise attention (R. A. Cohen, 1993), the most relevant appear to be structural (i.e., constraints of memory, the speed of neural processing) and energistic (e.g., the general arousal and motivational state of the individual). Although "simple" visual attention was not formally assessed, the performance of subjects on the SDMT suggested that sustained visual concentration abilities were within normal limits when compared to the normative sample. Because attention is fundamental to concentration (Lezak, 1981), by implication, visual attention abilities were assumed to be within normal limits. In addition, all subjects appeared to be sufficiently motivated to complete all experimental tasks.

The first of Sergent's criteria was addressed by giving subjects a period in which they were trained to complete the imagery task. This brief session gave subjects an opportunity to clarify task requirements and gave them several examples of stimuli that they would encounter. Subjects were not allowed to begin the imagery task until they demonstrated that they understood the instructions and were able to correctly answer the examples.

An attempt to control aspects of the second, third, and fourth of Sergent's criteria was made by requiring subjects to copy the alphabet, which was printed in the font used for all test stimuli. Subjects were not presented any test stimuli until each letter of their copy matched that of the stimulus font. Although this procedure ostensibly established a baseline for materials used in image generation, it is impossible to know if subjects utilized this information in their decisions or maintained this information over time without resorting to more idiosyncratic ways of forming letters. Future research with the imagery task should thus incorporate a memory test of letter shapes before stimuli are presented, during the task itself, and at the completion of the imagery task.

The sixth of Sergent's criteria relates to visual attention and the decision processes used by subjects once an image was formed. Because this task was novel for all subjects, they initially had no available heuristics to aid their performance and thus had to depend entirely upon their skill in generating and manipulating mental images. Significant correlations with attention would be expected for both of these processes (R. A. Cohen, 1993) if images had limited resolution and needed to be periodically refreshed (Kosslyn, 1980; 1988). Similarly, attention would be important in inspecting the final image and selecting appropriate responses from the pool of potential answers. An example of the steps that may be involved in this process is presented in Figure 1 for uppercase stimuli. The image potentially would need refreshing at several points in this diagram. It is notable that the imagery scale was not significantly correlated with either the written or oral versions of the SDMT for males, females, or the entire sample. Without knowing if the ability to generate, manipulate, or make decisions about stimuli was differentially sensitive to the ability to sustain attention, the nature of these results is unclear and should be interpreted with caution. Attention may indeed have been unimportant as a variable if decisions about stimuli were made quickly; if true, this would also negate the importance

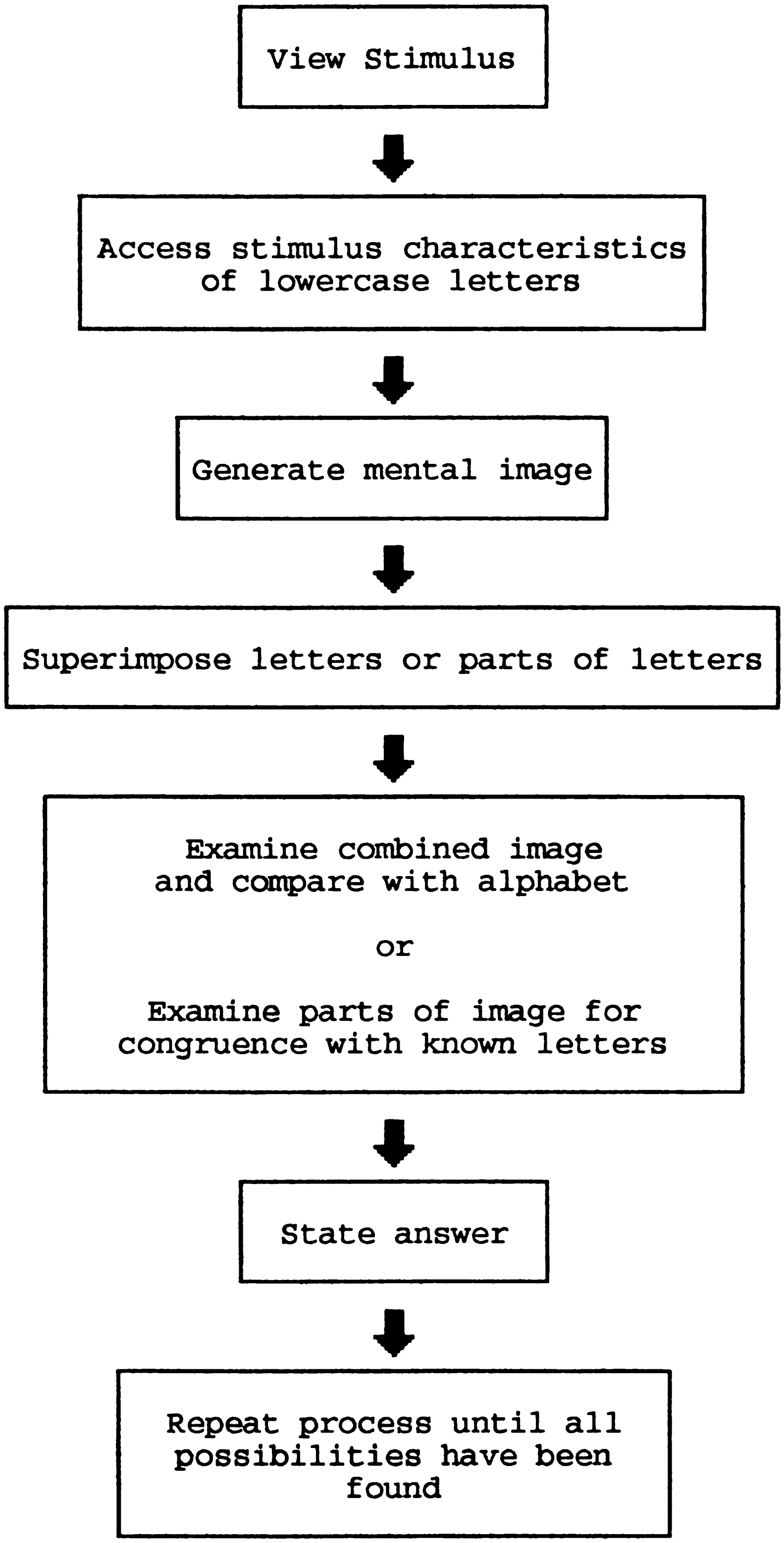


Figure 1. Diagram of the process used to make decisions on the initial items of the imagery task.

of vividness to imagery. However, if relatively long periods of time were required for any of the components of the imagery task, then visual attention and vividness of imagery may have proven to be crucial variables. A more comprehensive assessment of imagery ability that evaluates each component of the imagery task with respect to vividness and reaction time may discriminate between these hypotheses.

Scores on the imagery scale were not significantly correlated with cognitive flexibility or abstract reasoning for both males and females; the statistically significant difference between genders in the number of perseverative errors thus was likely of little practical concern in relation to creativity. Importantly, based on these results, manipulating images does not appear to be dependent on reconfiguring mental sets; furthermore, the ability to generate mental images and make decisions about them does not appear to be related to the ability to quickly develop and implement alternate problem-solving strategies by reconceptualizing stimuli. These conclusions run counter to the prediction forwarded by Richardson (1969; in Shaw & DeMers, 1987). Nonetheless, an analysis of subsets of imagery items (see Table 2) indicated that males and females eventually developed an alternative strategy to make decisions about those stimuli. Development of these strategies may have been based upon deductive reasoning ability.

Deductive reasoning is highly correlated with the ability to visualize and manipulate shapes (Guyote & Sternberg, 1981). Johnson-Laird (1985) argued that the relationship between deductive reasoning and spatial ability exists because problems that require logical reasoning are solved by mentally constructing subjective physical representations ("mental models") that represent the information in images. The form that this process may have taken on the imagery task is presented in Figure 2.

When compared to the process depicted in Figure 1, it is evident from Figure 2 that use of mental models to make decisions about tasks requires significantly less effort. That is, images do not have to be repeatedly generated and scanned. Instead, information regarding potential solutions for each letter of a stimulus pair is accessed from memory.

The abrupt decrease in strength of correlations evident for females by item 16 and for males by item 32 suggests that gender differences may have influenced development and implementation of mental models. Although Johnson-Laird's theory suggests that males, by virtue of superior spatial ability (and, by extension, deductive reasoning skills) would implement mental models earlier than would females, differential levels of spatial ability and cognitive flexibility between sexes may have influenced the length of time subjects were willing to base their decisions solely upon imagery. That is, the spatial component of the imagery task may have made the process of superimposing letters more

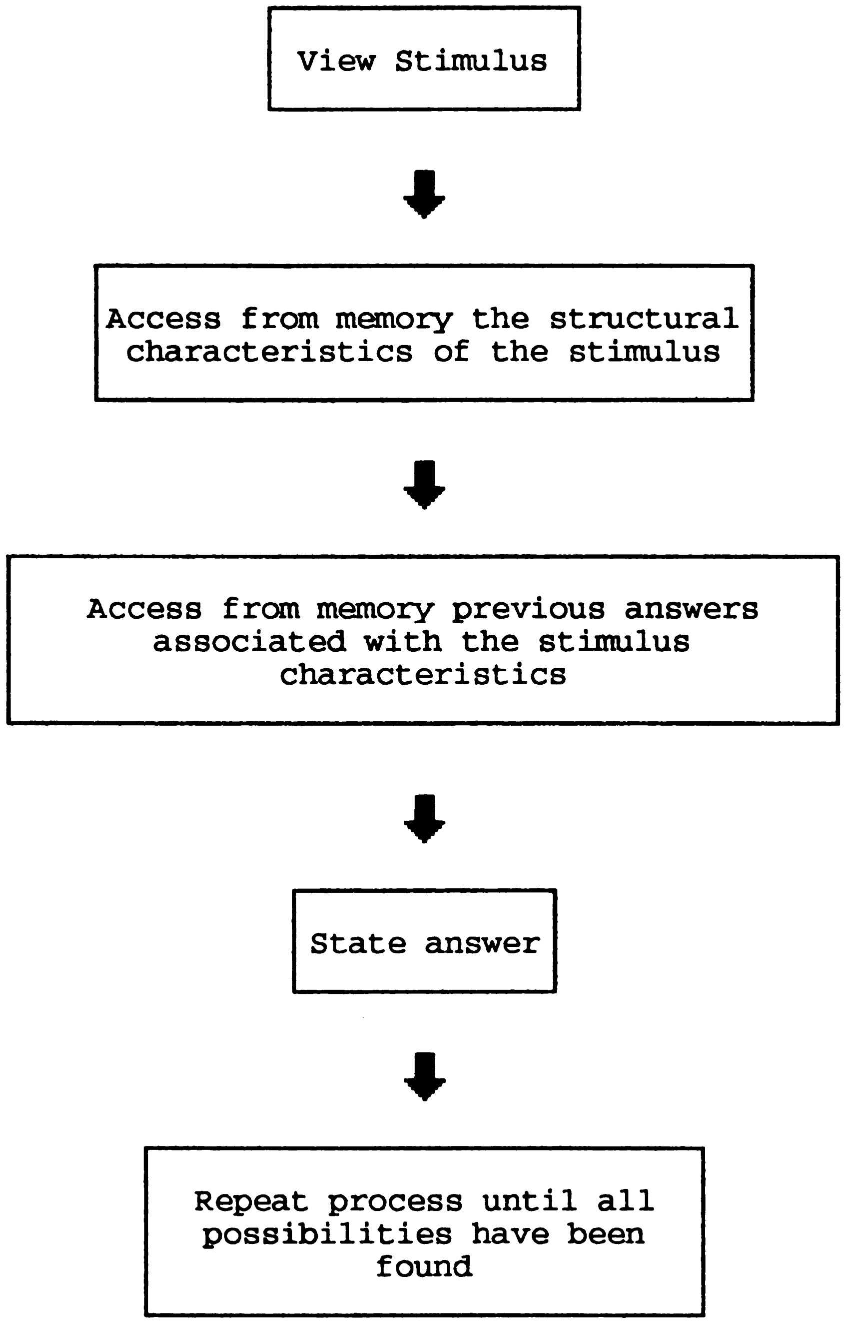


Figure 2. Diagram of the Process Used to Make Decisions on Later Items of the Imagery Task.

difficult for females, resulting in less confidence in their decisions and a concomitant desire to quickly and actively develop alternative strategies. In contrast, males may have perceived the task as less difficult because of the spatial component, resulting in a higher level of confidence in their decisions and a reluctance to use other strategies until they were proven to be more efficient. Alternatively, males may have been unable to modify their response method because of lower levels of cognitive flexibility. They may have developed mental models as a more efficient strategy only after consistent relationships between the characteristics of test stimuli and potential answers to the superimposition task were noted.

Creativity

With the exception of the lone statistically significant correlation between the Extroversion domain of the NEO-FFI and the Fluency subtest of the TTCT, the lack of significant correlations between the figural subtests of the TTCT and the imagery scale, the WCST, and the NEO-FFI was not predicted by available theoretical and empirical evidence. A possible explanation for these data is related to the distinct lack of consensus in defining and measuring creativity. Specifically, the TTCT may have measured aspects of creativity that were only marginally related to the imagery scale, personality variables, and cognitive variables.

Use of the TTCT in this study was mandated by both its extensive use in creativity research and its psychometric properties. However, although reliabilities are adequate, the content validity of this measure has been questioned (e.g., Wallach, 1968). This conceptual ambiguity can be traced to Torrance himself, whose definition of creativity closely parallels that of metacognition (e.g., Kaplan & Simon, 1990).

Metacognition is essentially the process by which individuals decide the nature of an intellectual problem, select a strategy for solving it, and allocate their resources accordingly. Absent from this description are the qualitative experiences traditionally associated with creative functioning, such as eccentric behavior, intensity of mood (Goodwin & Jamison, 1990), and euphoria (Andreasen & Canter, 1974). Furthermore, metacognition appears to differ from traditional conceptualizations of creativity in the processes that are associated with the formulation of artistic products. Many theories of creativity emphasize aspects of creative functioning which are seemingly irrational, such as insight (Wallas, 1927; in Shaw, 1987). Indeed, Metcalfe (1986) reported that insight into the solution of problems is sudden and cannot be predicted. In contrast, theories of metacognition imply that solutions to problems can be derived by a conscious and rational exploration of alternatives. It is tempting to speculate that the relative lack of significant correlations with creativity in the present study arose because subjects utilized mental models on both the imagery task and on the subtests of the TTCT, perhaps in response to the metacognitive components of the test.

Although some (e.g., Torrance, 1990) have argued that the correlation of scores on the TTCT with creative achievement is sufficient to allay concerns about validity, the nature of the link between creativity and metacognition is uncertain. Certainly, unconscious processes could be used to generate solutions on a metacognitive task. However, because metacognitive abilities may moderate creative ability in an unsuspected manner, factor analytic and path analytic studies need to be conducted before valid interpretations of performance on the TTCT can be made.

Creativity and Imagery

Although the current results appear to indicate that no significant relationship exists between creativity and imagery, it is difficult to ascertain the degree to which data from this study and in previous research was affected by variables affecting awareness and utilization of imagery, or to differences in the tasks used to assess imagery. Subject variables need to be controlled in future research, consensus must be reached on the inclusion of factors related to imagery, and appropriate measures of creativity need to be utilized. Because of these confounds, data from the present study should be interpreted cautiously.

Nonetheless, data regarding the homospatial process indicated that the ability to superimpose mental images is not closely related to higher scores on creativity measures.

Significant results in previous empirical studies (Rothenberg, 1976, 1980, 1986, 1988) likely arose because subjects were exposed to test stimuli, some of which contained superimposed images, for several minutes. This was ample time for subjects to develop novel associations to stimuli. The degree to which subsequent artistic products were judged to be creative was therefore independent of the ability to generate or superimpose images.

Creativity and Cognitive Variables

For males, females, and analyses involving the entire sample, no correlations between cognitive variables and the Creativity Index or subscales of the TTCT reached statistical significance. These results strongly suggest that cognitive variables are not important to several facets of creativity as measured by the TTCT, including the ability to consider a variety of stimuli before making decisions, the ability to capture the essence of creative products in another modality, and the quantity or novelty of creative products.

These results are somewhat surprising, particularly if the TTCT is sensitive to metacognitive processes. While the nature of these results is difficult to interpret without further research, it is possible that other variables have more salience to creativity. If true, cognitive processes may simply play a minor role in the mediation of other processes, such as sublimation or regression in the service of the ego.

Creativity and Personality

Only the correlation between the Extroversion domain of the NEO-FFI and the Fluency subtest of the TTCT for males reached statistical significance. The relative absence of significant correlations for both genders as well as analyses involving the entire sample was discrepant with previous research conducted by McCrae (1987). Surprisingly, no evidence was found to support the link between scores on the Openness to New Experience scale and scores on the TTCT. Taken at face value, these results would appear to suggest that personality variables are not a significant predictor of creative ability as measured by the TTCT. However, in light of extant research which indicates that creativity is associated with a distinct constellation of personality traits, these results are difficult to justify. The contribution of sampling error and/or beta error should not be discounted. It is also possible that, in contrast to claims by Kundu (1987) and Kabanoff (1991), the TTCT may not be sensitive to specific personality traits because it utilizes a definition of creativity that is similar to that of metacognition, and its component tasks are correspondingly cognitively based. If true, these results may suggest that subjects were somewhat guarded in their responses to the NEO-FFI and may have approached the TTCT as an intellectual exercise.

Linear Prediction of Creativity

No multiple regression equations were generated that predicted overall scores on the TTCT Creativity Index. However, two multiple regression equations were generated that predicted scores on subtests of the TTCT. Notably, of these equations, neither addressed creativity in females. This finding is not surprising, given the relative lack of significant correlations for females between individual variables and the figural subtests of the TTCT. As discussed previously, higher levels of spatial and deductive ability in males, the extent to which the TTCT measures metacognitive abilities, and the potential insensitivity of the TTCT Creativity Index for females may have sharply attenuated correlations.

For males, scores on the Conscientiousness and Openness to New Experience domains, as well as the number of WCST categories completed, predicted the amount of detail in drawings. This relationship seems to indicate that a central component of creativity is the ability to consider other viewpoints, benefit from corrective feedback, and apply oneself to the solution of a problem. When subjects were analyzed together, difficulties in shifting conceptual set, when coupled with an interpersonal style characterized by worry and vigilance to details of the environment, predicted the degree to which drawings were embellished with detail. These findings appear to suggest that a lack of cognitive flexibility restricts formation of abstract ideas and instead makes it more likely that attention is focused on the internal details of drawings.

These results appear to indicate that both cognitive and personality variables can be used as a starting point to predict the component processes of creative functioning. If predictive accuracy is eventually increased, these data have ramifications for programs developed to foster creativity. That is, creative individuals could potentially be identified with relative certainty and given focused training. Unfortunately, several programs are already in place within school systems nationally, despite a lack of conclusive evidence that such programs can successfully train students that have creative potential to be creative as adults (Feldhusen & Clinkenbeard, 1987). Moreover, the question of whether training efforts should be directed primarily at children with creative potential at the expense of those who are less creative is an ethical issue which requires immediate resolution.

Directions for Future Research

Despite extant theoretical and empirical evidence, there was a notable lack of significant correlations between cognitive, personality, and imagery variables and the TTCT in this study. Furthermore, neither of the multiple regression equations that were developed predicted behavior typically associated with creativity, such as originality. While these general failures may have been a consequence of low statistical power, sampling error, and/or the use of dependent measures that were not sensitive to independent variables, it is also probable that several variables important to creativity were not identified or included in this study. For example, a large body of evidence has accrued to suggest that unconscious processes (i.e., sublimation; regression in the service of the ego) are related to creative ability.

Therein lies a fundamental flaw of computational modeling. Selection of appropriate independent variables is heavily influenced by empirical methodology (Sergent, 1989). The existence of key variables may be neglected if the cognitive process has not been adequately decomposed. Furthermore, inclusion of variables in the computational model may be based upon evidence from empirical studies that did not have sufficient statistical power. Likewise, based on this evidence, other variables important to the process may be excluded because of Type II error; still others may be excluded because they do not fit into the theoretical paradigm used by the researcher.

Consideration should also be given to the factor structure of variables selected for analysis. Each variable distilled from the overall cognitive process may have numerous levels which are undetected. If multifactorial variables are treated as representing a single factor, the relative contribution of each factor to the prediction of the criterion variable will be unknown.

Obviously, building predictive models with computational theory is fraught with difficulties. Including variables in computer programs without first developing an understanding of the strength of their relationship to the cognitive process in question is dangerous. As evidenced by this study, theoretical knowledge and prediction of salient variables to include in a model of cognitive functioning is not always sufficient. Furthermore, use of an outcome measure which exhibits robust psychometric characteristics and is based upon a generally accepted definition of the construct being examined is fundamental. A sound theoretical rationale must also undergird both decomposition of the cognitive process and selection of appropriate independent variables. Evidence pertaining to the strength of relationship between the variables selected for inclusion in the model and the criterion variable must be evaluated in light of statistical power as well as experimental artifacts and confounds. The factor structure of these variables must be evaluated; variables that are multifactorial need to be further decomposed.

In addition to these methodological issues, it should be noted that computational theory also suffers from a major conceptual flaw. That is, developing a model of psychological functioning and confirming it with specific tests known to be related to those constructs is tautologous. Use of confirmatory factor analysis rather than computational modeling may be more appropriate in selecting appropriate independent variables for inclusion in a model. Attention to each of these details in future studies will increase predictive accuracy and further increase our understanding of the creative process.

APPENDICES

APPENDIX A

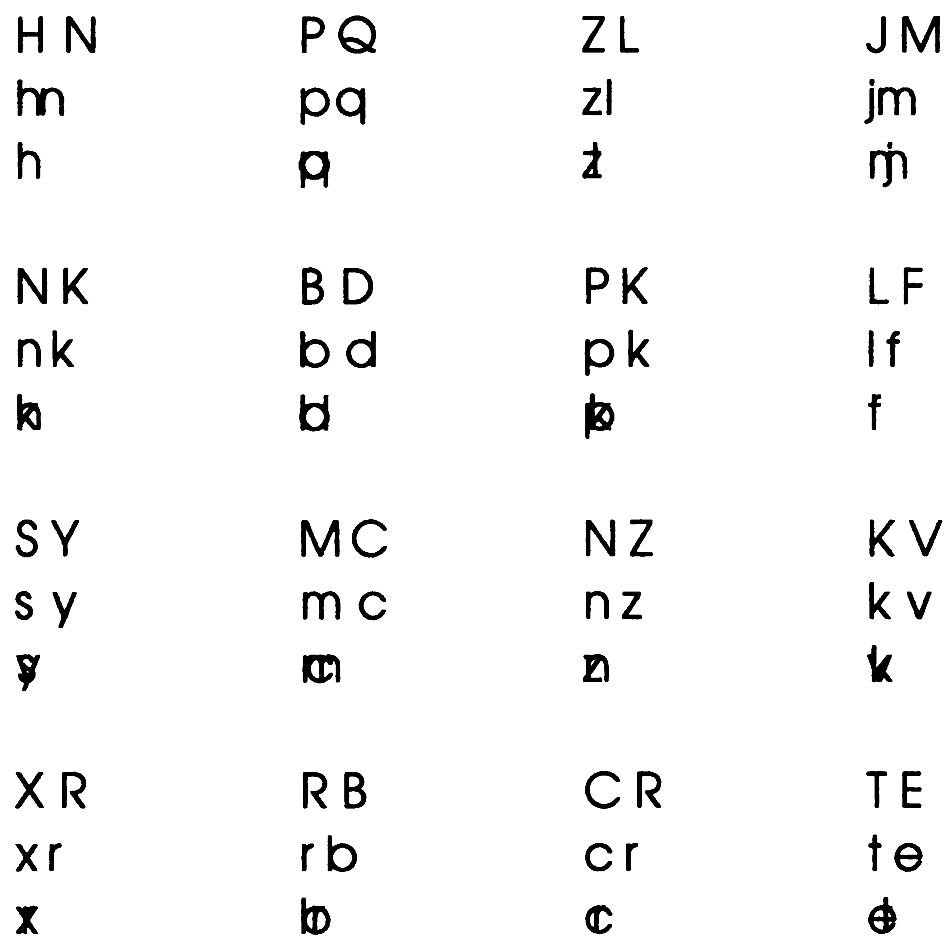
<u>Sample of the Font Used in the Imagery Task</u>

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

a b c d e f g h i j k l m n o p q r s t u v w x y z

APPENDIX B

Stimuli Used in the Letter Superimposition Task



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