The effects of animated practice on mental rotation tests

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THE EFFECTS OF ANIMATED PRACTICE
ON MENTAL ROTATION TESTS

by

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of the requirements for the degree of

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in

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Abstract

Mental rotation tests have been used to study the underlying process of mental imagery. In an attempt to better understand the nature of mental rotation, this study looked at the effects of practice with using animated feedback. A group with animated feedback, a group with non-animated feedback, and a control group were compared using a pretest-posttest design. The combined practice groups performed significantly better than the control group on both reaction time and accuracy. However, there were no significant differences between the animated and the non-animated groups. The animated group did perform significantly better on the posttest than the control group. There were no significant differences between the non-animated group and the control group. This study contributes to the understanding of the process of mental rotation and provides evidence suggesting that practice with animated feedback can significantly improve scores on tests of mental rotation.
Table of Contents

List of Figures................................................................. v

Acknowledgments.............................................................. vi

Chapter 1 Introduction........................................................ 1
  The Language of Mental Imagery..................................... 3
  The Imagery Debates...................................................... 4
  The Function and Nature of Mental Imagery..................... 6
  Purpose........................................................................... 9
  Research Questions.......................................................10

Chapter 2 Literature Review................................................12
  Historical Perspective.....................................................12
  Analog Theory.................................................................15
    Mental Rotation Tests....................................................15
    Practice Effects.............................................................18
    Summary of the Analog Theory......................................20
  Propositional Theory.......................................................21
  Neuropsychology of Mental Imagery................................23
  Summary...........................................................................24

Chapter 3 Methods..........................................................25
  Subjects............................................................................25
  Instruments.......................................................................25
    Tests and Practice Tests................................................26
  Procedures.......................................................................28
    Session 1....................................................................29
    Session 2.....................................................................30
    Session 3.....................................................................30

Chapter 4 Results............................................................32
  Question 1.....................................................................32
  Questions 2 and 3...........................................................33

Chapter 5 Discussion.........................................................36
  Limitations.....................................................................36
  Conclusion.....................................................................37

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List of Figures

Figure 1  Item #2 of the pretest-posttest .......................... 47
Figure 2  The five images............................................... 48
Figure 3  Examples of feedback....................................... 49
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Chapter 1

Introduction

According to Kosslyn (1994), mental imagery "is a basic form of cognition, and plays a central role in many human activities—ranging from navigation to memory to creative problem solving" (p. 1). Such early psychologists as Wilhelm Wundt and William James attempted to study the concept of mental imagery. However, they were criticized by other psychologists who argued that it was not possible to use the scientific method in studying such internal processes as mental imagery. Radical behaviorists, such as John B. Watson, also criticized the study of imagery. They believed that we should only observe external behaviors, by and large ignoring all the mental processes that were the underlying foundation for the expressed behaviors.

With the advent of psychotherapy, the use of introspection, or self-report, became a powerful tool. Though the research conducted by psychotherapists and behaviorists has proven quite useful in creating theories about internal mental processes, there has always been an argument that
simply observing one's behavior or subjective self-report (Kosslyn, 1994). These approaches were inadequate in developing sufficient evidence to justify an explanation of the internal mental processes underlying imagery (Cooper & Shepard, 1973).

The gain in popularity of cognitive psychology in the 1960's brought with it a rejuvenation of interest in mental imagery. Tests of spatial ability were used to predict such things as general intelligence and success in dental school. There seem to be aspects of mental imagery, based on tests of spatial ability, that coincide with skills associated with success in professions such as dentistry, engineering, mechanical trades, and piloting (Anastasi, 1988). However, up until then, the intuitive theories of internal mental processes were limited.

Along with the newly found interest came research that showed conclusively that mental imagery could be studied scientifically. In the 1970's Roger N. Shepard and his colleagues (Cooper & Shepard, 1973; Kosslyn, 1994; Kosslyn, Ball, & Reiser, 1978; Pylyshyn, 1988; Shepard, 1988; Shepard & Cooper, 1982; Shepard & Metzler, 1971) introduced mental rotation tasks to experimental cognitive psychology. Their main innovation was to measure reaction time taken to make decisions requiring mental rotation of a shape under varying experimental conditions (these conditions will be discussed in greater detail
in chapter 2). The research conducted by Shepard (Cooper & Shepard, 1973; Shepard, 1988; Shepard & Cooper, 1982; and Shepard & Metzler, 1971) and those who followed not only added to the repertoire of research methodologies for studying the process of mental imagery, but was able to "bridge successfully the chasm between what Cronbach called 'the two disciplines of scientific psychology,' the psychometric and the experimental" (Corballis, 1982, p.174).

The Language of Mental Imagery

A few key concepts need to be defined.

1. Mental imagery is an internal mental process that consists of creating or transforming images within our mind.

2. Mental images are those images that are created or transformed by mental imagery.

3. Images are external stimuli that can be viewed, such as a photograph or computer generated image.

4. Angular disparity is the difference in angle between two images, typically a pair of images presented as an item in a mental rotations test: This difference may either be in the picture plane, a two-dimensional rotation, or in depth, a three-dimensional rotation represented by two dimensional images.

5. Reaction time is the time it takes to respond to each item of a mental rotation test.
To understand the concepts of analog, propositional, and transformation, picture a park in your mind. It has a pond in the middle that is surrounded by trees, a walking path that weaves its way around the pond, and a few benches between the walking path and the pond. The image you have created is propositional: It is represented by a series of propositions, in this example the propositions are included in the previous sentence. Now, imagine that you are handed a picture of the same park and asked to remember what it looked like. The image you now see is analog, or isomorphic: There is a direct, one to one, relationship between what you see and the image itself. Now, with this picture in your mind, imagine what the park would look like if you were to view it from the other side. This last image is the result of a transformation.

**The Imagery Debates**

There are debates among cognitive psychologists about the nature of mental imagery, often referred to as "the imagery debates" (Corballis, 1982; Kosslyn, 1994; Tye, 1991). The literature discusses such things as the nature of the internal mental processes underlying mental imagery. More specifically, the debate focuses on whether the transformation of images—which takes place in representational space—is analog or propositional in nature. The fundamentals of the debate
seemed to have been explained and the framework established. The questions addressed by this research focused on this debate in an attempt to expand on the existing information (Kosslyn, 1994).

The debate has progressed through three stages. The first phase consisted of empirically testing theories of internal representations of mental imagery. Researchers agree on the existence of an internal representational space where transformations of mental images take place, however, the debates about the nature of this space and the internal mental process underlying mental imagery were left unresolved. The second phase was a retrospective analysis of the first phase. Researchers debated the meaning of the empirical evidence collected and discussed methodological problems with the experiments (Kosslyn, 1994; Pylyshyn, 1988). Some researchers believe that the second phase essentially resolved the debates, concluding that, while the nature of the transformations is analog, the images may be stored propositionally (Kosslyn, 1994). These researchers seem to agree that experiments should be continued to help understand mental imagery but should build on the existing framework. Other researchers believe that the study of mental imagery is in its third and, perhaps, final phase (Kosslyn, 1994; Stiles-Davis, Kritchevsky, & Bellugi, 1988). This third phase consists of
conducting neuropsychological research, such as using new methods of measuring brain activity to help better understand the internal mental process.

The concept of representational space is based on a theory that is supported heavily by literature (Corballis, 1982). The theory is that we have the ability to manipulate, or transform, mental images within a space in our minds. While introspectively this concept seems logical, researchers want to better understand the nature of these abilities. Perhaps if better ways of understanding the nature of this internal mental process are developed, we can better understand other internal mental processes and/or ways of studying them.

Function and Nature of Mental Imagery

Research concerned with mental imagery has focused on two separate but interrelated issues: the function of mental imagery and the nature of mental imagery. Research concerned with its function tends to focus around the "behavioral consequences of mental imagery," while research concerned with its nature tends to focus on the "internal structure of the mental images themselves" (Shepard & Cooper, 1982, p. 76). Before the 1960's, research primarily was structured around the function of mental imagery. That is to say, researchers wanted to know how mental imagery affected our everyday
lives. Perhaps the best example of this was shown by the significant improvement in motor skill performance (e.g., making free throws in basketball) as a result of mental practice (Richardson, 1969).

With innovative new ideas for experiments, researchers began to address questions concerning the nature of mental images. Questions of structure, modality, form, existence, process, representation, and newer models of cognition based on an analogy with the computer became of interest. Research paradigms were created to explore these questions. Two such paradigms are the selective interference and reaction time paradigms. The former primarily addresses the modality of mental imagery. Based on interference studies with different senses, it showed that the hardwiring, i.e., the brain structure, used for the information processing of external stimuli overlaps the hardwiring used for mental imagery (Kosslyn, 1994). The reaction time paradigm addresses the form, internal representation, and the internal mental processes of mental imagery and is a foundation for the present research. The paradigm originated as a result of a study by Shepard and Metzler (1971) that showed an incredibly strong linear relationship between angular disparity and reaction time. Though we still must rely on external observations to better understand mental processes, this paradigm has continued to
establish itself as a research tool that can objectively and scientifically promote theories concerning the function as well as the nature of mental processes.

A new school of theories has also been developed as a result of the computer. Using the computer model as an analogy, the theories include such things as encoding (input), working memory (RAM), storage (ROM), and retrieval (output). Among these theories are computer models of imagery. For example our working memory of mental images might be considered analog while the storage might be considered propositional. The nature of the reaction time paradigm and mental rotation tasks may contribute to the body of evidence that is now being created to support these theories (Kosslyn, 1994).

The modern computer has facilitated a closer examination of issues relevant to mental rotation tasks. With the development of the computer, the nature of psychological testing and psychometrics is changing. "We may be rapidly approaching the day when most or all testing will be administered, scored, and interpreted by the computer" (Goldstein & Hersen, 1990, p.3). Mental rotation tasks may be measured more reliably and with more accuracy because of improvements in graphics; chronometrics; and new
measurement tools, such as Item Response Theory, that require
the use of computers (Bejar, 1986, 1990).

The nature of the present study lends itself to using a
computer. The computers in this study were used to develop
and present mental rotation tests and provide animated and
non-animated feedback. Furthermore, the computer measured
accuracy and reaction time for each item. Such valuable data
would not have been available using a paper and pencil test.
Given the practical applications of mental rotation tests and
better assessment techniques using computers, understanding
the cognitive process underlying such tasks will become more
critical.

Purpose

The primary purpose of this study is to determine if there
is a decrease in reaction time on mental rotation tests as a
function of practice sessions using animated feedback. If there
is a significant decrease in reaction time as a result of practice
with animated feedback when compared to the decrease in
reaction time as a result of practice with non-animated
feedback, there would be indirect evidence to support the
notion that transformation of mental images is an analog
process.
This does not necessarily mean the opposite is true. If the decrease in reaction time of non-animated feedback is greater, this does not directly support the notion of transformations being propositional in nature. It has been shown that practice effects will be greater as a function of the similarity between practice sessions and actual tests (Longstreth & Alcorn, 1990). In this instance, if non-animated feedback provides greater improvement, it may be result of the greater similarity between the practice tests and the posttest.

**Research Questions**

There are three specific research questions addressed by this study.

1. What is the strength of the linear relationship between angular disparity and reaction time on mental rotation tests?

2. Will reaction time and the accuracy on a test of mental rotation decrease as a function of practice?

3. Is there a difference in reaction time and accuracy between practice groups given animated feedback and feedback without animation?

The first two questions are replications of previous research and, if the results are consistent, will contribute to the evidence of validity of the present study. The third research
question is related to the theoretical framework established by previous research. Shepard (1982) suggested that there is an "illusion of 'apparent' visual rotation" (p. 4) when subjects were presented with alternating static views of the same image.

"This produced an illusion of rigid rotation, suggesting that the subjects 'filled in' the interval between successive presentations with mental rotation. These properties also characterize mental rotation as measured by the reaction-time paradigm (Shepard & Metzler, 1971), and reinforce the interpretation that the rotation illusion is mediated by mental rotation" (Corballis, 1982, p. 187).

The animation, in this study, presents the same three-dimensional image in a series of orientations that create visual stimuli analogous to actual rotation, creating apparent motion using an analog process. This is similar to Shepard's 1976 study except that there are more than two static views being presented. The fundamental assumption of this question is that animation is analog in nature and that practice with animated feedback will result in greater improvement in reaction time and accuracy when compared to non-animated feedback. This study does not directly address the underlying nature of mental rotation as being either propositional or analog. However, if animated feedback shows greater improvement than non-animated feedback then there would be indirect evidence to support the notion that mental rotation is an analog process.
Delimitations

The primary limitations of research using mental rotation tests include a lack of generalization to other mental imagery tasks as well as susceptibility to practice effects. The implications of such research, including the present study, may not be generalized to all the aspects of mental imagery. This study has been designed to contribute to the existing information related specifically to tests of mental rotation. While it is also related to the aforementioned imagery debate, the primary purpose of this study is to test the effects of animated feedback on mental rotations tests. It is hoped that the information provided will contribute to future research, including neuropsychological research, by helping to create an understanding of the underlying process of mental rotation.
Chapter 2

Literature Review

The review which follows is a summary of the theory and empirical research regarding the imagery debate. The imagery debate involves a discussion about whether mental imagery is analog or propositional in nature. While there are advocates of both sides of the issue it seems that each side has a spokesperson. Zenon Pylyshyn (1988) has long supported the notion that mental imagery is "tacit" knowledge, or propositional in nature. Stephen Kosslyn (1994), on the other hand, supports the notion that mental imagery is an analog process. Neither of these researchers, nor the researchers who support their ideas, entirely discredits the opposing view. Debates about mental imagery are complex. The issues in dispute are not easy to resolve and have been a continuing source of controversy since the time of Aristotle (Tye, 1991).

Historical Perspective

Historically, philosophers, like Aristotle, introspectively theorized about the nature of mental imagery. In his book, The
Imagery Debate, Tye (1991) devotes a chapter to theories of mental imagery developed by such philosophers as Aristotle, Hume, and Locke. Typically, these philosophers support the notion that the internal mental process underlying imagery is analog in nature.

The theories developed by these philosophers also sometimes make a distinction between resemblance and representation. Resemblance was explained by saying that two images might resemble each other. For example, two people might look alike, however, just because two images resemble each other does not mean that they represent each other. One person does not represent the other person. Representation, on the other hand, was explained by saying that one image can represent another, but the reverse does not have to be true. For example, a picture might represent a person, however, the person does not have to represent the picture (Tye, 1991).

While this distinction is not central to the focus of the present study, it is interesting to note that even early philosophers were attempting to better understand the process of mental imagery.

Early psychologists, like Wilhelm Wundt and William James, also attempted to understand the process of mental imagery. Again, however, other early psychologists criticized their efforts in concern for establishing psychology as a true science. At this point, the verification of the theories based on
the writing of the early philosophers was still limited by the available research methodology (Tye, 1991). In almost direct contrast with Wundt, who believed introspection should be used as the research methodology for his field, were the behaviorists. The behaviorists limited observation in their research to external behavior almost entirely ignoring the underlying mental processes of the expressed behavior (Kosslyn, 1994). As the methods for studying mental imagery did not fit these limitations and as behaviorism gained popularity, the study of mental imagery greatly declined. It was not until the gain in popularity of cognitive psychology in the 1950's and 60's that there was a rejuvenation of interest in the study of mental imagery.

However, this new research focused only on the function of mental imagery. The previously cited research by Richardson (1969) in which he showed improvement in motor skills (e.g., free-throws in basketball) as a function of mental practice showed that mental imagery can result in improvement of a skill. The research did not conclude anything about the underlying mental process, only about the effects it had. In the 1970's Shepard and his colleagues (Cooper & Shepard, 1973; Kosslyn, 1994; Kosslyn, Ball, & Reiser, 1978; Pylyshyn, 1988; Shepard, 1988; Shepard & Cooper, 1982; Shepard & Metzler, 1971) conducted research using mental rotation tasks and a
reaction time paradigm. These studies focused on the process of mental imagery using research based on both experimental psychology as well as psychometrics.

**Analog Theory**

The major premise of the theory of mental imagery is that mental images have similar characteristics to external images. The theory originated as a result of the introspective ideas of early philosophers and psychologists. It was later supported empirically by cognitive psychologists. The primary tools used in developing this empirical evidence were mental rotation tests.

**Mental Rotation Tests.** Using mental rotation tests has proven to be quite useful in helping us understand the underlying process of mental imagery, but their use is not without weaknesses. Corballis (1982) went so far as to say,

Studies of mental rotation... (have) taken us into some the most fundamental topics of cognitive psychology, including the interface between perception and imagery, the nature of internal representations, the mechanisms of shape recognition, and the neurological bases of spatial cognition. I know of no experimental paradigm in mental imagery that has had broader implications or is more compelling. (p.194)
These tests have been part of the psychometric and cognitive development repertoires as far back as the 1950's, however, it was in the 1970's that Roger N. Shepard and his colleagues introduced mental rotation tasks to experimental cognitive psychology (Cooper & Shepard, 1973; Kosslyn, 1994; Kosslyn, Ball, & Reiser, 1978; Pylyshyn, 1988; Shepard, 1988; Shepard & Cooper, 1982; Shepard & Metzler, 1971). Their main innovation was to measure the reaction time taken to make decisions requiring a mental rotation of a shape under varying experimental conditions (Corballis, 1982).

An initial experiment using mental rotation was conducted by Shepard and Metzler (1971). They presented subjects with pairs of two-dimensional images that portrayed three-dimensional block designs. The images either had the same three-dimensional shape and were rotated or were mirror images of one another and rotated. The subjects were then asked to determine if the two objects were the same or different as quickly as they could while keeping errors to a minimum. The reaction time and the accuracy of their responses were measured.

The rotation was done in one of two ways. The first way was to simply rotate the two-dimensional images, this would be a picture plane rotation. The second way was to rotate the three-dimensional image about a vertical axis, this would be a
rotation in depth. The rotation was done in increments of 20 degrees. The difference between the angles of the two objects is referred to as angular disparity.

There were two important findings in this study. The first is that there is a strong linear relationship between reaction time and angular disparity. The second is that there is no difference in the slope and the y-intercept for this relationship whether rotation takes place in the picture plane or when rotation takes place in depth. These findings directly support the notion that the process of mental rotation is analog and therefore support the notion that mental imagery is an analog process (Shepard, 1971). This support is based on the idea that if an analog, or holistic, rotation takes place in one's mind the greater the angular disparity is between two images the longer it would take to decide if they were the same. Furthermore, this research laid the foundation for more research to be conducted using mental rotation tests and the reaction time paradigm under varying experimental conditions.

Many other researchers have since added to the mental rotations paradigm (Bejar, 1986, 1990; Bosma, 1984; Kail, 1986; Kail and Park, 1990; and McDaniel, 1985) by supporting and clarifying broader questions that "are implicit in the paradigm itself (including)... the role of imagery in human cognition, the nature of mental representation and mental process, and the
appropriateness of models based on analogy with the digital computer" (Corballis, 1982, p. 174-175). Research using mental rotation tests has not solved the imagery debate, but it has contributed greatly to our understanding of the mental process underlying imagery and many researchers agree that it has supported the theory that mental imagery is an analog process.

Mental rotation tests do have limitations as tools to completely resolve the debate. One of the limitations is that mental rotation tests have been shown to measure different aspects of mental imagery as well as use different hardwiring functions in the brain (McDaniel, 1985; Morrow & Ratcliff, 1988). An additional limitation of mental rotation tests that should be discussed is their susceptibility to practice effects.

**Practice Effects.** Like the underlying mental process of imagery, the underlying mental processes of practice effects has not yet been completely explained although the effects of practice have been well researched (Dempster, 1989; Kail, 1986; Kail & Park, 1990; Longstreth & Alcorn, 1990). The presence of practice effects can raise questions about the valid use of tests scores. Caution needs to be taken when these scores are used for decision making and when considering the results of related research studies.
Practice effects on mental rotation tests have been well documented. Two studies discussed these effects (Kail 1986; Kail & Park, 1990). The first study used alphanumeric images in 30 degree increments for the test items. Subjects were given 16 test sessions over four weeks. During the practice sessions they received item level feedback as to the accuracy of their responses. The study showed a significant decrease in reaction time as well as improved accuracy as a function of practice. It also showed the underlying mental process of imagery is the same for children, adolescents, and adults.

This study also presents a concern for these type of tests. The concern is a speed-accuracy tradeoff. "On most cognitive tasks, including mental rotation, increases in accuracy occur at the cost of slower responses" (Kail, 1986, p. 389). This trade off should be considered when viewing the results of similar studies, including the present study.

The second study (Kail & Park, 1990) was a more detailed analysis of the effect of practice on the speed of mental rotation. Using similar methods as the first study, changes in speed were analyzed with more detail. It was found that "massive amounts of practice produced change in rate of mental rotation for children but not for adults" (p. 233), this effect did not transfer to unfamiliar "letter-like" characters. It was also shown that within the practice groups females improved more that males.
Summary of the Analog Theory. Stephen Kosslyn is, perhaps, identified most with the analog theory. In his book, Image and Brain, Kosslyn (1994) attempts to address the underlying process of mental imagery, or what he calls "depictive imagery representations" (p. 5). This attempt includes a look at how such images are produced and used. It is Kosslyn's contention that cognitive psychologists, including himself, have developed a theory and methods for studying the nature of mental imagery and that research using the brain can now fill the void in the behavioral data. It is projected that research involving properties of the brain, genetics, and imagery can "map behavior into the mind..." (Kosslyn, 1994, p. 407). Having filled this gap, the study of mental imagery is changing hands to neuropsychology, but the use of mental rotation tests and research conducted by cognitive psychologists still have their place.

The limitations of research using mental rotation tests includes a lack of generalization to other mental imagery as well as susceptibility to practice effects. However, this research has contributed a great deal of information about and has provided for a better understanding of mental imagery. In using a reaction time paradigm with these tests, it has been shown that there are characteristics of mental imagery similar to real external images.
Propositional Theory

The premise that imagery must be propositional in nature is based on the notion that even the empirical evidence that supports the analog theory can be better explained through propositional accounts. In "The Imagery Debate: Analogue Media Versus Tacit Knowledge", Pylyshyn (1988) summarizes his views of the debate. It is his belief that a propositional account of mental imagery is a more plausible and general account. It includes a review of literature with extensive comments on the research findings of Kosslyn. It also makes reference to studies by Pylyshyn that support the notion that some characteristics of mental imagery can be explained propositionally.

There were two studies Pylyshyn used to demonstrate his beliefs (cited in Pylyshyn, 1988). The first was similar to a study conducted by Kosslyn, Ball, and Reiser (1978). Pylyshyn found that giving the same directions as the original study resulted in the familiar strong linear relationship between angular disparity (in this case distance) and reaction time. The directions were to mentally move a "speck" from one place to another on a mental image of a map with which subjects were familiar. However, by simply changing the instructions to asking the subjects to give a bearing on the second location with respect to the first, the linear relationship vanished. This
finding is by no means concrete evidence that all mental images are propositional, but it does establish a situation in which subjects are required to use mental imagery and the explanation for the results is best characterized by propositional characteristics.

The second study discussed by Pylyshyn (1988) was similar to the first. A new group of subjects were familiarized with a map. Again they were required to find different locations on the map starting at an original location. One group had to "keep the image before their 'mind's eye' and to use this image to read off the correct answer" (p. 611). The other group was allowed to look at the map. He again found a linear relationship between distance and reaction time ($r=.5$, $p<.05$), but only for the group allowed to look at the map. There was no significant correlation for the other group ($r=-.03$, ns).

Pylyshyn (1988) provides a detailed analysis of these findings as well as a response to Kosslyn's analysis. It is Pylyshyn's view that the inadequacies of the results in studies of mental imagery can better be explained using propositional accounts. He suggests that mental imagery is not limited to the same constraints as external images, e.g., grain and resolution. This provides a better explanation of other findings that have shown distortions in recall of detailed images or scenes as being limited by behavior or propositional notions. Finally, Pylyshyn
(1988) comments about the issue of mental imagery saying that, "a theory of the underlying process should account for how imagery can come to have this character, not use the very property as an explanatory principle" (p. 613).

**Neuropsychology of Mental Imagery**

Though the second phase of the imagery debate has established a theoretical framework for mental imagery, neuropsychological studies continue to build on the foundation and can be considered a third phase of the debate (Farah, 1988). With new methods of studying the brain and creative studies using subjects with cerebral damage researchers have been successful in "delineating the cognitive structures of spatial disorders" as well as contribute to the theories of the internal mental process of imagery (Morrow & Ratcliff, 1988, p. 6).

Morrow and Ratcliff (1988) suggested that, "while valuable information can be gained from clinical studies of brain damaged individuals or small groups of patients, further progress in understanding the factors which limit spatial performance can only be achieved when the behavioral deficits, as well as the spatial tasks themselves, are more clearly defined" (p. 25-26).

Like the work done by Kosslyn (1994), the present study attempts to create a better understanding of spatial tasks and, therefore, indirectly contributes to this third phase of the imagery debate which will involve the methods of
neuropsychological research, including new ways of studying the brain and research using subjects with cerebral damage.

**Summary**

The process of mental imagery cannot be fully understood and the analog versus propositional debate cannot be resolved without using elements of both the analog and the propositional theory. Corballis substantiates this notion by saying that while there is empirical evidence to show that transformations of mental images are analog in nature, the storage of the images has propositional characteristics. This would explain evidence found by Pylyshyn that suggests that "omissions and distortions of remembered scenes seem to follow propositional rules" (Corballis, 1982, p. 15) as well as justify the overwhelming evidence found by Shepard (1988) and Kosslyn (1994) that suggests that transformations, particularly on mental rotation tests, seem to be analog.
Chapter 3

Methods

Subjects

Subjects for this study consisted of 76 college student volunteers. A majority of them were undergraduate students in education classes—specifically, Educational Psychology and Tests and Measurements. They were randomly assigned to one of three groups: control, animated practice, and non-animated practice. Due to drop-out, experimenter oversight, or not following directions, 15 subjects were dropped from the analysis. Of the remaining subjects, 21 were in the control group, 20 were in the animated practice group, and 20 were in the non-animated practice group. Of the subjects in the analysis, 17 were men and 44 were women.

Instruments

The pretest-posttest and practice tests were created and administered using basic programming software called HyperCard (Hills, 1991) on an Apple Macintosh. The tests were based on a revised paper-pencil version of the Shepard-Metzler
Mental Rotation Test (see Appendix A) (Vandenberg, 1971). In addition to the pretest and posttest, the control group used a math drill-and-practice software game called "Number Munchers" on a Macintosh (Number Munchers, 1990). The computers used in this study were all in a computer laboratory and ranged from the SE model to a Power PC Quadra 650. The monitors used in the study also varied, however, the size of the window was standardized and the tests were presented in black and white. There should be no differential effect using the various computers.

Tests and Practice Tests. There were nine tests developed for the present study. Each test consisted of twenty items. For each item subjects were instructed to determine if two three-dimensional block images presented by the computer were the same or different (see Figure 1). There were 5 images used in this study which were developed by Shepard for his 1971 study. Each image was made up of "perspective line drawings portraying a fixed number of cubes fastened face-to-face to make a three-dimensional structure that cannot be transformed into itself" (see Figure 2) (Shepard, 1982, p. 20). The images were presented in both their original form and mirror images. Each image also had an original position and rotated positions in ten degree increments from the original position. For the
present study the rotation was only in depth, that is to say, the images were rotated around a vertical axis. The original position was used only as a reference, it was not used in any items. The angular disparity between images and their original position was given for each image as part of the revised test used as the reference for developing the tests for the present study (see p. 8 of Appendix A).

For each item in this study, the angular disparity was determined as the difference in angular disparities between the two images. For example, in item 2 of the pretest-posttest the given disparity for the image on the left is 60 degrees and the given disparity for the image on the right is 100 degrees (see Figure 1). The angular disparity for item 2 would then be calculated by subtracting 60 degrees from 100 degrees, which is 40 degrees.

The computer recorded the accuracy of the subjects responses as well as the reaction time for each item. Reaction time was recorded in 1/60 second intervals. The pretest and posttest were identical and provided no item level feedback to subjects. There were 13 items with the same image: items 2, 3, 6, 7, 9, 10, 11, 12, 13, 14, 15, 18, 19; and 7 items with different images. Of the items with different images, for 3 items the image on the right mirrored the image on the left: items 1, 5,
and 17; and 4 items had two entirely different images: items 4, 8, 16, and 20 (see Figure 2).

The remaining tests were designed for practice and did provide item level feedback. They were similar to the pretest-posttest except that after the subject responded to each item the computer informed them if they were "Correct" or "Incorrect" followed appropriately by either "They are different" or "They are the same" (see Figure 3). Four of the practice tests provided animated feedback for the animated practice group. In these tests, following the aforementioned feedback and regardless of accuracy of the response, if the images were the same the image on the right would rotate until it was presented at the same angle as the image on the left. Following a two-second pause the image was rotated back to its original position and the subject was prompted to "Press return for the next item" (see Figure 3). The other four practice tests were developed for the non-animated practice group. These tests only informed the subject if they were "Correct" or "Incorrect" followed appropriately by "They are different" or "They are the same" after the subject responded to each item (see Figure 3). After a three second pause the subject was prompted to "Press return for the next item" (see Figure 3). The items for each of the practice sessions for the animated and non-animated practice groups were identical, the type of
Feedback was the only difference between the two groups, and the practice sessions contained no items that were identical to the items used on the pretest-posttest.

**Procedures**

Each subject signed up for three one-hour sessions for three consecutive weeks. It has been documented that spaced practice is a more effective learning device than massed practice (Dempster, 1989).

**Session 1.** During the first session each subject signed an informed consent form (see Appendix B). Following this, the pretest was administered (see Appendix C). Subjects were told "If you have any questions (about the instructions on the computer), just ask". Upon completion each subject was told their number of incorrect responses on the pretest.

The subjects assigned to the animated practice group were then given one animated practice test with appropriate item level feedback. The subjects assigned to the non-animated practice group were also given a practice test that provided appropriate feedback (see Appendix D). Both the animated practice and the non-animated practice group took approximately 8 to 12 minutes to complete each practice session. Part of this time was spent copying the data from the
computer on to a disk. Following the pretest, the control group spent approximately 12 minutes playing "Number Munchers." The computer provided instructions on how to play and, if time was available, the experimenter would sometimes explain the directions. After each subject completed the first session they were told "Please do not to discuss what you have done with anyone else until after you have finished your third and final session".

Session 2. During the second session the subjects in the animated group were given two more practice tests with appropriate feedback and the subjects in the non-animated group were also given two more practice tests with appropriate feedback (see Figure 3). Again, each practice test took approximately 8 to 12 minutes to complete, including data collection. The control group played "Number Munchers" for 20-25 minutes.

Session 3. During the third session the animated feedback group was given one more practice test followed by the posttest. The non-animated group was also given one more practice test followed by the posttest (see Appendix C). While the subjects were accustomed to the procedures of the study and did take a shorter time on average to complete each test, it
still took approximately 8 to 12 minutes to complete each test including data collection. The control group played "Number Munchers" for about 12 minutes then took the posttest, which took approximately 8-12 minutes to complete including data collection. When each subject was finished, they were given a debriefing form (see Appendix E) and allowed to ask the experimenter questions regarding the study. For all the sessions the sound on each computer was turned down to the minimum. The subjects were also spaced apart in the computer labs to minimize each subject's knowledge of what the other subjects were doing. The number of subjects during a session ranged from 1 to 14. The computer lab seated 30 students, so in all sessions students were seated at least one computer apart.
Chapter 4

Results

For each of the following analyses there was one item on the pretest-posttest that was not used due to a flaw in one of the images. There was a total of 19 items used from the pretest-posttest. Furthermore, of the 40 subjects in the practice groups 14 were given incorrect feedback on one of the items. The programming error was corrected for the remaining subjects. There was a total of 61 subjects: 21 in the control group, 20 in the non-animated feedback practice group, and 20 in the animated feedback practice group.

Question 1

The first research question was: What is the strength of the linear relationship between angular disparity and reaction time on mental rotation tests? Evidence relating to this question was developed by correlating the posttest reaction times, averaged over all subjects, with angular disparity for each item with images that were the same. The linear relationship (Pearson correlation) observed was not significant.
(r=.3, ns). While this may raise a concern for the internal validity of this study, the lack of significance may be explained by the small number of items (n=12) as well as the limited range in angular disparity, only 5 disparities out of a possible 17. The pool of items included images with angular disparities from 10 degrees to 170 degrees. However, the 12 items used in this analysis had disparities that ranged from 30 degrees to 140 degrees. This restriction may result in attenuation of the correlation.

Questions 2 and 3

Evidence for these questions was developed by conducting analysis of covariance and post hoc comparisons. Separate analyses were conducted for the outcomes of reaction time and accuracy. In both cases the respective pretest scores were used as covariates. After controlling for the pretest scores, there was a significant difference between the posttest reaction times \[F(2,57)=3.55, p<.05, \eta^2=.075\] and the posttest accuracy rate \[F(2,57)=3.69, p<.05, \eta^2=.085\].

The second question was: Will reaction time and the accuracy on a test of mental rotation decrease as a function of practice? Evidence for this question specifically was developed with a post hoc comparison using Scheffe' contrasts for both
reaction time and accuracy. The two practice groups were combined and compared to the control group.

The mean reaction time for the combined practice groups was 7.91 seconds and the mean reaction time for the control group was 9.74 seconds (see Table 1). The combined practice groups performed significantly better than the control group with respect to reaction time ($t=2.26$, $p<.05$). The mean accuracy rate (out of 19 items) for the combined practice groups was 87% and the mean accuracy rate for the control group was 82% (see Figure 1). There was a significant difference between the combined practice groups and the control group with respect to accuracy ($t=2.42$, $p<.05$). These results support previous research suggesting that mental rotation tests are susceptible to practice effects.

The third question was: Is there a difference in reaction time and accuracy between practice groups given animated feedback and feedback without animation? Evidence for this question specifically was developed with a post hoc comparison using Scheffe' contrasts for both reaction time and accuracy comparing between the two practice groups. The mean reaction time for the practice group with non-animated feedback group was 8.66 seconds and for the mean reaction time for the practice group with animated feedback was 7.15 seconds (see Table 1). The accuracy rate for the non-animated group was
85% and the accuracy rate for the animate group was 89% (see Table 1). There was no significant difference found between the practice groups with respect to reaction time \( t=1.41, \text{ ns} \) or accuracy \( t=1.25, \text{ ns} \).

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Insert Table 1 about here

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In addition to the two comparisons for the second and third research questions, post hoc comparisons were observed between each of the practice groups and the control group using analysis of covariance. There was no significant difference between the practice group with non-animated feedback and the control group for reaction time \( t=1.23, \text{ ns} \) or accuracy \( t=1.47, \text{ ns} \). There was a significant difference between the control group and the group with animated feedback for both reaction time \( t=2.66, p<.05 \) and accuracy \( t=2.71, p<.05 \).
Chapter 5

Discussion

Limitations

There are important limitations in the present research. The assumption that animation is an analog process is controversial. Any implications described in this research referring to the imagery debate are limited by this assumption. Furthermore, if mental rotation is an analog process then the difference in processing for the practice groups is that the non-animated group practices mentally while the animated group practices mentally with visual stimuli.

The failure to replicate the strong linear relationship between angular disparity and reaction time is a concern for the internal validity of this study. The low relationship may be due to the limited number of items on the pretest-posttest and the limited range of disparities for these items are also concerns for the internal validity. However, since the items used in this study were identical to items used by Shepard in his 1971 employing these test items to measure speed and accuracy on mental rotation seems reasonable.
Threats to the external validity are present in characteristics of the subject pool. The sample size was small with only about 20 subjects per group. The subjects were almost entirely undergraduate college students in education courses and the gender split was disproportionately female. While homogenous groups may be useful in theoretical research that looks for differences between experimental groups, population generalization of the results is greatly limited.

Conclusions

The first two research questions were attempts to replicate previous research which consistently showed a linear relationship between angular disparity and reaction time and evidence of practice effects on mental rotation tasks. Successful replication would also serve as evidence of the measurement validity for this study. Results relating to the correlation between angular disparity and reaction time failed to replicate previous consistent findings indicating a strong linear relationship between angular disparity and reaction time. The failure to replicate may be due to the limited range in angular disparity for the 12 items used in the analysis. Future research considering using similar internal validation procedures should consider increasing the amount of practice and using a greater number of test items with the full range of angular disparity.
The purpose of the second research question was to determine if reaction time and accuracy would improve as a function of practice. Results of the comparison of the two practice groups with the control group for both reaction time and accuracy reinforced previous research findings that have shown the susceptibility of mental rotation tests to practice effects. This susceptibility should be considered when reviewing research that uses similar tests as well as when planning research that will use similar tests.

The third question presented the unique contribution of this research to the analog versus propositional imagery debate. The primary analysis developed for this question was to compare the practice group with animated feedback to the practice group without animated feedback. There was an underlying assumption that animation is an analog process. Therefore, if animated feedback would have results in improved reaction time and accuracy when compared to non-animated feedback then there would have been indirect evidence to support the notion that mental rotation is an analog process. While there was no significant difference between these two groups, the group of subjects that was given practice tests with animated feedback did significantly better than a control group. The same comparison for the group without
animated feedback was not significant, therefore, the results provide no evidence to suggest weakness in the analog theory.

The strength of association statistics ($\eta^2$) showed little evidence of practical significance. This could be due to the small sample size, the low number of items, and/or the limited range in angular disparity. To improve practical significance in future research it would help to increase the sample size, the number of items, and the range of disparities.

The underlying mental process of imagery when using mental rotation tests seems to be analog in nature, however, the propositional theory should not be completely disregarded. While evidence provided by this study further supports the analog theory, a complete understanding of mental images has not been accounted for by analog characteristics and, as shown in the literature review, what remains to be explained may be better accounted for by propositional characteristics.

While tests of mental rotation are most often used for theoretical research, similar measures are sometimes used in selection decisions (e.g., the Dental Entrance Exam) (New Rudman's, 1995). If the evidence regarding the practice effects of mental rotation tests generalizes to similar measures, it would be good advice to suggest practice before taking the actual test. Also, the more similar the practice test is with the actual test the greater the practice effect should be (Longstreth
& Alcorn, 1990). It would also be good advice for decision makers that use such tests to take the presence of practice effects into consideration. This is not to imply that tests of spatial ability should not be used. In fact, there is "considerable evidence that spatial ability items are more highly g-loaded than any other kind of item" (Longstreth & Alcorn, 1990, p. 2). Other tests of spatial ability have been shown to have high correlations with such things as success in dental school and piloting airplanes (Anastasi, 1988).

The study of mental imagery seems to be changing hands from cognitive psychologists to neuropsychologists. It was projected that new studies involving mental imagery and the brain may fill a gap that was present with behavioral research. This study contributes to the understanding of mental imagery, specifically with respect to mental rotation, and should contribute to any future research involved with mental rotation tasks, including neuropsychological studies. Though the debate seems to have been resolved, cognitive psychologists will continue to develop a better understanding of mental imagery using such behavioral research strategies as the reaction time paradigm or mental rotation tests. Neuropsychologists will continue to use new methods of studying the brain and creative research strategies using individuals with brain damage. By
combining these research methods, a more complete understanding of mental imagery will be established.
References


43


Table 1

Average Reaction Times and Accuracy Rates

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Figure 1

Item #2 of the Pretest-Posttest. This is one of the problems given as part of the pretest-posttest. The image on the right is 60 degrees from the original image and the image on the left is 100 degrees from the original. The angular disparity for the item is 40 degrees.
The five images. These are examples of each of the five images used in this study. They are rotated from their original position 10, 10, 60, 20 and 50 degrees, respectively. Each image is positive and cannot be "transformed into itself" (Shepard, 1982, p. 20).
Examples of feedback. Figure A is an example of what the subject saw after responding to an item on the pretest-posttest. Figures B and C are examples of what the practice groups saw after responding to an item on a practice test. The non-animated practice group would see Figure B for 3 seconds followed by Figure C. The animated group would see Figure B for 3 seconds; then the image on the right would rotate until it had the same disparity as the image on the left, pause for two seconds, then rotate back; this would be followed by Figure C.
Appendix A

Mental Rotation Test. This is a paper/pencil version of Shepard's (1971) mental rotation test.

This is a test of your ability to look at a drawing of a given object and find the same object within a set of dissimilar objects. The only difference between the original object and the chosen object will be that they are presented at different angles. An illustration of this principle is given below, where the same single object is given in five different positions. Look at each of them to satisfy yourself that they are only presented at different angles from one another.

Below are two drawings of new objects. They cannot be made to match the above five drawings. Please note that you may not turn over the objects. Satisfy yourself that they are different from the above.

Now let's do some sample problems. For each problem there is a primary object on the far left. You are to determine which two of four objects to the right are the same object given on the far left. In each problem always two of the four drawings are the same object as the one on the left. You are to put Xs in the boxes below the correct ones, and leave the incorrect ones blank. The first sample problem is done for you.

Go to the next page
Do the rest of the sample problems yourself. Which two drawings of the four on the right show the same object as the one on the left? There are always two and only two correct answers for each problem. Put an X under the two correct drawings.

Answers: (1) first and second drawings are correct
(2) first and third drawings are correct
(3) second and third drawings are correct

This test has two parts. You will have 3 minutes for each of the two parts. Each part has two pages. When you have finished Part I, STOP. Please do not go one to Part 2 until you are asked to do so. Remember: There are always two and only two correct answers for each item.

Work as quickly as you can without sacrificing accuracy. Your score on this test will reflect both the correct and incorrect responses. Therefore, it will not be to your advantage to guess unless you have some idea which choice is correct.
DO NOT TURN THIS PAGE UNTIL ASKED TO DO SO.  STOP
ANSWER KEY FOR MENTAL ROTATIONS TEST

The test contains 20 items in four pages of 5 items each. Each item is composed of a criterion figure, two correct alternatives and two distractors. The criterion figure (C) in each item is one of the four different structures used by Shepard and Metzler (1971). Correct alternatives are always identical to the criterion in structure, but are shown in a rotated position. For half the items, the distractors are rotated mirror-images of the criterion, while distractors in the other items are rotated images of one or two of the other structures.

Correct responses for the examples and 20 test items are presented in Table 1, which also gives three additional pieces of information for each choice. The letters A through E indicate which of the five Shepard and Metzler figures was used. The letters "p" and "n" indicate whether the image is a positive one or a negative mirror-image. Finally, the numbers 1 through 17 index the amount of rotation of the image from a standard position.

The recommended way of scoring is to give 2 credits for a line with both choices correct, none if one choice is correct but the other one incorrect, or if both are incorrect. If only one design was chosen and it is correct, 1 point is given. This system eliminates the need to apply a correction for guessing.

The time limit is 10 minutes or 5 minutes for each half, if a test-retest correlation is wanted. For college students 6 minutes (or 3 minutes for each half) is recommended. Not everyone will complete within these time limits, but the great majority will.
(underlined choices are the correct ones)

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### Centiles of Mental Rotation Test Scores (continued)

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Appendix B Informed Consent Form

Research Title: Mental Rotation Tests

Researcher: Russell W. Smith, master's degree student in the department of counseling & educational psychology

Contacts: for questions about this research

Russell W. Smith 895-3839 or Department of counseling & ed. psych. 895-3253

for questions about the rights of research subjects

Office of Sponsored Programs 895-1357

The research you are being asked to participate in consists of engaging in a series of computerized tests and practice sessions that are designed to measure mental rotation ability. You are free to withdraw from the research at any time without jeopardy to current or future relationships with the researcher, the department of counseling and educational psychology, the College of Education, and the University. There are no known risks involved in any part of this research and your anonymity will be protected. Subject codes will be used throughout and your name will not appear on any response records.

Your signature below indicates that you have decided to volunteer as a research subject and that you have read the information provided above.

(date) (signature of participant)

(date) (signature of investigator)

Please also include your phone #: __________________________.

61
Appendix C

Pretest-Posttest

Mental Rotation Test

This is a test of your ability to look at two drawings and determine if they are the same or different. The only difference between some of the drawings is that they are presented at different angles. An illustration of one pair is shown below, where the same object is presented at two different positions. Each of these drawings is exactly the same, except that they are only presented at different angles from one another. Press "Return" when you are ready to go on.

Directions:

This is a memory task. Each pair will consist of a pair of drawings. You are to determine if these two drawings are the same or different. Again, the only difference between some of the pairs will be that they are presented at different angles. If you think the objects are the same press the letter "S". If you think the objects are different press the letter "D".

Please work as quickly as you can with the least amount of errors. Each pair is drawn from the same angle as seen from the perspective you require. You are not being tested between drawings. After your response, the computer will prompt you to go on to the next question. Please return for a sample problem.

Sample problem:
This is a sample problem. The images are the same, as you would expect. Press "S", "R", "U", "P", when you are ready to begin the test.

Sample problem:
This is a sample problem. The images are the same, as you would expect. Press "S", "R", "U", "P", when you are ready to begin the test.
Appendix D

Practice Test 1

This is a test of your ability to look at two drawings and determine if they are the same or different. The only difference between similar objects is that they are presented at different angles. An example of this principle is given below: when the same single object is shown in the different positions, look at each of them to see if there are any differences in the arrangement of parts one another. Please "Start" when you are ready to go on.

Below are two drawings of two objects. They can not be made to match. Please note that no matter which way they are placed, they cannot be made to match. The question on the graph is not that high, please consider every cube to be equal in size and every image to consist of one of these cubes. Please "Start" when you are ready to go on.

Each pair will consist of a pair of objects. You are to determine if those pairs are the same or different. Again, the only difference between objects that are the same will be that they are presented at different angles. If you think the objects are the same press the letter "S". If you think the objects are different press the letter "D".

Please work as quickly so you can with the least amount of errors. Each item is timed from the time the image appears until you respond. You are left with several hundred questions. After your response the computer will prompt you to go on to the next question. Please return for a sample problem.

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Appendix D

Practice Test 2

Material Relations Test

There is a test of your ability to look at two drawings and determine if they are the same or different. This is different from matching exactly the same drawings. In the exercise a pair of drawings is shown that are the same. The only difference is that the position of the objects is slightly altered. Look at each of them to make certain that they are not presented at different angles from one another. Please "Report" when you are ready to go on.

Directions:

This is a memory span test. Each pair will consist of a pair of drawings. You are to determine if these pairs are the same or different. The only difference will be that they are presented at different angles. If you think the objects are the same press the letter "S". If you think the objects are different press the letter "D".

Please work as quickly as you can with the least amount of errors. You are given a break from the time the images appear until you respond. You are not using mental rotation. After your response, the images will disappear and you will go on to the next question. Please return for a further test.

Below are two drawings of same cube. They can not be made to match. Please note that no matter which way they are disposed, they cannot be made to match. To pass the question, you must put them in a position that makes them equal in size and appearance. Please "Report" when you are ready to go on.

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Appendix D

Mental Rotation Test

Practice Test 3

Examples:

The task is to determine whether two drawings are the same or different. The only difference between objects that are the same will be that they are presented at different angles. If you think the objects are the same, press the letter "S". If you think the objects are different press the letter "D".

Example problem:

This is a sample problem. The images are the same, so you would press "S", and "D" when you are ready to begin the test.

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Appendix D

Mental Rotation Test

This is a test of your ability to look at two drawings and determine if they are the same or different. The only difference between similar pairs is the relative positions of the objects in the diagrams. Each pair of drawings is a good example of the principle of a great letter, where the same single object is presented in different positions. Look at each pair of drawings and ask yourself, "Are they only presented at different angles from one another?

Practice Test 4

There are two drawings of each object. They cannot be made to match. Please note that no matter which way they are angled, they cannot be made to match. The instruction on the graphics is not that helpful. Please consider every circle to be equal in size and every circle to consist of a pair of cubes. Press 'Next' when you are ready to go on.

Directions:
The test is a twenty item test. Each item will consist of a pair of drawings. You are to determine if these items are the same or different. Again, the only difference between objects that are the same is that they are presented at different angles. If you think the objects are different, press the letter "D". If you think the objects are different press the letter "D1".

Please work on each test so you can complete the test within the allotted amount of errors. Each item is timed for you and the images appear until you respond. You are not being tested between questions. After your response, the computer will prompt you to go on to the next question.

Press return for a sample problem.

Sample problem:

This is a sample problem. The images are the same, so you would press "D". Press "Next" when you are ready to have the test.
"Computer Study" Debriefing

The primary purpose of the study in which you participated was to test the practice effects involved with mental rotation tests. A secondary goal was to contribute to the understanding the implications practice effects have on such tests and the underlying cognitive process involved. Mental rotation tests have proven both sensitive and versatile in revealing basic cognitive and perceptual mechanisms since the early 70's. Recent researchers have used these tests to study "the role of imagery in human cognition, the nature of mental representation and mental process, and the appropriateness of models based on analogy with the digital computer" (Corballis, 174-175).

You were given a pre-test and a post-test based on the Shepard Metzler Mental Rotation Test. You were also randomly assigned to one of three groups: practice using sample problems, practice using sample problems with animation, or a control group (Number Munchers). I will be looking for similarities and differences between these groups to see if there are significant practice effects.

If you are interested in seeing your results for the pre and post-tests you may make an appointment with Russell at (895-3839) after March 20 but before the semester ends. If you are interested in obtaining a copy of the results of the study, you may leave your name and address at the same number.

Reference:

DATE: January 23, 1995

TO: Russell W. Smith (CEP)
M/S 3003

FROM: Dr. William E. Schulze, Director
Office of Sponsored Programs (X1357)

RE: Status of Human Subject Protocol Entitled: "Practice Effects and Their Implications on a Mental Rotation Test

OSP #301s0196-126e

The protocol for the project referenced above has been reviewed by the Office of Sponsored Programs, and it has been determined that it meets the criteria for exemption from full review by the UNLV human subjects Institutional Review Board. Except for any required conditions or modifications noted below, this protocol is approved for a period of one year from the date of this notification, and work on the project may proceed.

Should the use of human subjects described in this protocol continue beyond a year from the date of this notification, it will be necessary to request an extension.

cc: K. Crehan (CEP-3003)
OSP File