Table of Contents
Volume 3 • 1997 - 2003

Running head: COLOR EFFECTS

The Effects of the Color Red on Taste Perception

Keisha Denise Riley

Concord College

The Effects of the Color Red on Taste Perception

When you think about your favorite foods and beverages, what are the qualities in these foods that make them enjoyable for you? It would seem obvious that the taste would be the deciding factor. However, the actual taste of a food or drink is not necessarily all that is interpreted by the human brain. Information from other sensory systems, such as the sense of smell or vision, can actually influence your perception of taste more than the taste buds on your tongue (Birren, 1945, 1961; Myers, 1999).

Several factors have been demonstrated to influence the evaluation of the taste quality of a food or drink. The odor, temperature, physical state, appearance, and color of a food are all very important when it comes to perceiving how something tastes (Alley & Alley, 1998; Pavey, 1980). Furthermore, based on these factors, people may even have unexplainable mental expectations about how a food should taste, thus influencing their perception (O'Donnell, 1997).

The interaction of these factors on taste perception has raised many interesting questions. A great deal of research has been conducted by both psychologists and food technologists to investigate these variables, with the greatest amount of research focusing on the effects of color on taste perception. The effect of color was a hot topic from the 1930's through the 1970's, and many books and articles were written on the subject. Many renowned psychologists, such as Freud, Eyesenck, and Rorschach, have studied the effects of color on the mind. Several prominent food scientists, such as O'Donnell and Hutchings, have also conducted a number of influential studies in this field.

As a result of this intense period of study, several theories were proposed to try to explain why color plays such a significant role in the formation of taste perception. One theory suggested that being observant of the color of the foods that we eat might have developed as a result of evolution (Hutchings, 1999). It has been suggested that this color-awareness may have arisen because it was imperative for primitive man to know what to eat and what not to eat. Meats that were rotted or green would be dangerous to consume, as would certain types of poisonous plants such as the vividly red snake berry (Hutchings, 1999).

Other researchers have theorized that color expectations about foods are learned. In other words, humans can learn conditioned responses to the color of food just like any other learned responses (Pavey, 1980). However, it should be noted that these two theories are not incompatible. The learning theory does not discount the evolutionary theory; it could be suggested that humans have evolved to learn to adapt to the color aspects of food. In addition, a wealth of research exists to support both theories (see Sharpe, 1974). Regardless of the explanation for why, it seems that humans have somehow acquired strong expectations for tastes based simply on food colors (Francis, 1999).

Although there is no agreed-upon theory to explain why humans have color-flavor expectations, it is accepted that the addition, or enhancement, of food coloring is a worthwhile endeavor. Colorants are regularly added to foods in order to compensate for the loss of color due to processing, to make sure a food is an "appropriate" color, and to serve as an indication of quality (Hutchings, 1999). Although the "why" is still unclear, past research has demonstrated that color can influence taste perception (Hutchings, 1999; O'Donnell 1997, 1998). For example, the common association of the color orange with a citrus taste can lead to the expectation that an orange food or drink is going to be a bit sour or tangy. This expectation is so strong that in a study by Pavey (1980), children and adults were given a clear, lime flavored drink colored orange and the participants actually believed that the flavor of the drink that they were tasting was orange! Other color-flavor associations have been demonstrated with other colors as well. For instance, the color blue can lead to an expectation of a berry taste, and brown drinks are automatically associated with cola, coffee, tea, or cocoa (Pavey, 1980).

Chan and Martinelli (1997) have also noted that color has a tremendous impact on flavor attributes after conducting an experiment that varied the color intensities of both chicken broth and chocolate pudding. They found that people tend to think that any colored solution will taste better than any clear solution, even if the colored and clear solutions are identical in flavor.

A significant amount of research on the effects of food coloring has been devoted to the study of the influence of the color red. This color seems to have more effects on taste perceptions than any other color studied (Birren, 1945). Past research has shown that since the color red is commonly considered the most "appealing" color for foods, red foods and drinks are expected to be highly flavored and/or sweeter than other foods or drinks. This expectation might occur because red is generally associated with many tasty foods, such as apples, cherries, strawberries, and even a rare cut of beef (Birren, 1945).

Since the addition of red coloring to foods has been found to enhance the expected taste quality of food more than any other color, food technologists are constantly striving to find methods to create a red colorant that is deeper and more vivid. Materials such as the skins of purple Concord grapes, beets, and other deeply red substances have been added to many foods in order to obtain a red coloring that will imply a premium taste (Meggos, 1994). Support for the use of deep red coloring can be seen in research presented by Francis (1999). This study employed identical sucrose solutions in variations of the color red and other colors, such as orange and green. It was demonstrated that the sucrose solutions that were colored a deep red were perceived to be sweeter than solutions of other colors or clear solutions containing the same amount of sugar.

The current research focuses on the effects that the color red may have on children's perceptions of flavor. Schoolchildren have been used frequently in similar research in the field for several reasons. One reason is that since children have not had as many learning experiences as adults (Sharpe, 1974), they would have relatively limited color expectations, making them better subjects in color psychology and food science studies compared to adults. A second reason is that color has been shown to consistently affect children's moods, emotional development, play and food choices (Pavey, 1980; Sharpe, 1974). Lastly, children have been found to be highly color-dominant. Color dominance refers to a person's tendency to make decisions based simply on the factor of color alone. On the other hand, adults have been found to be predominantly form-dominant. Adults will attend primarily to an object's form and have an inclination to make decisions based on this stimulus dimension before anything else, especially color. For example, a study by Riley (1998) reported that adults rarely responded to the experimental drinks' color dimension but responded to its flavor. Therefore, it is expected that children will be more highly responsive to a food's color in forming taste perceptions than an adult.

In addition to the previously mentioned reasons, studies in color psychology have also shown that the color red is a key color in youth, and that nearly all children throughout the world are invariably attracted to it (Birren, 1965). Sharpe (1974) and Birren (1945, 1961) have found that this color is the most preferred color during the early childhood years. It is usually the first paint or crayon to be used up, and the preferred color of their foods and drinks. Thus, the color is purposefully used in marketing strategies to appeal to children (Pavey, 1980).

Despite all of the research, experiments designed to test the idea that the color red automatically enhances or changes taste perception have yielded mixed results. Although the concept of the color red's significance has been supported consistently in food science, its importance has not been consistently demonstrated in psychological experiments. Several studies have shown that red coloring can be a major contributing factor to taste, especially with children (O'Donnell, 1998). However, others have shown that the addition of the color red, or any other supplemental color, usually does not demonstrate significant results (Alley & Alley, 1998). Furthermore, some research suggests that red coloring does reliably alter solid-food taste perceptions (Chan & Martinelli, 1997) but only infrequently alters perceptions of liquid foods (Alley & Alley, 1998). The mixed findings may be partly due to differences in sample sizes and experimenter biases. It may also be that since preferences are subjective experiences, they may be difficult to study. Since studies on taste perception are based on a person's subjective opinion of taste, it may just be that there is no objective "reality" out there that can be reliably tested.

Conducting further research on the effects of the color red on taste perception could generate results that might lead to more conclusive findings and clarify the confusion regarding the effects of coloring on taste perception. According to Hutchings (1999), three conditions must be met in order for color to influence taste perception. The red color must be appealing, it must be appropriate for the food to be consumed, and it must indicate a pleasant taste quality of the food. Each of these conditions was addressed in the current experiment. Exact measurements of food coloring ensured an appealing and vivid coloring. The red coloring was appropriate for the liquid samples, and the vivid color indicated a pleasant taste quality to the subjects and the experimenter. Thus, a significant color-flavor preference should be demonstrated. The current experiment has two purposes, to determine if these conditions are necessary to influence a child's taste perceptions and to determine if children are truly color-dominant when making their preferences. The experiment was conducted with red and colorless flavored-water samples of both sweet and sour tastes on children four to eight years of age. The subjects consumed all samples under the guise of a taste test and then indicated their taste preferences to the experimenter. The hypothesis was that the children would significantly prefer a red colored liquid, regardless of whether it was sweet or sour, to a clear liquid of the exact same flavor.

Method

Participants

Seventy-four students enrolled at Athens Elementary School participated in the experiment. The sample was composed of 34 females and 40 males in kindergarten to third grade. The students' ages ranged from five to nine years with a mean age of 6.42

years. Of the sample, 73 of the participants were Caucasian, and one was African-American. Only children with permission from their parents or guardians were allowed to participate.

Materials

Several items were used to conduct the experiment. There were 12 bottles of Sam's Choice ™ peach flavored carbonated water, two bottles of McCormick's ™ brand red food coloring, two bottles of McCormick's™ brand pure lemon extract, two bottles of distilled water, and 300 four-ounce styrofoam cups. The peach flavor was chosen for the sweet samples because it is not typically associated with the color red. Thus, use of this color would control for any possible red-color associations. Lemon extract was chosen in order to create the sour-tasting samples. McCormick's™ brand food coloring was used because, according to its makers, it does not affect the taste of the substances it is used on. A medicine dropper was used to distribute the red food coloring into the appropriate samples and a measuring cup was used to distribute the lemon extract into the appropriate samples.

Procedure

The current experiment was composed of control and experimental conditions for both the sweet and sour phases of the experiment. The control condition consisted of colorless liquid samples that received no red food coloring. The experimental condition consisted of clear liquid samples that received a uniform amount of red food coloring. All participants were exposed to each of the four conditions.

Before the experiment, 15 ml of red food coloring were added to six of the peach flavored bottles of water. To maintain color consistency in all samples, 60 ml of red food coloring were added to one of the gallons of distilled water. In order to create the sour tasting samples, 1/8 cup of lemon extract was added to both gallons of distilled water. This amount did not cloud the distilled water but was enough to make the water taste sour.

To maintain the temperature of the liquids, all samples were refrigerated for two days after the lemon and coloring were added. This was done so that the food coloring and lemon extract would remain consistent in all samples.

On the day of the experiment, a table was set up on the main floor of the elementary school. Cups were filled with one ounce of liquid and placed on the table before testing the first group of students in order to expedite the testing process. An assistant to the experimenter placed additional samples onto the table as the supply depleted.

Two other assistants escorted each class to one end of the hallway opposite of the testing table. The children were then sent one by one to the testing table. Each child was tested individually to avoid the possible influence of other children's opinions on their preference. The children were first asked if they would like to taste some juices. Then the experimenter handed the child either a red or a clear sample of either the sweet or sour liquids for the child to drink, dependent upon counterbalancing techniques. Again, all children participated in all conditions of the experiment. The participants stated their preference between the red and clear drink immediately after drinking the sweet drinks and again immediately after the drinking the sour drinks. Data gathered from the experiment on the child's age, gender, grade in school, and their preferences were recorded on data sheets (see Appendix A). The experimenter then visited all classrooms to thank the participants for their time, debrief them in regards to the true purpose of the study, and answer any questions.

Results

The number of children who preferred the red or clear drink in each of the two taste conditions was analyzed using chi-squared tests of independence. Thirty-three students reported a red drink preference while 40 students reported a clear drink preference in the sweet condition of the experiment. One student reported both drinks tasted the same. Thirty-nine students reported a red drink preference while 28 students reported a clear drink preference in the sour condition. Seven students reported that the sour drinks tasted the same. The overall main effect of color preference was not statistically significant, $X^2(2) = 0.5404$, $p > 0.05$. However, the color by flavor interaction effect was statistically significant, $X^2(2) = 6.5293$, $p < 0.05$.

Insert Figures 1 and 2 About Here

There were also no significant effects of grade in school, gender of child, or order of drinks, all X^2s $(2) \leq 3.39$, all p's > 0.05.

Insert Figures 3a, 3b, 4, and 5 About Here

Discussion

The experimental hypothesis was partially supported. It was hypothesized that more children would prefer the red drinks, regardless of whether they were sour or sweet. That is, a significant difference should have been found between the number of overall red-liquid preferences and clear-liquid preferences and in both the sweet and sour conditions of the experiment as well. This was not the case. There were actually more clear-liquid preferences in the sweet condition, and several reports of the drinks tasting the same (see Figure 1). However, there was a significant effect in regards to color-by-flavor interaction (see Figure 2). This effect was demonstrated by the children's preference for the red colored drink when the taste was sour but preferring the clear drink when the taste was sweet. The significant effect found here is valuable to the current research. It demonstrates that color does have an influential role in taste perception, however its influence is contingent upon the flavor of the sample.

These findings were not expected using the sample of five-to-nine year olds, as children are supposedly more likely to respond to the color red in forming their taste preferences, regardless of flavor (Sharpe, 1974). Likewise, Chan and Martinelli (1997) reported that people tend to think any colored solution will have a more pleasant taste quality than a clear one, regardless of the solution's flavor. However, this was only true in the current experiment for the children's preferences in the sour condition. The outcome of the current research suggests that the color red alone does not simply influence taste perception, but that it interacts with the flavor of the drink in producing an effect. These results are rather interesting and they justify conducting further research on the topic.

The results of the current experiment also do not demonstrate that children are primarily color-dominant in making food choices (Sharpe, 1974). In other words, the age of the child did not appear to be a significant factor in determining the children's taste perceptions (see Figure 3a and 3b). According to research by both Sharpe (1974) and Birren (1945), children should be more responsive than adults to the colorings of foods.

The results of the current study do not appear to support this hypothesis as the color only showed significant effects when interacting with the flavor of the drink.

The fact that being a child did not influence taste preference decisions also appears to be in conflict with the theories that assume that children have limited color-flavor expectations compared to those of adults (Sharpe, 1974). Perhaps the children in this study were equally as sophisticated as adults in the manner that they did not blindly choose one drink over another based simply on its color. There is also the possibility that no age effects were demonstrated because the age range was too narrow. It may be necessary to compare the current study to similar research using other age ranges. Perhaps utilizing a wider age range or conducting age-comparative studies may yield significant age effects. Further research pertaining to age effects needs to be conducted in the future to address these possibilities.

A child's gender was also not an influential factor in forming taste perceptions in the current research (see Figure 4). In addition, the order in which the drinks were received did not appear to affect taste perception (see Figure 5).

It is assumed by nearly all food technologists that manipulating the color and appearance of foods help form consumers' opinions (Pavey, 1980; Hutchings, 1999). The results of the current study question this opinion, however, because color only seemed to have an effect in certain circumstances. Food technologists assume that the addition of red food coloring will undeniably make a food item more pleasurable to consume (Francis, 1999; Meggos, 1994). This appears to be highly dependent upon the flavor of the food. As stated earlier, Alley and Alley (1998) found that although the addition of food coloring may alter solid-food taste perceptions, it does not reliably alter the taste perceptions of liquid foods. Since liquid samples were chosen for the current study, it is possible that using coloring of any type would not have yielded significant results alone. There may also be the possibility that red food coloring will only enhance taste perception when the food to be consumed is sour or unpleasant in taste. In other words, if a food is pleasant in taste, the coloring of that food does not really make the taste perception of that food any better. But if the food is unpleasant, coloring can enhance the negative perception of taste into a more tolerable one. This could be why many medications and unpleasant-tasting daily use products such as mouthwash are colored red.

The outcome of this study also warrants further research that will investigate in greater detail whether color's role in taste perception is inborn or learned. Since the current study did not approach these aspects, it is unclear whether the existing biological or environmental theories play a role in forming color-based taste perceptions. A replication of the current study that takes these aspects into consideration may help explain the surprising findings.

There were a few concerns that arose during the current experiment. Both carbonated and uncarbonated samples were used in the experiment. The differences in carbonation may have altered the children's taste perception in some way, thereby affecting the results of the experiment. In addition, several children seemed to be aware of the true purpose of the experiment. This may have been due to interactions with their parents or their peers. Other students seemed to try to either intentionally please or displease the experimenter in making their preference decisions. Conducting a replication of this experiment using a larger, more diverse sample and taking precautions to guard against these issues will hopefully lead to clearer results.

Although the results of the current research were somewhat unexpected, they are not entirely inconsistent with past research. A preference for the red drink was demonstrated, but only when the drink was sour. These results do add to the body of information that demonstrates that the color red can have an impact on taste perception. Considering the color-by-flavor interaction and the control procedures employed, the current study supports the notion that the color of a food or beverage can play a significant role in forming taste perceptions, but the flavor of the food or beverage must also be taken into consideration. In the future, other carefully conducted studies may aid in the development of a simple, testable theory that describes exactly how and under what circumstances color affects taste perception.

References

Alley, R.L. & Alley, T.R. (1998). The influence of physical state and color on perceived sweetness. The Journal of Psychology, 132 (5), 561-569.

Birren, F. (1945). Selling with Color. (1st edition). New York: McGraw-Hill Book Company Inc.

Birren, F. (1961). Color Psychology and Color Therapy. New Hyde Park, New York: University Books.

Chan, M.M. & Martinelli, C.K. (1997). The effect of color on perceived flavor intensity and acceptance of foods by young adults and elderly adults. Journal of the American Dietetic Association, 97 (6), 657-660.

Francis, F.J. (1999). Colorants. St. Paul, Minnesota: Eagan Press.

Hutchings, J.B. (1999). Food Color and Appearance. (2nd edition). Gaithersburg, Maryland: Aspen Publishers.

Meggos, H.N. (1994). Effective utilization of food colors. Food Technology, 48 (1), 112.

Myers, D.G. (1999). Exploring Psychology. (4th edition). New York: Worth Publishers.

O'Donnell, C.D. (1997). Colorful experiences. Prepared Foods, 166 (7), 32-35.

O'Donnell, C.D. (1998). Colorings: Key to food quality. Prepared Foods, 167 (5), 113-116.

Pavey, D. (1980). Color. Los Angeles: The Knapp Press.

Riley, K.D. (1998). Color effects on taste perception. Unpublished manuscript. Concord College, Athens, West Virginia.

Sharpe, D. (1974). The Psychology of Color and Design. Chicago: Nelson-Hall Company.

Figure Captions

Figure 1. Bar graph showing the number of children in the study and their overall drink preferences. The graph displays nearly a half-and-half split, and there was no statistically significant effect.

Figure 2. Bar graph representing the children's drink preferences, according to the actual drink category. Here, a statistically significant color by flavor effect was demonstrated.

Figure 3a. Bar graph representing the children's sweet drink preferences, according to the children's grade in school.

Figure 3b. Bar graph representing the children's sour drink preferences, according to the children's grade in school.

Figure 4. Bar graph representing the children's drink preferences, according to the child's gender.

Figure 5. Bar graph representing the children's drink preference, according to the sequence of the drinks they received.

Figure 1. Overall Drink Preferences

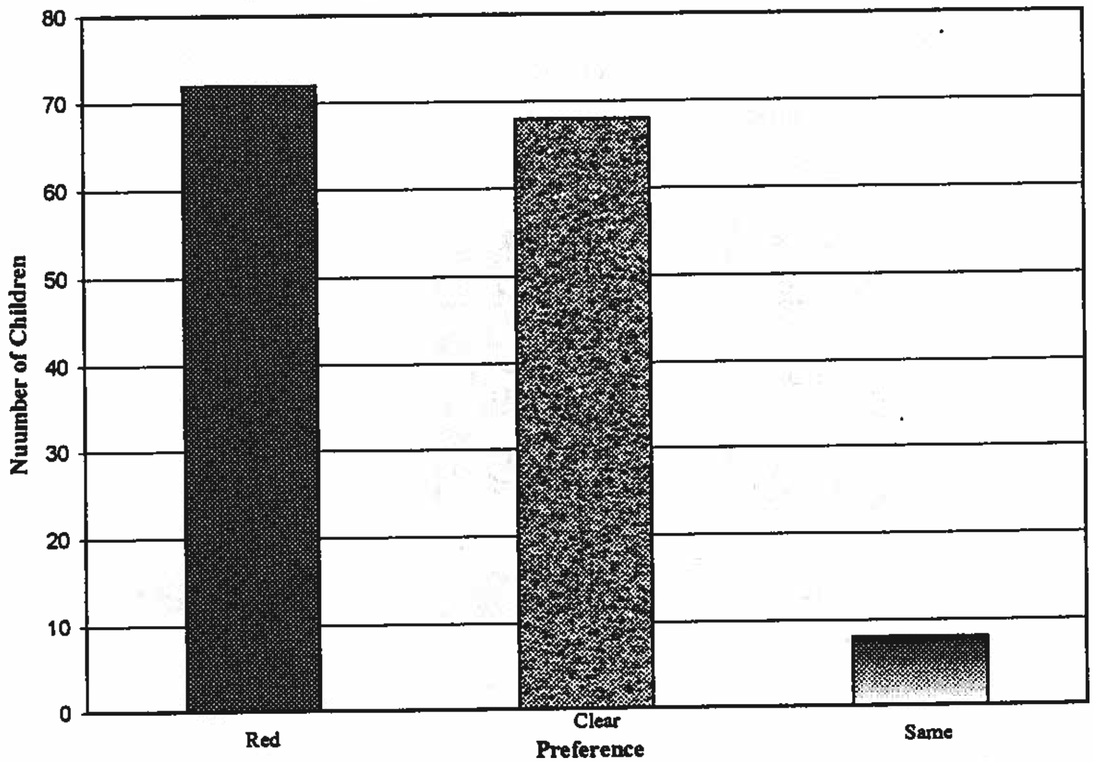


Figure 2. Drink Preferences According to Category

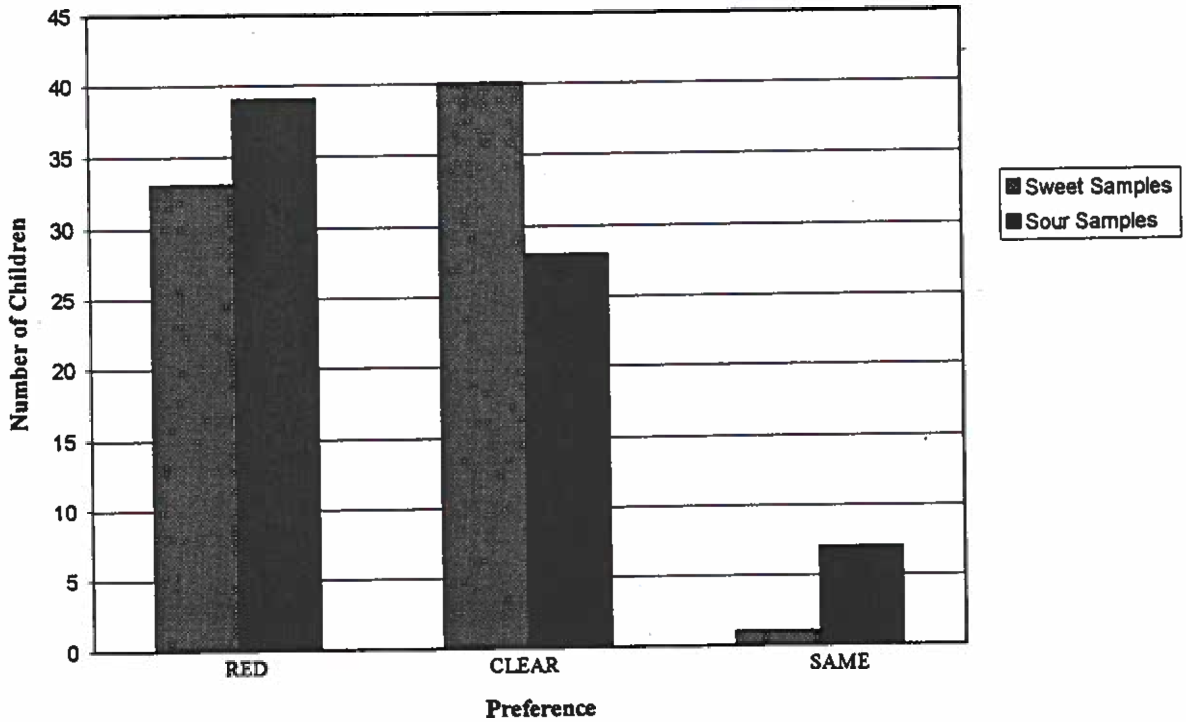


Figure 3(A). Drink Preferences According to Grade in School: Sweet Samples

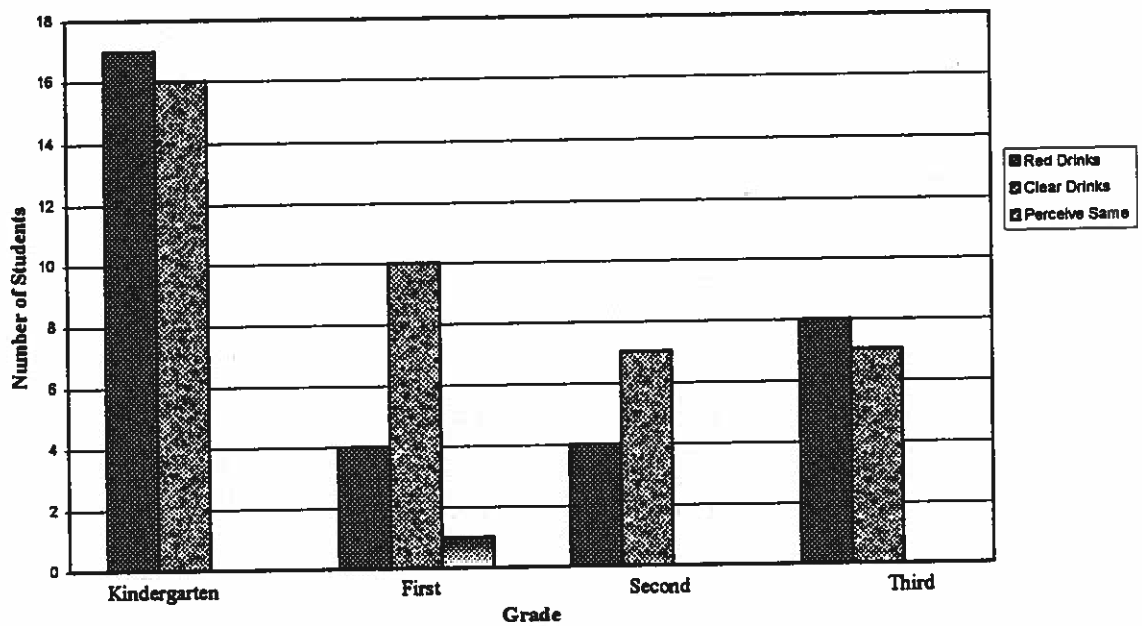


Figure 3(B). Drink Preferences According to Grade in School: Sour Samples

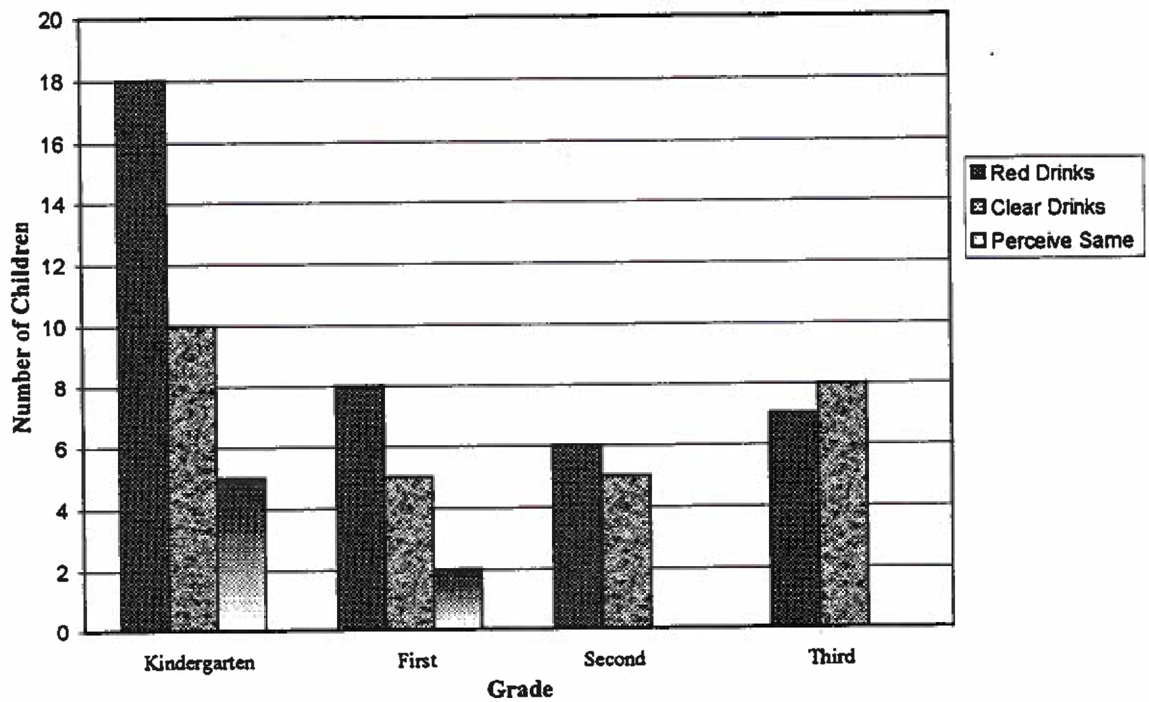


Figure 4. Drink Preferences According to Gender

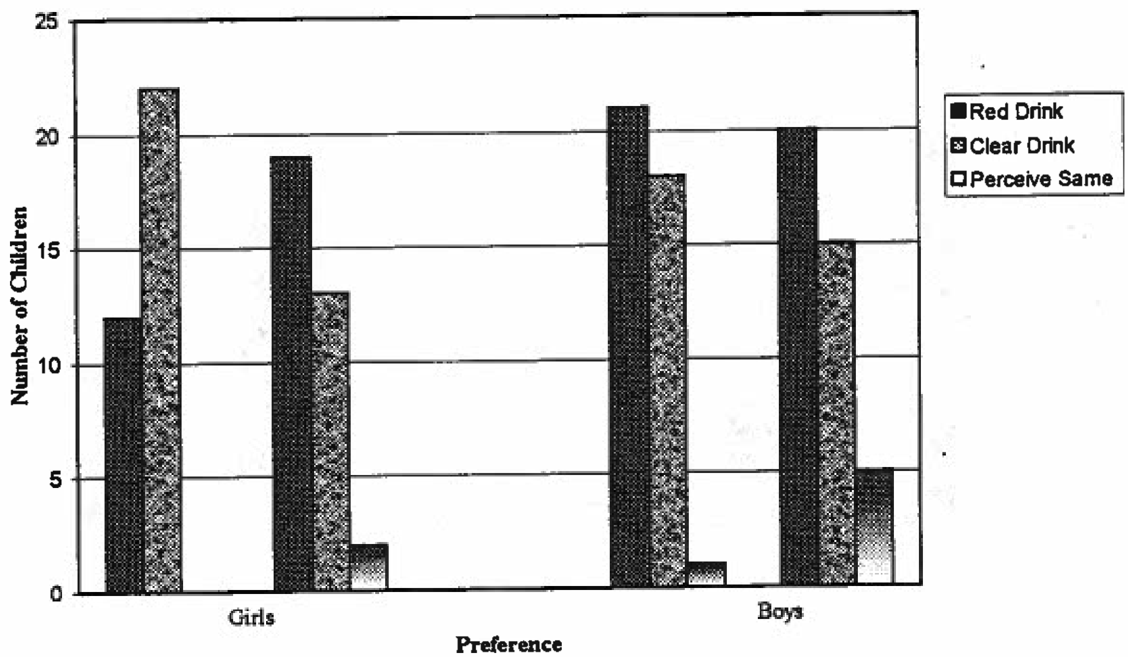
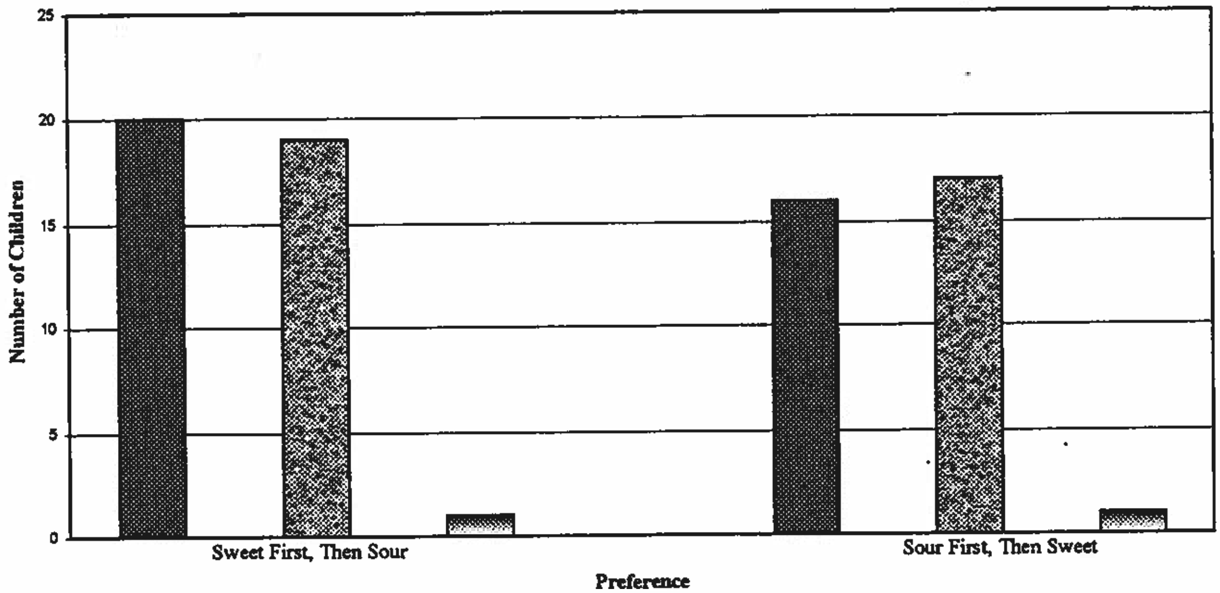


Figure 5. Drink Preferences According to Sequence



Appendix A

Preference Data Sheets.

Keisha Denise Riley
Mentor: Dr. Rodney Klein
Concord College, Athens, West Virginia
Title: "Effects of the Color Red on Taste Perception"
Department: Psychology

ABSTRACT: Extensive research concerning food technology and psychology studies on food coloring yielded the hypothesis that the color of a liquid solution can impact the taste perceptions of children aged four to nine. Taste perceptions are defined as mental ideas of flavor that influence a person's opinions about how a certain food tastes. Much of the past research on the topic focused on the effects of the color red on taste perception. In addition, findings derived from past research on the topic have been invariably mixed and inconclusive. The current research was conducted in an attempt to support the hypothesis in a consistent manner.

Using a sample of elementary students and red food coloring, experiments were conducted to test the hypothesis. Sweet-tasting and sour-tasting samples were manipulated with red food coloring to test color-taste preferences. Chi-squared statistical analyses were conducted in order to determine statistical significance. The overall main effect of color preference was not statistically significant, $X^2(2) = 0.5404$, $p > 0.05$. For color by flavor interactions, there was a statistically significant effect, $X^2(2) = 6.5293$, $p < 0.05$. Surprisingly, red color preferences were only noticeably higher in sour condition of the experiment. There were not any statistically significant effects regarding the child's grade in school, gender of child, or order of drinks, all X^2's (2) ≤ 3.39, all p's > 0.05.

Although the results of the current study were somewhat unexpected, they are not entirely inconsistent with past research. A preference for the red drink was demonstrated, but only when the drink was sour tasting. These results do add to the body of research that demonstrates that the color red can have an impact on taste perception. Considering the color-by-flavor interaction and the control procedures employed, the current study supports the notion that the color of a food or beverage can play a significant role in forming taste perceptions, but the flavor must also be taken into consideration. In the future, other carefully conducted studies may aid in the development of a simple, testable theory that describes exactly how and under what circumstances color effects taste perception.

References

Alley, R.L. & Alley, T.R. (1998). The influence of physical state and color on perceived sweetness. The Journal of Psychology, 132 (5), 561-569.

Birren, F. (1945). Selling with Color. (1st edition). New York: McGraw-Hill Book Company Inc.

Birren, F. (1961). Color Psychology and Color Therapy. New Hyde Park, New York: University Books.

Chan, M.M. & Martinelli, C.K. (1997). The effect of color on perceived flavor intensity and acceptance of foods by young adults and elderly adults. Journal of the American Dietetic Association, 97 (6), 657-660.

Francis, F.J. (1999). Colorants. St. Paul, Minnesota: Eagan Press.

Hutchings, J.B. (1999). Food Color and Appearance. (2nd edition). Gaithersburg, Maryland: Aspen Publishers.

Meggos, H.N. (1994). Effective utilization of food colors. Food Technology, 48 (1), 112.

Myers, D.G. (1999). Exploring Psychology. (4th edition). New York: Worth Publishers.

O'Donnell, C.D. (1997). Colorful experiences. Prepared Foods, 166 (7), 32-35.

O'Donnell, C.D. (1998). Colorings: Key to food quality. Prepared Foods, 167 (5), 113-116.

Pavey, D. (1980). Color. Los Angeles: The Knapp Press.

Riley, K.D. (1998). Color effects on taste perception. Unpublished manuscript. Concord College, Athens, West Virginia.

Sharpe, D. (1974). The Psychology of Color and Design. Chicago: Nelson-Hall Company.

Keisha Denise Riley is graduating as valedictorian from Concord College in May 2001. She is planning to study Clinical Psychology at Marshall University in the fall.

Stimulus Equivalence and Its Relation to Verbal Behavior

Rebecca G. Ryan

Concord College

Stimulus Equivalence and its Relation to Verbal Behavior

Language, or verbal behavior, and its interactions with other behaviors are now at the center of a great deal of research. Behavior analysts are now dealing with behavioral complexities such as word meaning, semantic relations, and symbolic behavior. (Horne & Lowe, 1996). Most identify the basic unit of verbal behavior, or language, to be naming. This ability to name comes about in the first two years of life. (Horne & Lowe, 1996). Infants are considered to have a developmental delay if they display fewer than three meaningful words by 18 months and a lack of putting words together by two years of age (American Family Physician, 1996).

The categorization of verbal behavior has often times been dictated by research dealing with stimulus equivalence. Numerous experiments have shown that utilizing stimulus equivalence procedures helps to promote the acquisition of language skills. For example, a study by Mochizuki, Nozaki, Watanabe, and Yamamoto (1988) showed that equivalence training could be applied to promote functional communication. In their study, they used subjects with intellectual disabilities who were also deaf. These men demonstrated equivalence between written words, objects, and signs after conditional discrimination training.

Maquire, Stromer, Mackay, and Demis (1994) compiled a list of those who have supported the notion that advances in our understanding of stimulus class phenomena have begun to contribute to the development of technologies for teaching generative behaviors, the list includes: Mackay (1991), McIlvane (1992), Sidman (1990), Spradlin and Saunders (1984), Stromer (1991), and Stromer et al (1992).

Much research has been done in recent years to examine stimulus equivalence classes and due to this, there have been theoretical advances in our understanding of stimulus equivalence. Many of these studies have demonstrated a close relationship between the formation of equivalence classes and language (Carr & Felce, 2000). The study of stimulus equivalence has brought about useful tools to be utilized in aiding language development. Carr and Felce (2000) suggest that this research could have a wide range of applications in current language intervention programs.

Their applications might include identification of specific linguistic defects in individuals, establishing, expanding and integrating receptive and expressive vocabularies, acquisition and use of signs or graphic symbols, and promoting more sophisticated linguistic concepts, such as syntax and categorization.

It is obvious that to be better able to advance language development one must first have an understanding of the fundamental principles that underlie language formation. Because of past research that demonstrates the relationship between language formation and stimulus equivalence, it follows that further understanding of stimulus equivalence would lead to new insights pertaining to language formation. Inquiring to see just how closely the relationship is between the emergence of stimulus equivalence and the emergence of language would assist researchers in determining what level a person is at developmentally.

Stimulus equivalence is the substitutability of one stimulus for another within a particular context. When a range of stimuli is shown to be interchangeable under certain conditions, these stimuli may be said to belong to an equivalence class (Sidman, 1997). The key feature of the relationship between the stimuli in an equivalence class is that they are not taught directly, but in laboratory situations they emerge spontaneously after training in a selective range of conditional discriminations (Carr & Felce, 2000).

The matching-to-sample procedure is a type of conditional discrimination procedure. In an arbitrary matching-to-stimulus task, a subject may be taught that when stimulus A1 occurs as the sample, stimulus B1 is the correct comparison and B2 is the incorrect choice. When stimulus A2 is the sample, choice B2 is correct, and choice B1 is incorrect. This training could be denoted as A-B.

The subject may also be taught that when A1 is the sample, C1 is the correct comparison and C2 is the incorrect comparison, and that when A2 is the sample, C2 is the correct comparison and C1 is incorrect (A-C). Following this training, unreinforced tests can be given to assess emergent conditional performances that are not directly trained: B1-A1 and B2-A2, C1-A1 and C2-A2, B1-C1 and B2-C2, and C1-B1 and C2-B2. When these relations are demonstrated, evidence is obtained for the development of two arbitrary stimulus classes A1B1C1 and A2B2C2.

In general, a stimulus class, as operationally defined, contains a number of stimuli with each stimulus being conditionally related to every other member of that particular stimulus class. For a conditional relation to be termed an equivalence relation, it is required to have three properties, reflexivity, symmetry, and transitivity. Reflexivity refers to situations where the stimuli that are conditionally related must show the same relation to themselves – A-A, B-B, C-C. Symmetry refers to the reverse of the relationship being true, if A-B then B-A. Transitivity refers to the functional exchange of the sample and comparison functions, if A-B, and B-C, then A-C (Shenk, 1993).

The relationship between language development and stimulus equivalence can be appreciated when one considers how verbal behavior is first learned. When a child is learning to speak, the relations that they form are between arbitrary stimuli just like when a person at any age learns an equivalence class during stimulus equivalence training in an experiment. Language is thought to come about as a result of operating in a verbal community (Clayton & Hayes, 1999). As physical entities, the corresponding sounds and symbols of spoken and written language are arbitrary in the sense that they have nothing in common; so when a child learns to associate the spoken word "ball" with the object "ball" that child is forming an equivalence class between two physically unrelated stimuli (Carr & Felce, 2000).

As any developmental psychologist or parent could tell you, there seems to be an explosion of language around two years of age. This sudden increase in language use mirrors the occurrence of categorization that is seen after an equivalence class is formed. Maguire, Stromer, Mackay, and Demis (1994) suggest that the acquisition of stimulus classes may be essential to such a broad network of adaptive discriminative behavior.

After forming an equivalence class, a person may then generalize what little they have learned to a broad array of stimuli, thus enabling them to better adapt to the world around them. In research the mastery of stimulus equivalence has been demonstrated in most typically developing children and some with mental retardation between the ages of 2 and 7 years (Saunders, Drake, & Spradlin, 1999).

Theories that consider the relationship between equivalence and language differ in some details, but they commonly regard the property of symmetry to be pivotal in the formation of equivalence relations between symbolic/linguistic representations (Carr & Felce, 2000). Some researchers have used equivalence phenomena to develop a behavior-analytic interpretation of symbolic meaning and the generative nature of grammar (Barnes & Hampson, 1997).

Experimental research in equivalence relations indicates that a difficulty in deriving equivalence relations between arbitrary stimuli correlates with the presence of severe semantic and language disabilities (Carr & Felce, 2000). For example, Devany, Hayes and Nelson (1986) demonstrated that children who were language-disabled were less likely to form equivalence classes than children who were language able. This contributes to the notion that the ability to demonstrate stimulus equivalence is closely related to language skill.

Stimulus equivalence research involving young children as participants has differed from that of research involving older participants. College students and adults with mental retardation may bring repertoires to the experiment that are undeveloped in young children, and these repertoires could override the stimulus controls established by training alone (Saunders, Drake, & Spradlin, 1999). Smeets and Barnes (1997) examined stimulus equivalence as derived from simple discriminations in children and adults and found that the majority of the children matched the directly paired stimuli with one another while only a few of them also matched the indirectly paired stimuli with one another. In contrast, all normal adults matched all paired stimuli to one another.

A possible explanation for the different performances of children and adults in Smeets and Barne's study and in others could be the relational-frame account of stimulus equivalence. This approach predicts that mentally older subjects are more likely to demonstrate conditional stimulus relations after training as a result of their extended and varied histories of reinforcement for responding in accordance with a wide variety of relations, including but not limited to, equivalence relations.

Because of this, it would come as no surprise that, as humans grow older and become more intellectually advanced and better educated, they are capable of deriving complex relation networks from procedures. These studies contribute to our knowledge of how stimulus equivalence and language development are related over time, but they only examine this after the occurrence of both.

It is stated by Rogers-Warren and Warren (1980) that language deficiency may be characterized most accurately by viewing variables in combination rather than relying on single measures. Evaluating a person's ability to demonstrate stimulus equivalence would benefit because it would add to these variables. Knowledge on just how closely stimulus equivalence and language development are related in time would contribute to our overall understanding of how these two procedures work together. The aforementioned explosion of language could be due to the newly acquired ability to demonstrate stimulus equivalence.

Not only has mastery of stimulus equivalence been used in experiments but speed analysis has been used as well. Our ability to predict and control responding to the relations among stimuli in equivalence classes might be enhanced by measures that include time as a dimension of behavior (Spencer & Chase, 1996). Measuring not just the ability to master stimulus equivalence but also the speed with which one can do so would allow for yet another way to utilize this phenomena to assess the developmental level of persons. Including time in their research, Spencer and Chase (1996) stated that measuring time can provide a more sensitive measure of performance than accuracy alone, because temporal differences in responding may be evident even after response accuracy has stabilized. Due to time adding another useful factor for analysis the current study will use this factor in addition to testing for mastery of stimulus equivalence.

Experiment 1

Method

Participants

The participants were three (two females, one male) children from the childcare facilities at a small, public, four-year college in West Virginia. The participant's ages were 21, 23, and 30 months. Consent forms were distributed at the childcare facilities to all the parents of children ages 18 to 24 months. A copy of the consent form can be found in Appendix A. A separate consent form was distributed to those parents who signed the first that gave allowance for the researchers to walk the children from the childcare facilities to the testing location. A copy of the second consent form can be found in Appendix B.

Materials

Equipment for the testing of stimulus equivalence included two computers equipped with touch screens. The 21 and 23-month-old children were tested in a different room and by different researchers. The 21 and 23-month-old children were tested in a small experimental lab with a child sized table and chairs. The 30-month-old participant was tested in a room with a full size table and chairs and was placed in a booster seat so that he could easily reach the screen.

A computer program was formulated and written with technical assistance. This program included three tests of reflexivity, two tests of symmetry, and one test of transitivity. Each test consisted of 10 trials and mastery was defined as eight or more correct responses. Three stimuli appeared on the screen with each trial. One stimulus was located at the top of the screen and the comparison stimuli were located beside each other below the top stimulus. An example of each of the tests can be found in Appendix C.

In order to evaluate the participant's level of language development the McArthur Communicative Development Inventories was used. The purpose of this test as stated in Mental Measurements is to evaluate young children's communication skills with norm-referenced parent checklists. The MCDI currently provides the most thorough means for documenting the vocabulary skills of children between 8 and 30 months according to Mental Measurements which also states that the format provides a highly reliable and valid means of using parent-report data for documenting children's language skills and that the inventories have proven their value in language research.

In order to compare the language development of the participants in this study the raw score from Part I of the Words and Sentences Inventory was used. This section consists of a 680-word productive vocabulary checklist organized into 22 semantic categories for helping verbs and connecting words and a separation of the noun category for outdoor things and places to go. The MCDI test has a self-explanatory format and is in checklist form so its completion required no formal instruction. A copy of the form sent with each of the MCDI tests can be found in Appendix D.

<u>Procedure</u>

The MCDI tests were distributed to the parents of the participants at the child-care facilities with instruction to complete them promptly upon receiving them and turn them in to the childcare personnel at their convenience.

Two researchers tested participants individually with the stimulus equivalence program. One researcher tested the 21 and 23-month-old participants and the other researcher tested the 30-month-old participant. Testing with the stimulus equivalence program was sporadic due to the time constants of the testers, illnesses, absence of the children and parental issues. For the most part every day that the children were present and it was not noted that the parents did not want them to be tested that day the child was tested. Testing times varied depending on the mood of the child. If at any time the child expressed that they wished to return to the child-care facilities or that they no longer wanted to "play" the computer game they were taken back. Testing continued for as long as the child was participating and usually did not exceed an hour each day.

After the child was walked to the administration building and taken into the research lab, they were seated in front of the computer in reach of the screen. The researcher then brought up the program and the child was instructed to look at the stimulus at the top of the screen. Then they were told to select, by touching it with their finger, which of the stimuli at the bottom "goes with" the stimulus at the top. If a correct response was made then the child was reinforced with verbal praise, cheese crackers, and different animated cartoons (Appendix E) that appeared on the screen accompanied with music. If an incorrect response was made then a large red X against a black background was displayed on the screen.

The researcher documented the participant's responses on paper recording the stimuli that appeared on each screen, the stimuli that the participant selected, and whether or not the participant's response was correct. These papers where kept in the research labs in folders until the cessation of the study. Each paper was labeled with the name of the participant and the date of the testing.

Results

Each participant's progression with the stimulus equivalence test was graphed chronologically showing the total number of correct responses for each trial. The 21-month-old achieved mastery on the three tests of reflexivity (Appendix F) and the 23-month-old achieved mastery on the first two tests of reflexivity (Appendix G). The 30-month-old achieved mastery on all three tests of reflexivity, the two tests of symmetry, and the one test of transitivity (Appendix H) thus he was deemed to have mastered stimulus equivalence as defined by this study.

The total number of trials to mastery for each participant of first and second test of reflexivity was graphed as well to compare their ability at mastering these tests (Appendix I). The total number of trails to mastery [After scoring the initial MCDI tests it was found that the 21-month-old participant had a raw score of 191, the 23-month-old a raw score of 257, and the 30-month-old a raw score of 461. A graph of these scores can be found in Appendix J. A final graph showing comparing the score on the MCDI tests and the total number of trails to mastery can be found in Appendix K.

Experiment 2

Method

Participants

The participants were twelve (seven females, five males) adult students attending college at a small, public, four-year college in West Virginia. The mean age of the participants was 21.5. Extra credit for participation was offered to students attending five lower level courses in the social sciences. Those interested in participating could sign up for testing.

Materials

The equipment used for the stimulus equivalence testing included one computer equipped with a mouse for selecting the stimulus. All subjects were tested in a small experimental lab furnished with a large table for the computer and three chairs. The same experimenter tested all participants. A stopwatch was used to document the time that it took each participant to complete the stimulus equivalence testing. The experimenter used a sketchpad and pencil in order to document the responses the participants made during equivalence testing.

A new computer program was formulated in order to test the older participants. Due to the age and maturity of the participants this program included only mixed symmetry and transitivity training. The program consisted of 20 trials of training and 20 trials of testing. Throughout the testing portion there was a random mix of two equivalence classes and the position and order of the stimuli was random as well. The training consisted of forming A-B, B-C, X-Y, and Y-Z relations with the symbols randomly appearing either as the stimulus of reference or the comparison stimulus and the right left position of the stimulus were also random. The testing consisted of random A-C and X-Z relations. The participants were reinforced with a cartoon and the word right appearing on the screen for correct responses and a large red X appeared for incorrect responses. Mastery was defined as all of the responses being correct, so the participants realized that testing would not be completed until all responses were correct and this probably also served as incentive to learn. Examples of the screens may be found in Appendix L.

In order to evaluate the level of language development, the Shipley Institute of Living Scale was used. This test contains a 40-item vocabulary test and a 20-item abstraction test. The vocabulary items are presented in a four-alternative, multiple-choice format. Items of the abstraction test require respondents to complete a series by supplying the numeral or letter that best completes the stimulus sequence. As stated in the manual the abstraction section measures abstract concept formation. Specific component skills include abstract thinking, verbal and numerical concept formation, attention to detail, analysis and synthesis, cognitive flexibility, concentration, mental alertness, intellectual speed, and both intermediate-and long-term memory, as well as specific vocabulary and arithmetic skills. Thus, in general, abstraction is the more difficult of the two subtests. The correlation of the SILS and WAIS and WAIS-R scores contained in the manual range from the mid.70s to mid.80s. Raw scores from the vocabulary and abstraction tests as well as a total raw score were utilized to compare the participants.

Procedure

All of the individuals who signed up for a testing time and who showed up at that time were tested. Upon arrival all participants were taken into the lab and asked to take a seat at the table. The SILS was already in place with a pencil and all participants were instructed to fill out the personal information and then read all the directions and begin. Ten minutes were given to complete each section. Immediately after completing the SILS the computer testing began.

After bringing up the first training screen in the stimulus equivalence testing program the experimenter instructed the participants to use the mouse to select the stimulus at the bottom of the screen that they believed went with the stimulus at the top of the screen. After each participant responded to all of the 20 trials correctly the testing portion of the program was brought up and the procedure was repeated. Throughout the testing the experimenter documented all of the participants responses and timed from the onset of the testing to the mastery of the equivalence program. Testing times varied from three minutes forty-seven seconds to thirty-five minutes with a mean time of twelve minutes fourteen seconds. Testing was conducted over a three-week period for a total of nine days. Each participant was thanked after completing the equivalence testing and their name was documented for the professors so that they received their extra credit points.

Results

A multiple regression coefficient was figured with the data in order to assess extent of the relationship between each of the factors. With number of trials to mastery as the dependent measure it was found that the vocabulary raw score with t=2.054, p=. 074, the abstraction raw score with t=1.253, p=. 186, and the total raw score with t=-1.313, p=. 226. With time as the dependent measure it was found that the vocabulary raw score with t=2.134, p=0.65, the abstraction raw score with t=-2.082, p=. 067, and the total raw score with t=-1.918, p=0.91. The alpha value remained constant throughout at the tests at .05.

Graphs showing the comparison of the participant's number of trails to mastery and the time taken are shown in Appendix M. The participant's time to completion of the equivalence testing and their scores on the SILS can be found in Appendix N. Comparisons of the number of trails to mastery and the scores on the SILS were also graphed (Appendix O).

Discussion

In the toddler study, the eldest participant mastered the entire computer program and so he was deemed as having mastered stimulus equivalence. The test is a viable tool for measuring stimulus equivalence because it was successful at determining his ability to master the subject. Later research could develop norms for the test and it could be used as a test of cognitive ability.

As evidenced by Appendix J there was a positive trend between the toddlers scoring high on the MCDI test and mastery of stimulus equivalence. This suggests that there was a relation between language development and stimulus equivalence. This was expected to be found and it coincides with the current notion that stimulus equivalence is a major part of our ability to develop language.

A limitation of the toddler study was the obvious impact that age had on the results. A future study could address this issue by testing participants who are the same age and looking to see if there are any differences between them. Another limitation was the amount of time that was available to test the participants. With this type of training it would have been beneficial to have access to the participants every day and sometimes more than once a day but that was not possible for this study.

No statistically significant differences were found with the adults. However, the findings, with the number of trails to mastery as the dependent measure, the vocabulary raw score did yield a marginally significant difference with a p=. 074. Also with time as the dependent measure the vocabulary and abstraction raw scores both yielded a marginally significant difference with p=0.65 and p=. 067. These findings do suggest that there is a relationship between these measures of verbal ability and mastery of stimulus equivalence testing. The abstraction test proved to be a good predictor as well and so future research could explore its relation to verbal behavior as well.

A possible limitation of the adult study could have been that the measures were not sensitive enough to show differences in the participants. Future studies could utilize a more detailed test of language development and harder stimulus equivalence testing. It would be beneficial to explore the viability of other measures as well with this age of participants. Perhaps mathematical/analytical tests would serve this purpose better than tests of vocabulary. The extent of a person's vocabulary has more to do with past learning history and experience than level of cognitive abilities at this age and so other tests may serve better as a predictor of stimulus equivalence abilities in adults.

Another factor could have been the relative similarities in all of the participants. Future research using a more diverse population would no doubt yield more differences. This brings about the notion that testing prior to selecting participants would well serve those who conduct future research in this area. Assessing the participant's level of language development prior to testing would enable the researcher to select participants with a wide range of abilities and thus examine their skill at stimulus equivalence in more detail.

Time, as much or more so than the number of trials to mastery, was shown to be a viable measure as well. Participants who took nine trials to complete the stimulus equivalence testing varied in the actual time that it took them to complete these nine trials. Future testing would do well to time stimulus equivalence testing as well as document the number of trials to mastery. With data being collected in this way the participant's speed of processing could be explored as well.

An interesting effect was seen with the oldest participant. As would be expected with age, the ability to learn novel stimuli declines, but overall knowledge does not. This example of the effects of age on cognitive abilities brought up an effect that a future study could explore. Fluid intelligence is the information processing system. It refers to the ability to think and reason. It includes the speed with which information can be analyzed, and also includes attention and memory capacity. Crystallized intelligence is accumulated information and vocabulary acquired from school and everyday life. It also encompasses the application of skills and knowledge to solving problems.

Many studies have shown that fluid intelligence is more likely to decline with age than crystallized intelligence. In fact, crystallized intelligence may continue to improve with age. With this type of research the stimulus equivalence testing would be an assessment of fluid intelligence and the testing of verbal skill would assess crystallized intelligence (Golde, 2001). Because of this it would be expected that older adults would demonstrate the opposite relation when compared to young individuals; higher verbal abilities but lower mastery of stimulus equivalence.

This research does provide another possible way to evaluate the cognitive development of children. Upon future testing of many children and the development of norms, this stimulus equivalence program could be a useful tool in comparing children's cognitive abilities and developmental levels. Future tests could continue to compare the relation on language development to stimulus equivalence and seek out that critical period of language explosion and perhaps find a subsequent explosion of stimulus equivalence progression on this program at that same time.

References

Barnes, D., & Hampson, P. J., (1997). Connectionist models of arbitrarily applicable relations responding. Biobehavioral Foundations, 121, 496-521.

Canadian Family Physician, (1996). Developmental delay in infants. American Family Physician, 54, 2307-2309 ?

Carr, D., & Felce, D., (2000). Application of stimulus equivalence to language intervention for individuals with severe linguistic disabilities. Journal of Intellectual and Developmental Disability, 25, 181-205.

Clayton, M. C., & Hayes L. J., (1999). Conceptual differences in the analysis of stimulus equivalence. The Psychological Record, 49, 145-150.

Devany, J. M., Hayes, S. C. & Nelson, S. O., (1986). Equivalence class formation in language able and language disabled children. Journal of the Experimental Analysis of Behavior, 46, 243-257.

Golde, T., (2001). Topics in the biology of aging. The American Federation for Aging Research, 6, 56-59.

Horne, P. J., & Lowe, C. F., (1996). The origins of naming and other symbolic behavior. Journal of the Experimental Analysis of Behavior, 65, 185-241.

Maguire, R.W., Stromer, R., Mackay, H. A., & Demis, C. A., (1994). Matching to complex samples and stimulus class formation in adults with autism and young children. Journal of Autism and Developmental Disorders, 24, 753-772

Mochizuki, A., Nozaki, K., Watanabe, H., & Yamamoto, J., (1998). Acquisition and functional use of signing and writing in deaf adults with mental retardation through conditional discrimination. Journal of Multihandicapped Persons, 1, 233-249.

Rogers-Warren, A., & Warren, S. F., (1980). Mands for verbalization: facilitating the display of newly trained language in children. Behavior Modification, 4, 361-382.

Saunders, R. R., Drake, K. M. & Spradlin, J. E., (1999). Equivalence class establishment, expansion, and modification in preschool children. Journal of the Experimental Analysis of Behavior, 71, 195-214.

Schenk, J. J., (1993). Emergent conditional discrimination in children: matching to compound stimuli. The Quarterly Journal of Experimental Psychology, 46B, 345-365.

Sidman, M., (1997). Equivalence Relations. Journal of the Experimental Analysis of Behavior, 68, 258-266.

Smeets, P. M., & Barnes D., (1997). Emergent conditional discriminations in children and adults: stimulus equivalence derived from simple discriminations. Journal of Experimental Child Psychology, 66, 64-84.

Spence, T. J., & Chase P. N., (1996). Speed analysis of stimulus equivalence. Journal of the Experimental Analysis of Behavior, 65, 643-659.

Appendix A

Dear Parent/Guardian,

I would like to invite your child to participate in a research project that I am conducting in association with the McNair Scholars Program and Dr. Karen Griffee; a psychology professor here at Concord. This research project would entail administering the McArthur language development test to your child in order to assess their level of language skill so that I can group those who are most similar. The McArthur is a written report that I will ask you to fill out that deals with your child's level of language skill. This test is widely recognized and used for this purpose. After examining their scores on this test I may then select your child to participate in the actual experiment. If your child is selected and you approve for them to be a participant I would require information on your child's schedule so that I can set up times to test your child Monday through Friday for about an hour each day. I would continue to assess your child's level of language ability with the McArthur test about every other week and I would also examine another aspect of your child's language skill by having them play a game in which different shapes will appear on a computer screen and they will have the opportunity to select a specific shape by touching the screen. This game will enable me to see how your child forms categories and associates symbols. To reward you child for correct responses they may receive crackers or fruit treats as well as verbal praise. I would very much appreciate you allowing your child to participate in this research project. Please indicate your approval by filling in your son or daughter's name and date of birth. Once you have signed this consent form please return it to your child's teacher. All of the information gathered about each child's performance will be kept completely confidential.

Please feel free to contact me in the evenings at (304) 466-0653, (304) 445-2792, or e-mail me at gelflin20@hotmail.com if you have any questions concerning this activity. Thank you for your cooperation.

Sincerely,

Rebecca G. Ryan

____

Your Child's Name

____

Your Child's Date of Birth

____

Parent/Guardian Signature

At the present time the computer testing is to be conducted at the Concord Child Development Center, if for any reason there is an issue with the computers there and it is necessary to test with the computer program at a computer room in the administration building would you allow your child to be tested at that location?

__________________________ __________________________

Yes (Parent/Guardian Signature) No (Parent/Guardian Signature)

Appendix B

Dear Parent/Guardian,

Due to time constraints and to alleviate aggravation on the part of the childcare personnel the children that are participating in the stimulus equivalence study will be walked over by the testers (Rebecca and Amy). At specified times the children will be walked from the childcare center to the administration building (room 110) and back for the study. During the testing the child will be under the constant supervision of the tester and the responsibility of the tester and the supervisor of this study – Dr. Karen Griffee. This study will continue as time permits until the second week of December and the testers will be contacting you in order to get an understanding of your child's schedule. The testing times will vary depending on how long the child stays interested and if any time for any reason the child wishes to return to the childcare center they will be immediately walked back. If you have any questions please feel free to call Dr. Griffee (5201) or myself (Rebecca Ryan 575-2096).

Thank you,

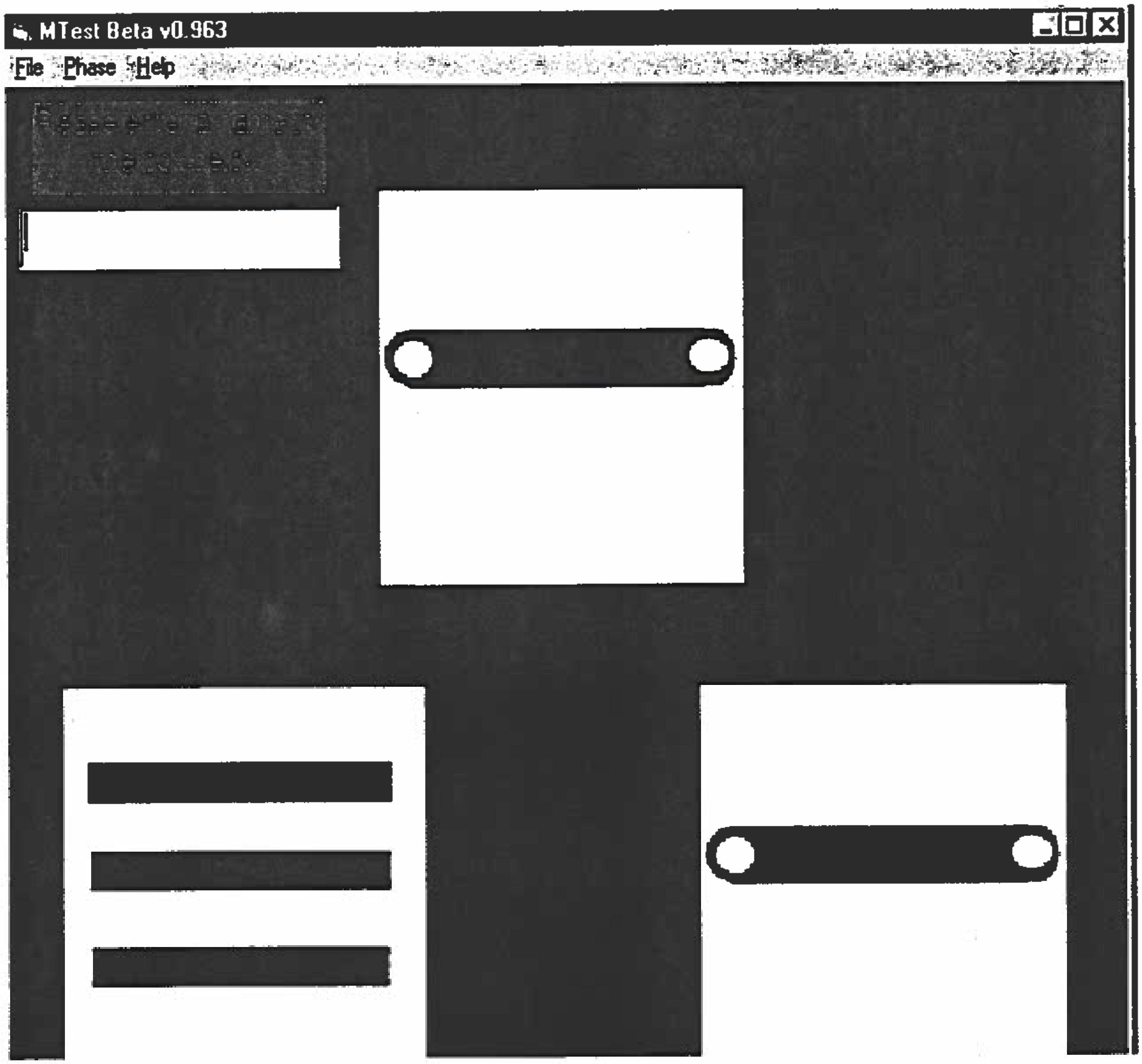
Rebecca Ryan

____

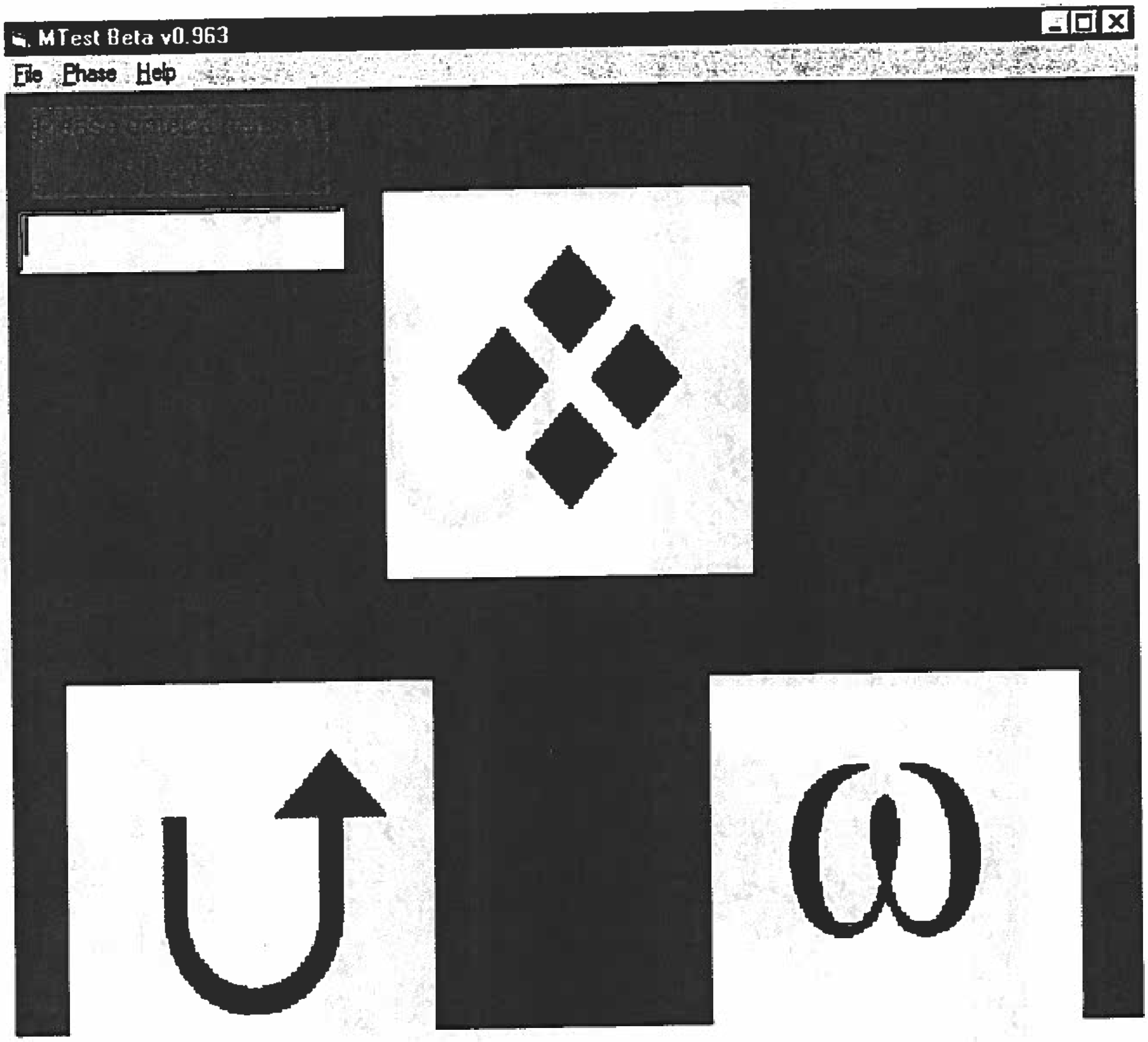
Parent/Guardian Signature

<u>Appendix C</u>

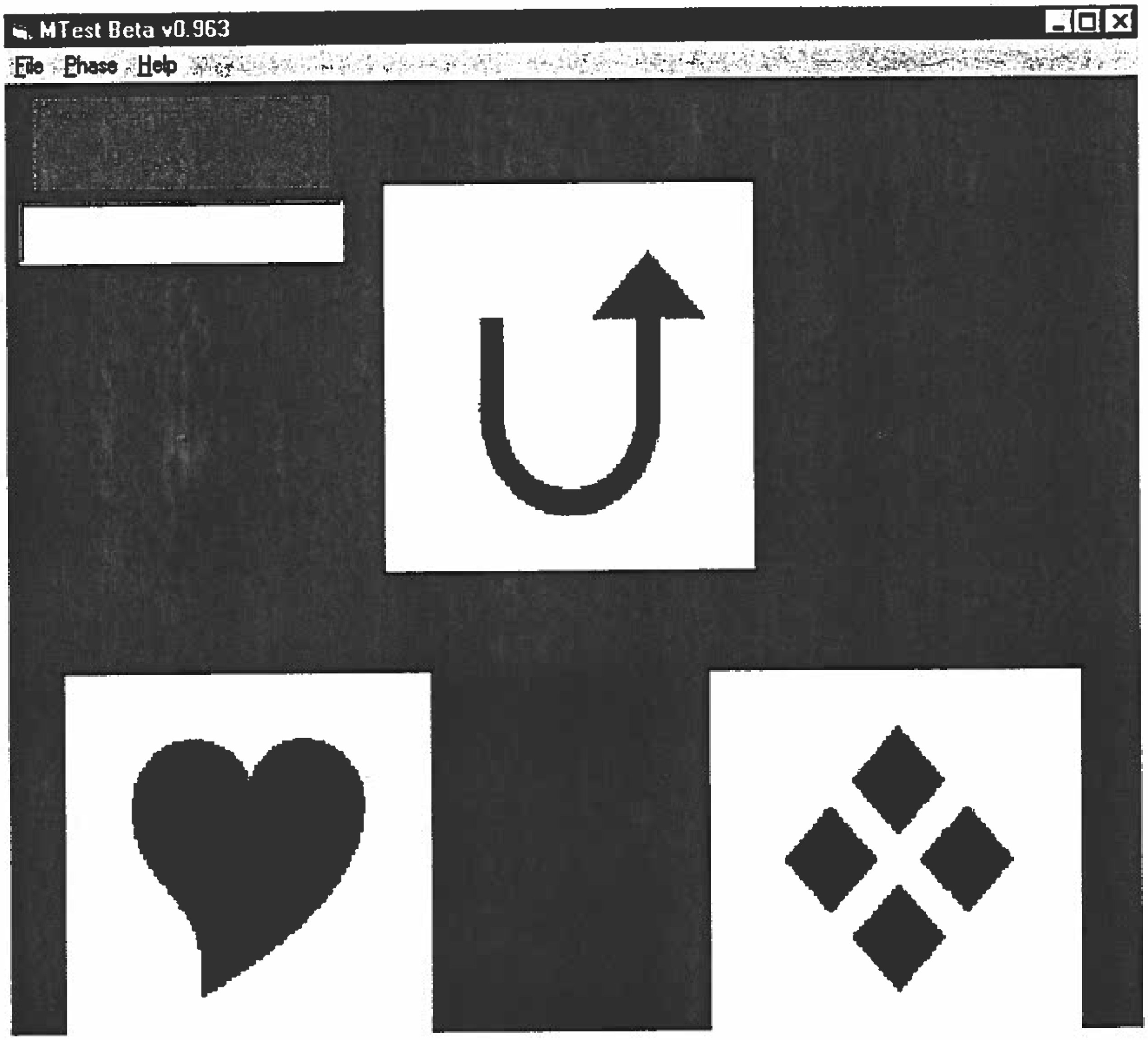
Reflexivity



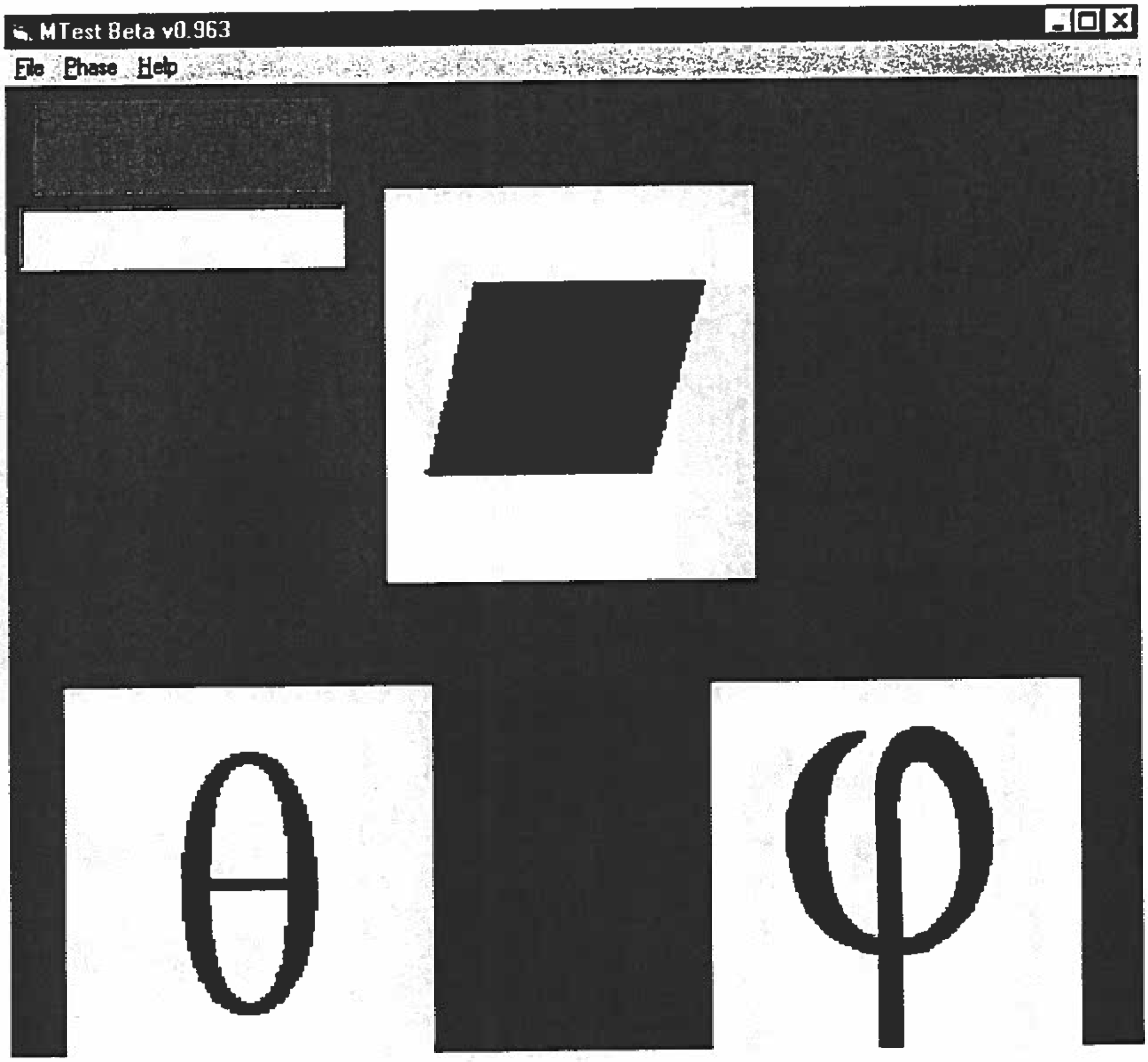
Symmetry 1



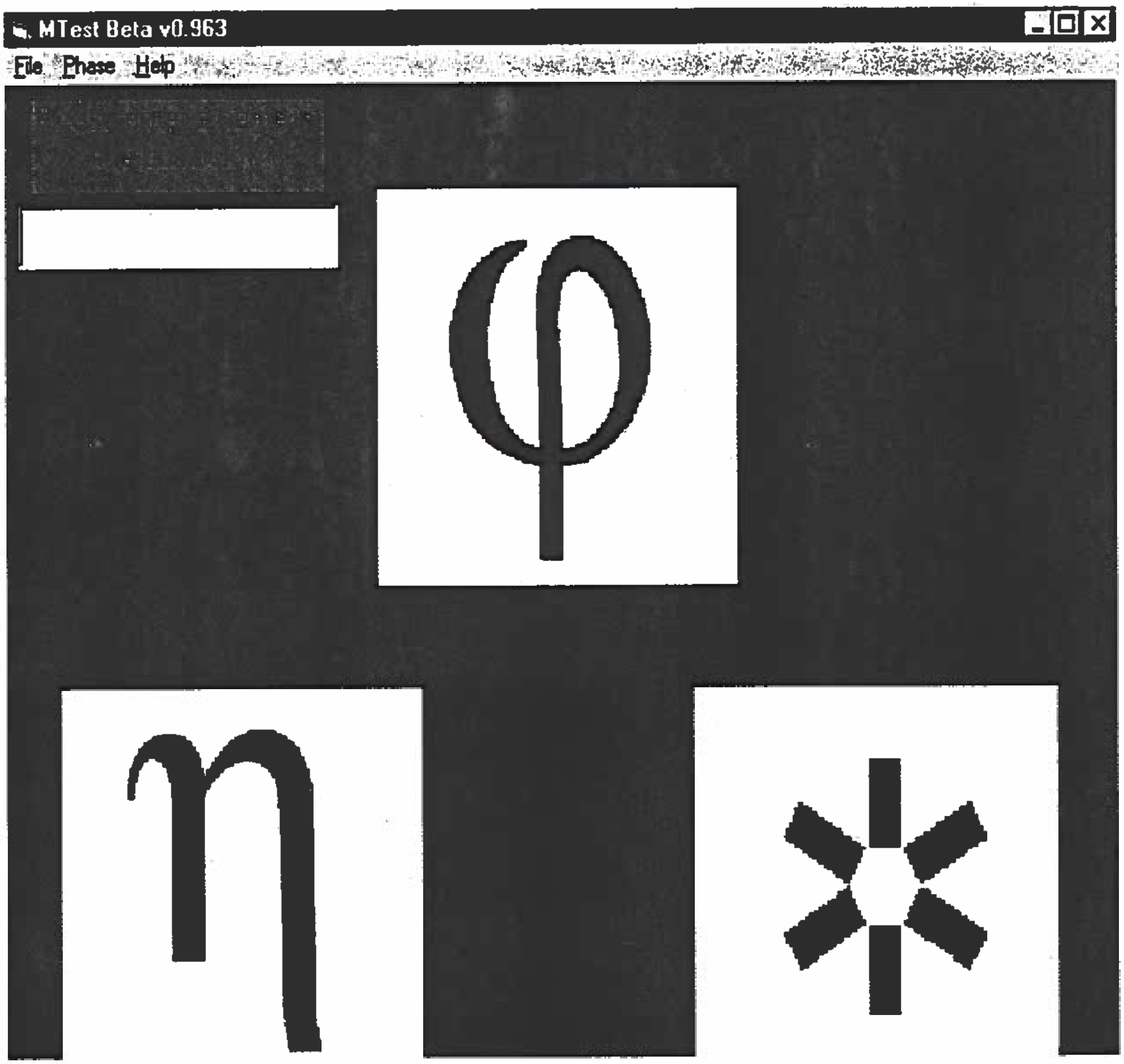
Symmetry 2



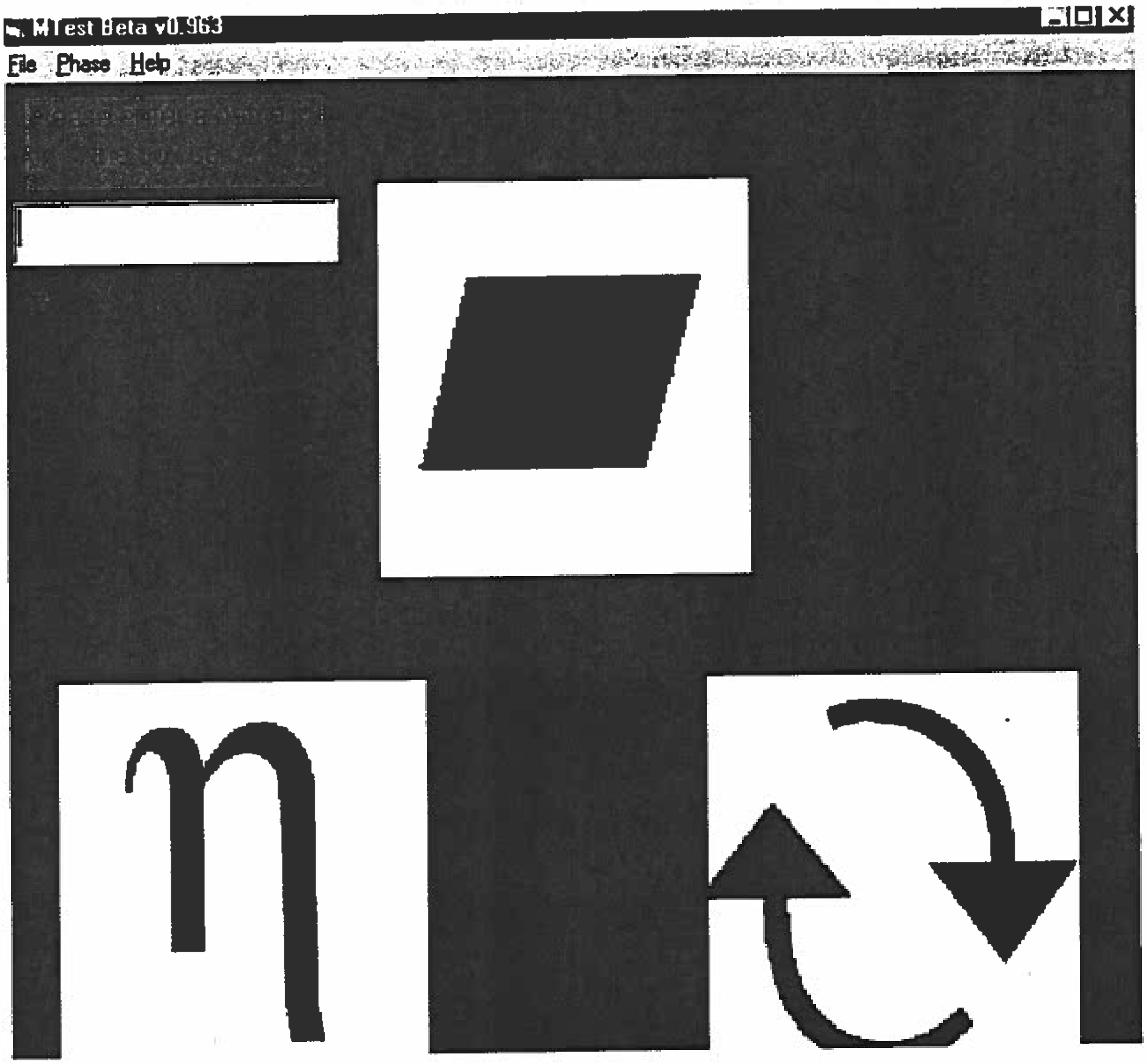
Transitivity 1



Transitivity 2



Transitivity 3



<u>Appendix D</u>

Dear Parent/Guardian,

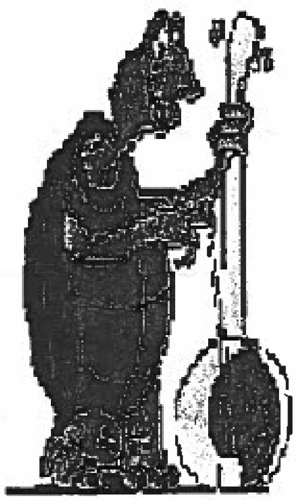
This is the McArthur Communicative Development Inventories test that I will be using to assess your child's level of language development. The test is self-explanatory. Please read the instructions and fill it out in the appropriate manner. It should take no more than fifteen minutes. Please be prompt in filling them out as soon as you receive them, and then turn them in to your child's teacher at your convenience.

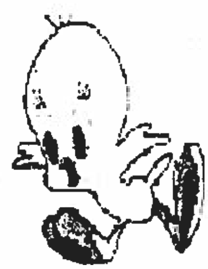
If you have any questions at all about this test or how to fill it out, please feel free to call me, Rebecca Ryan (445-2792) or contact Dr. Karen Griffee (ext. 5201).

Thank you,

Rebecca Ryan

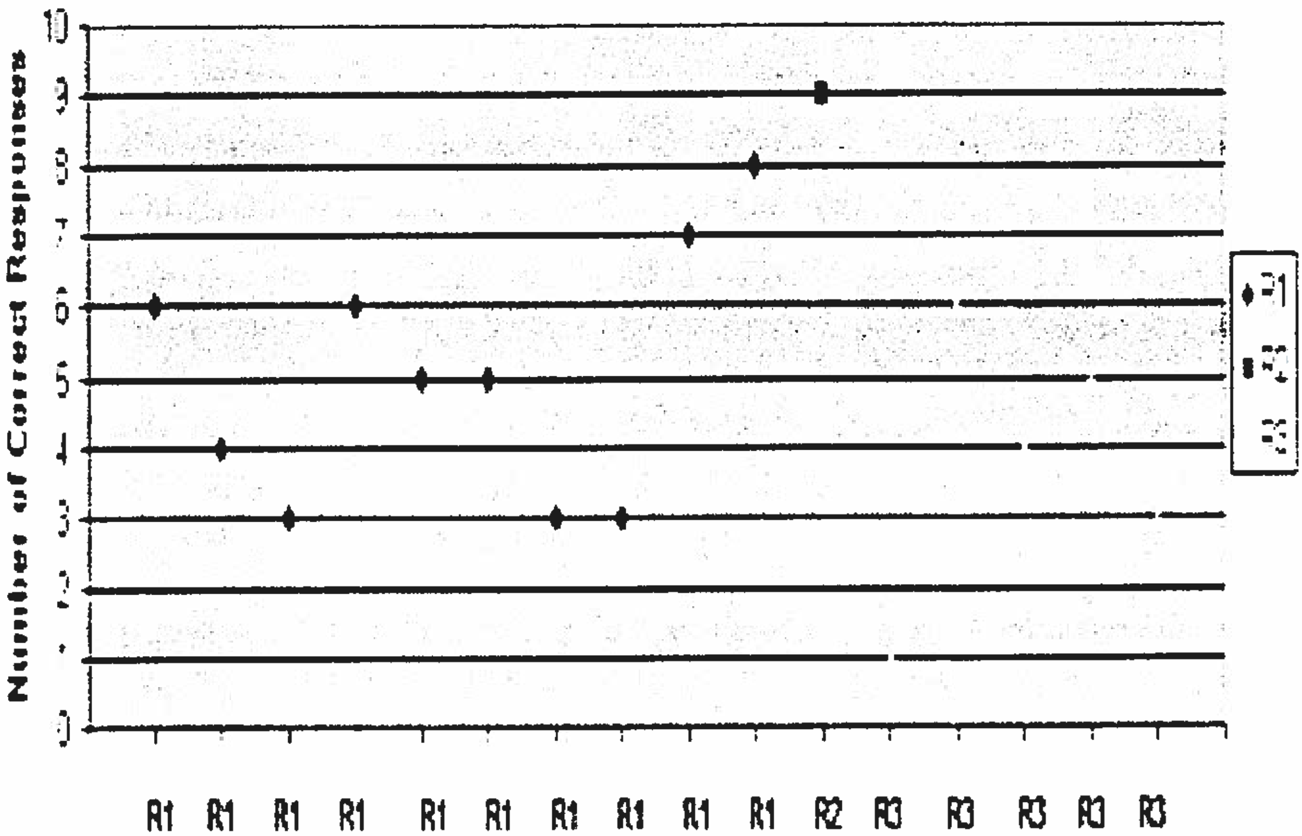
Appendix E



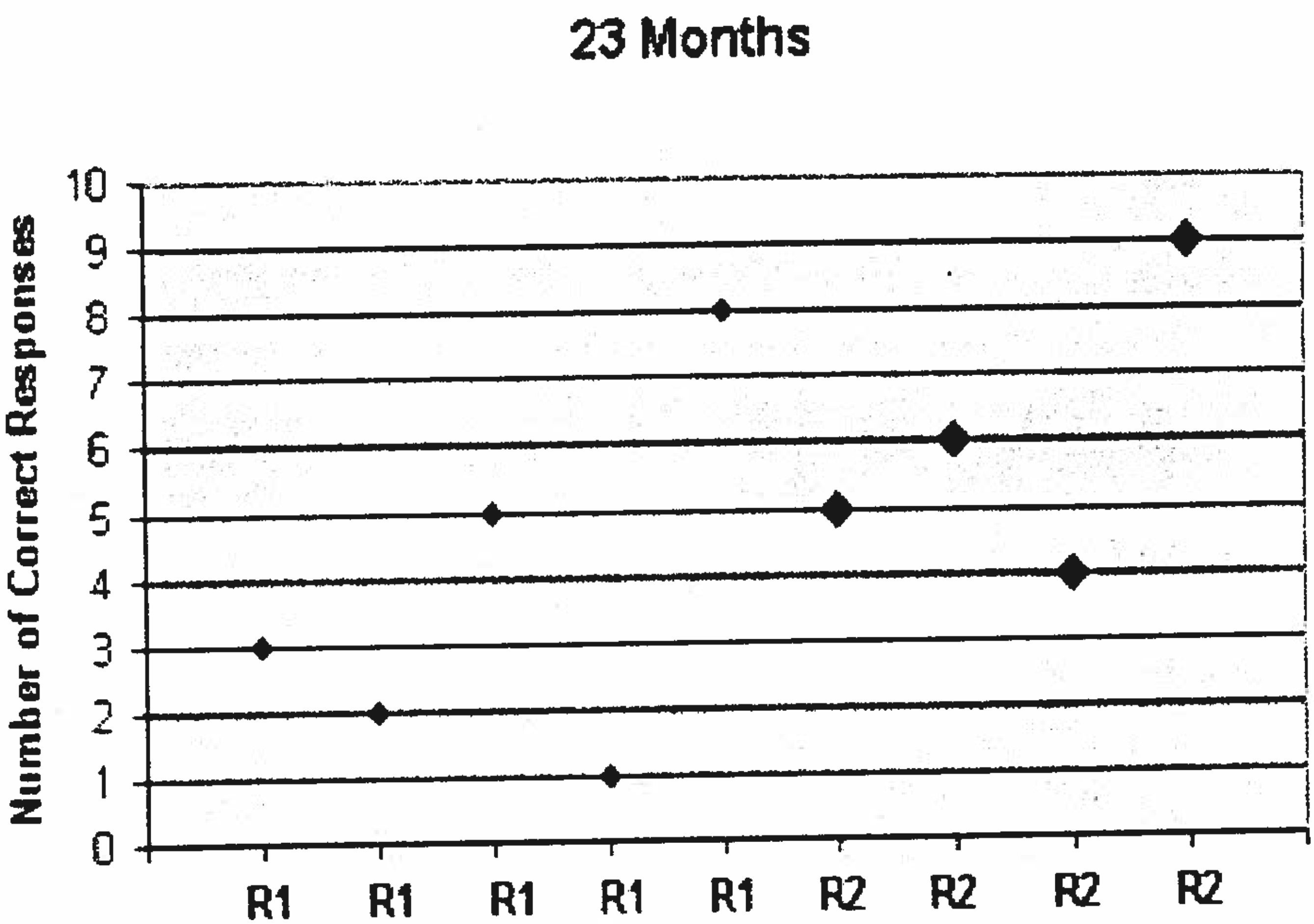


Appendix F

21 Months

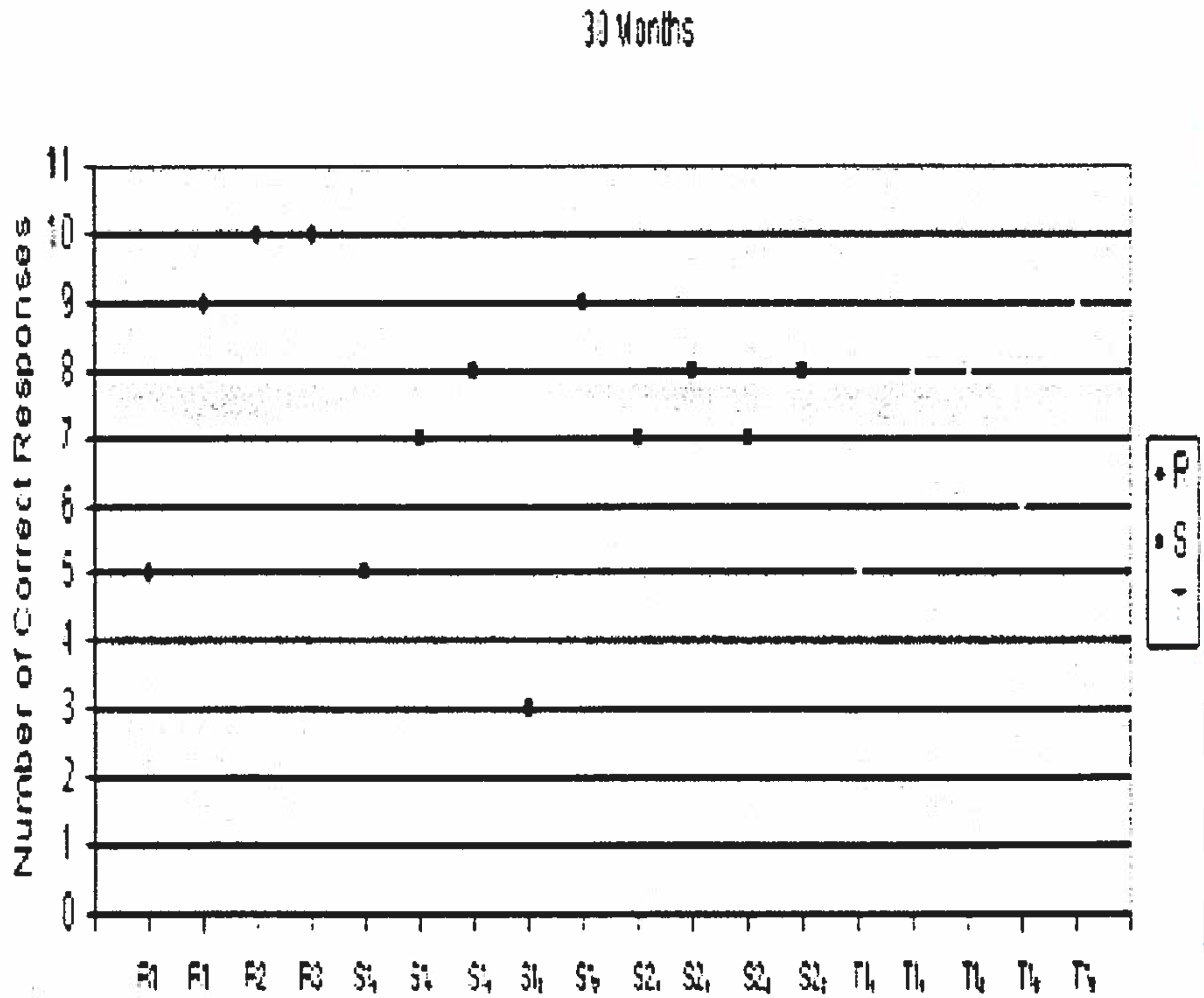


Appendix G

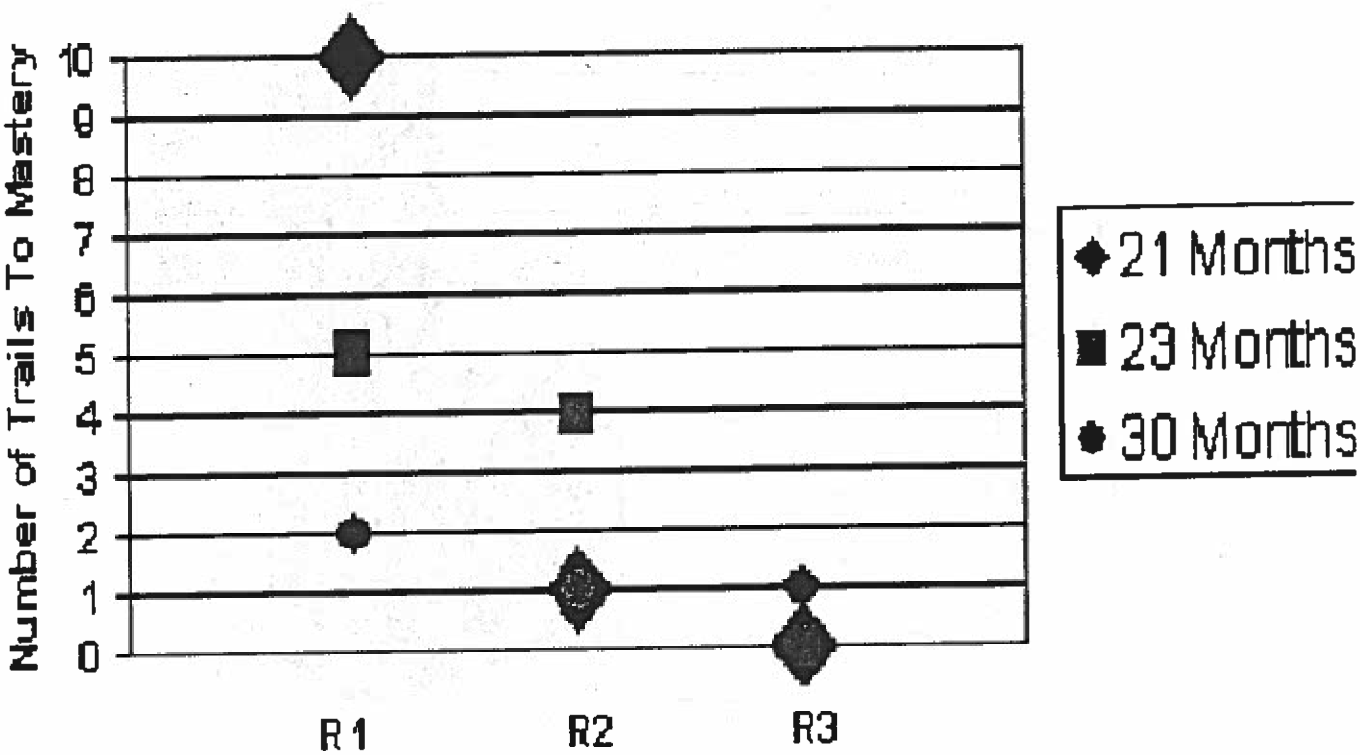


23 Months
Number of Correct Responses
10
9
8
7
6
5
4
3
2
1
0
R1
R1
R1
R1
R1
R2
R2
R2
R2

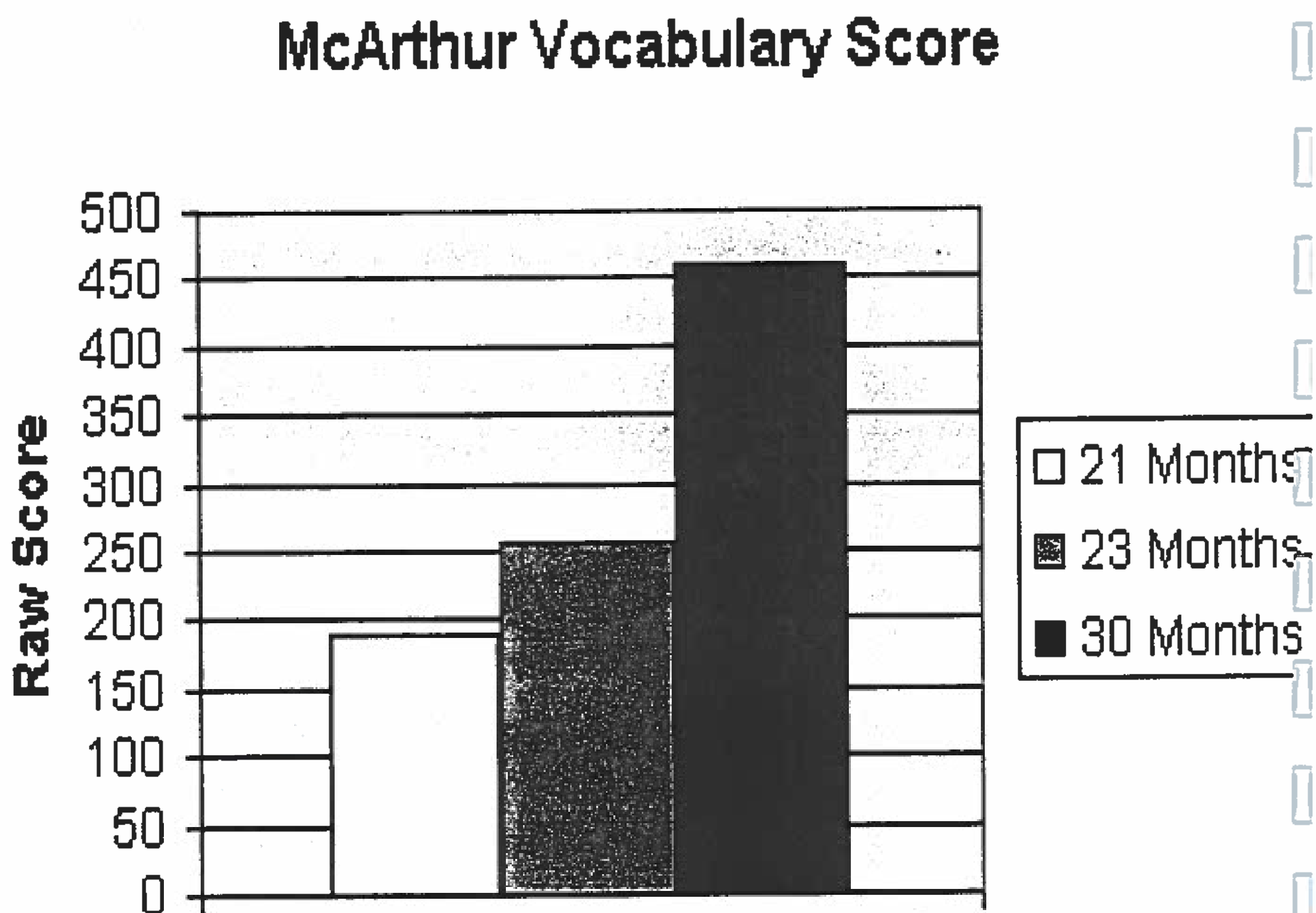
Appendix H



Appendix I

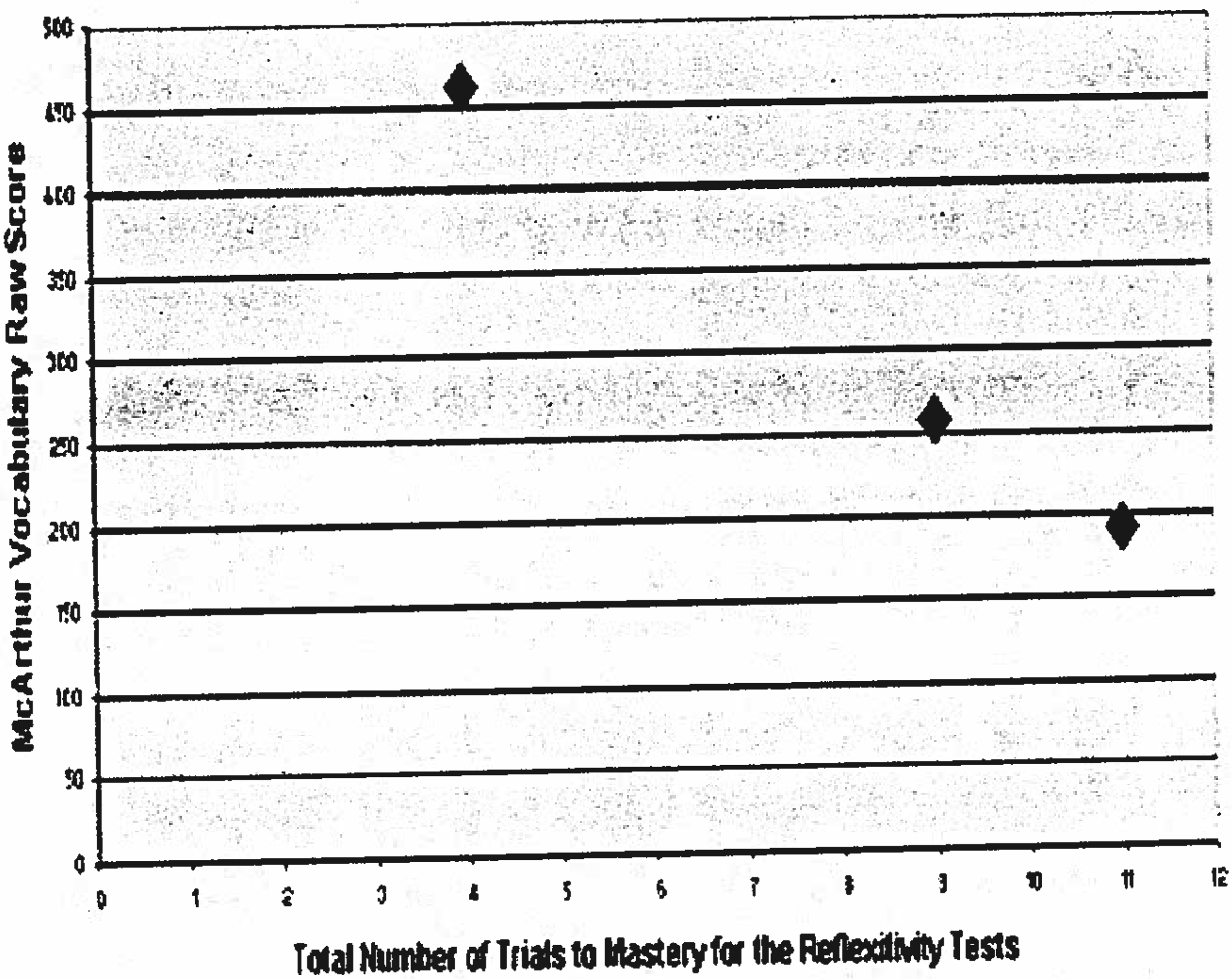

Number of Trails To Mastery
10
9
8
7
6
5
4
3
2
1
0
R1
R2
R3
21 Months
23 Months
30 Months

Appendix J



McArthur Vocabulary Score
Raw Score
500
450
400
350
300
250
200
150
100
50
0
21 Months
23 Months
30 Months

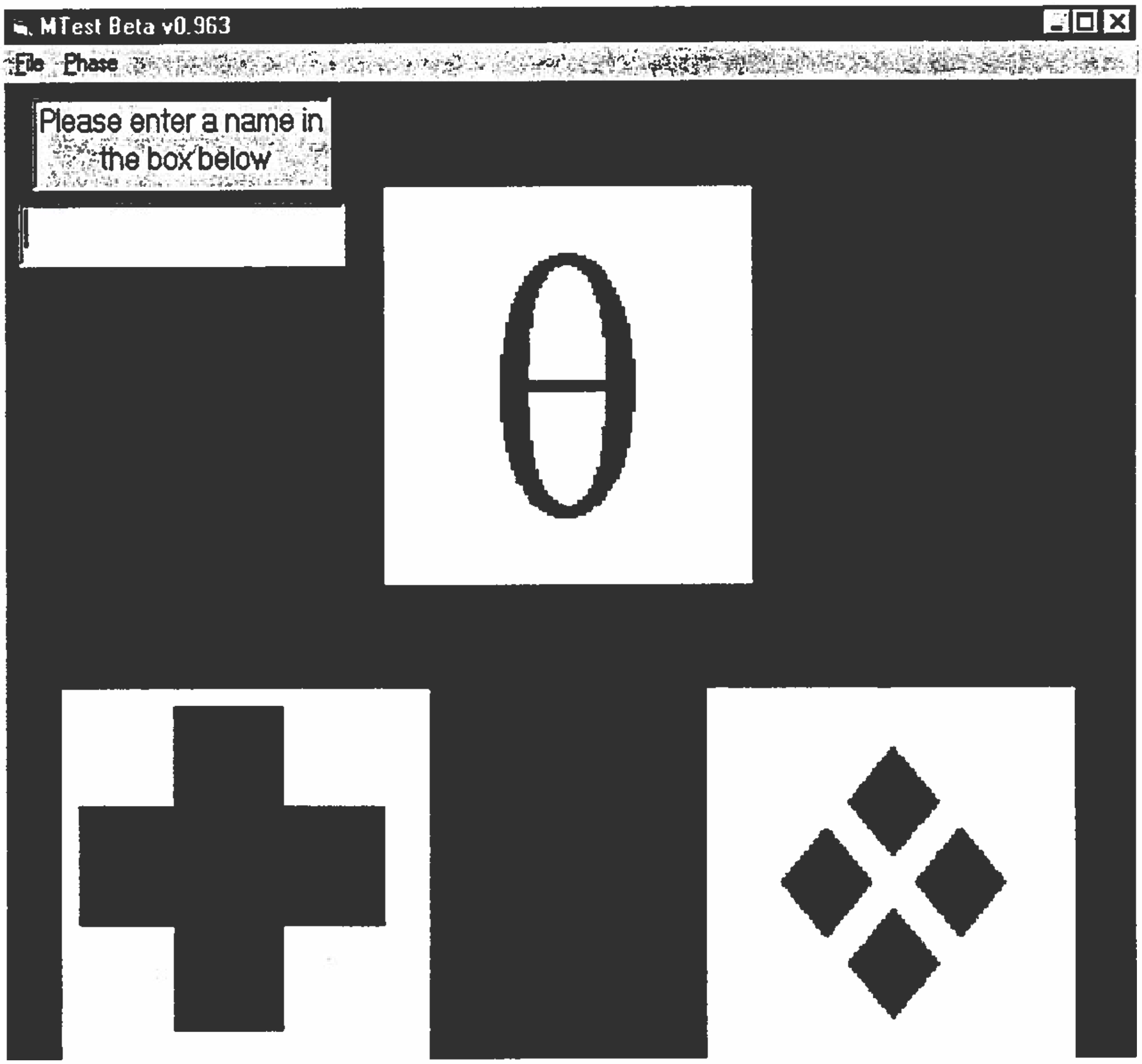
Appendix K



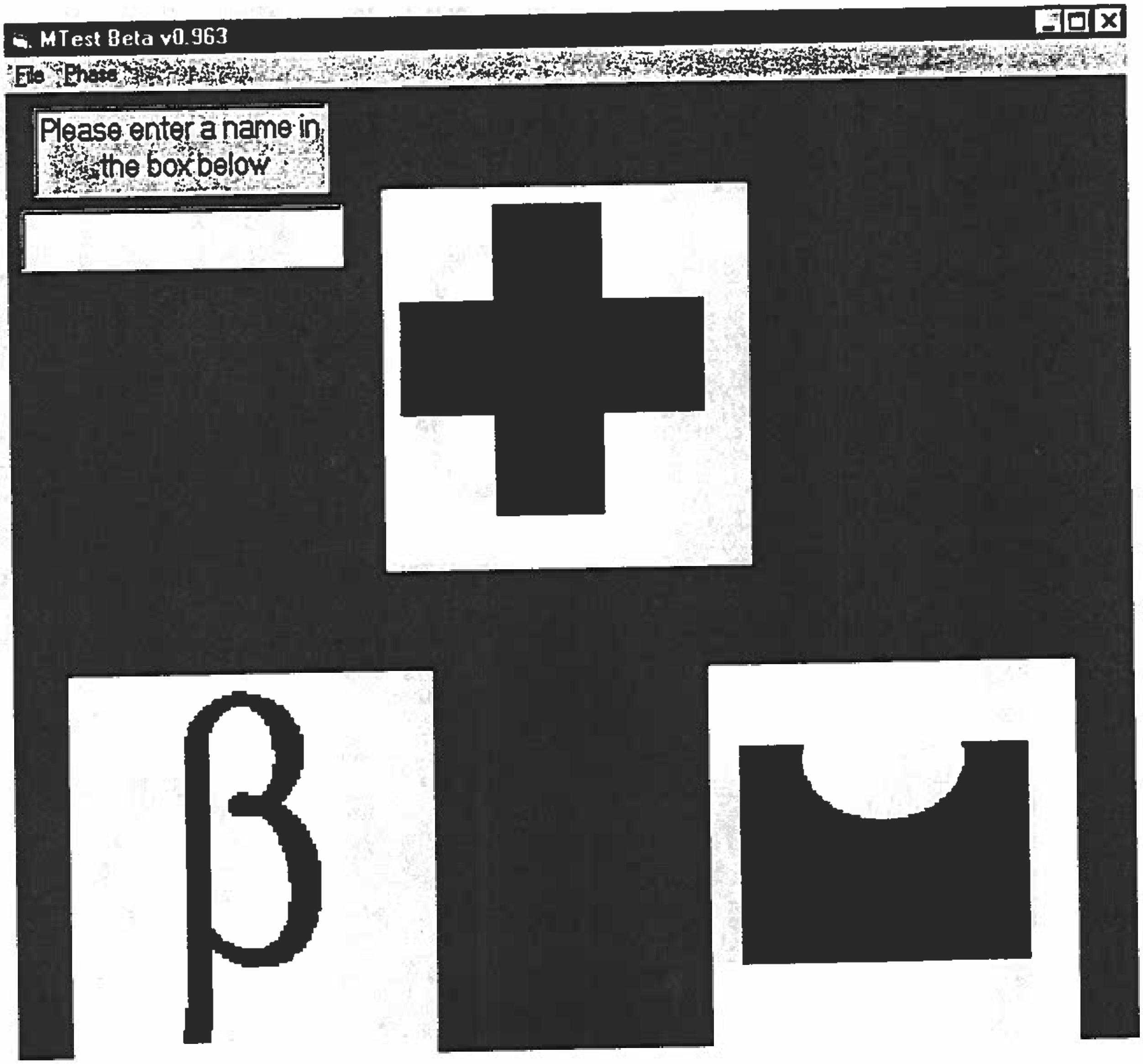
McArthur Vocabulary Raw Score
500
450
400
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
9
10
11
12
Total Number of Trials to Mastery for the Reflexivity Tests

Appendix L

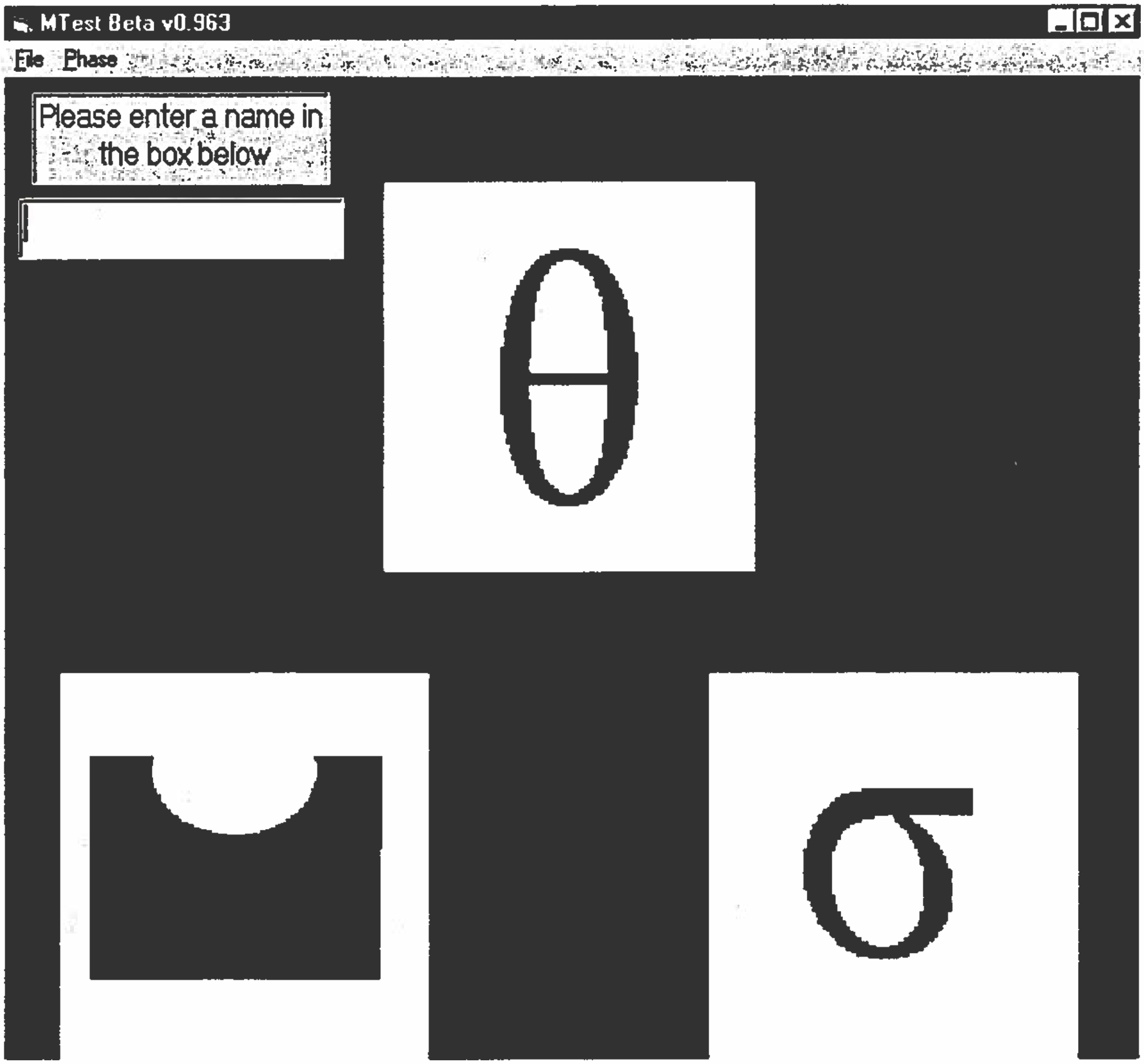
Train



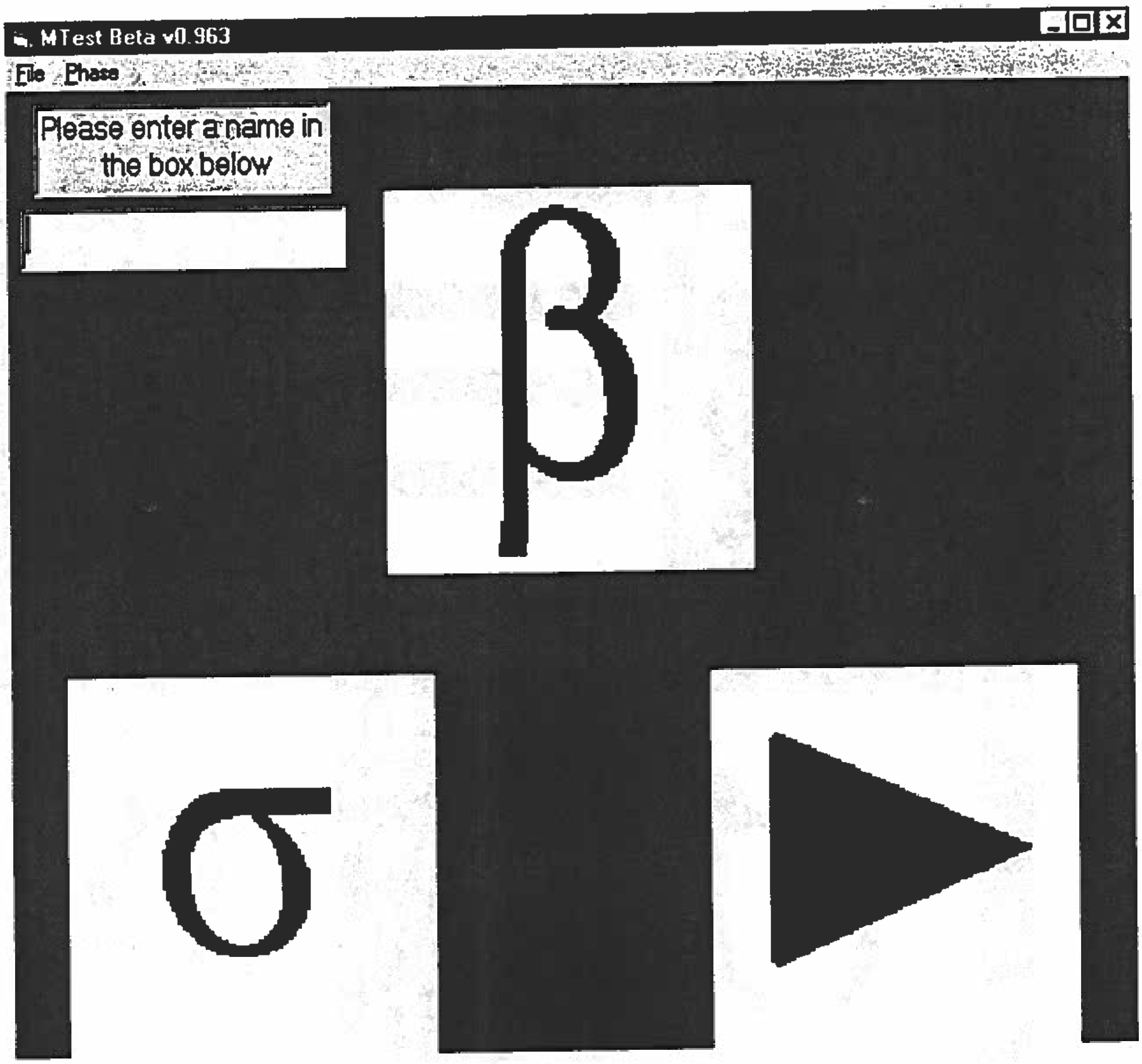
Train


MTest Beta v0.963
File Phase
Please enter a name in the box below

Test

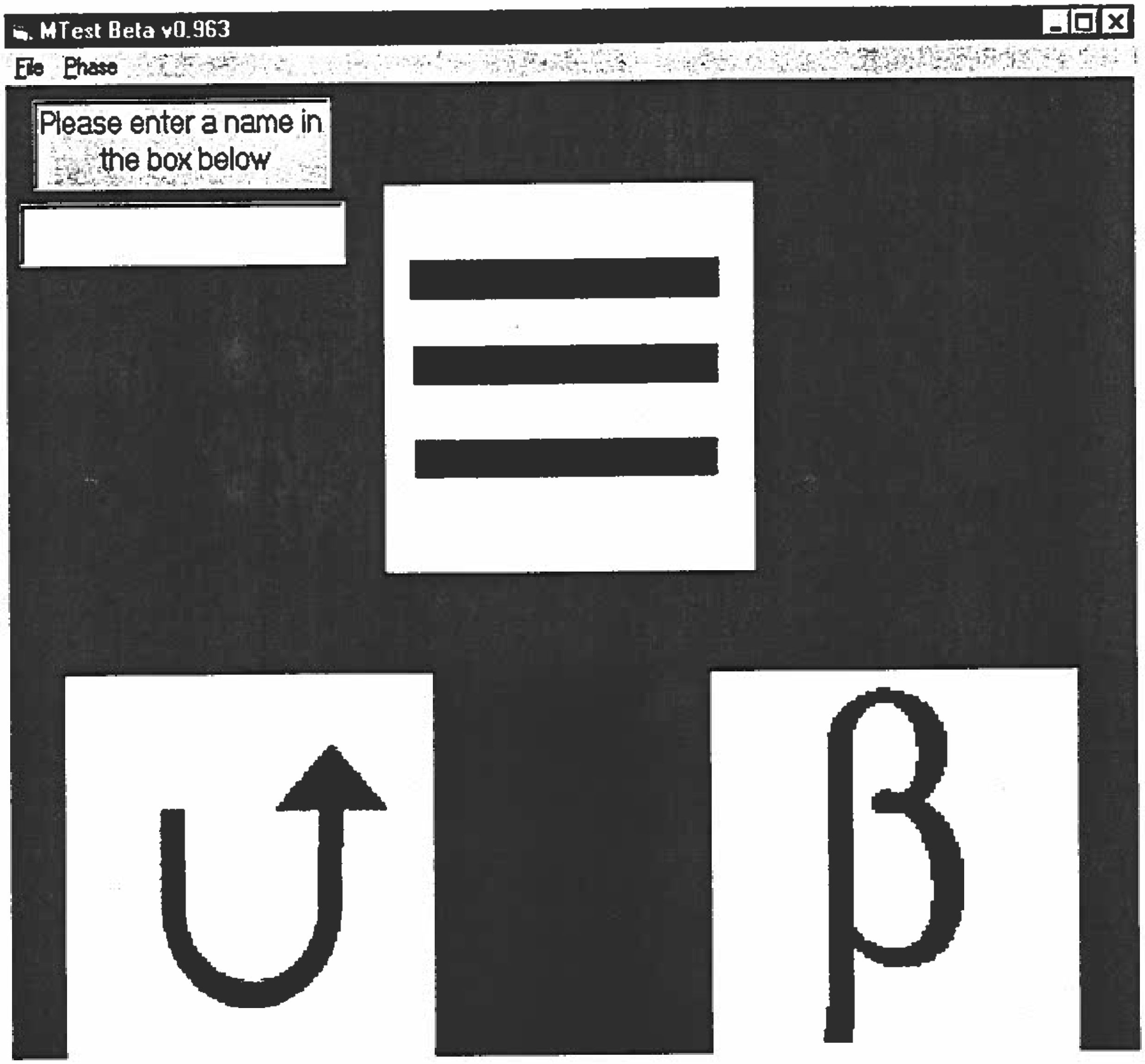

MTest Beta v0.963
File Phase
Please enter a name in the box below

Train

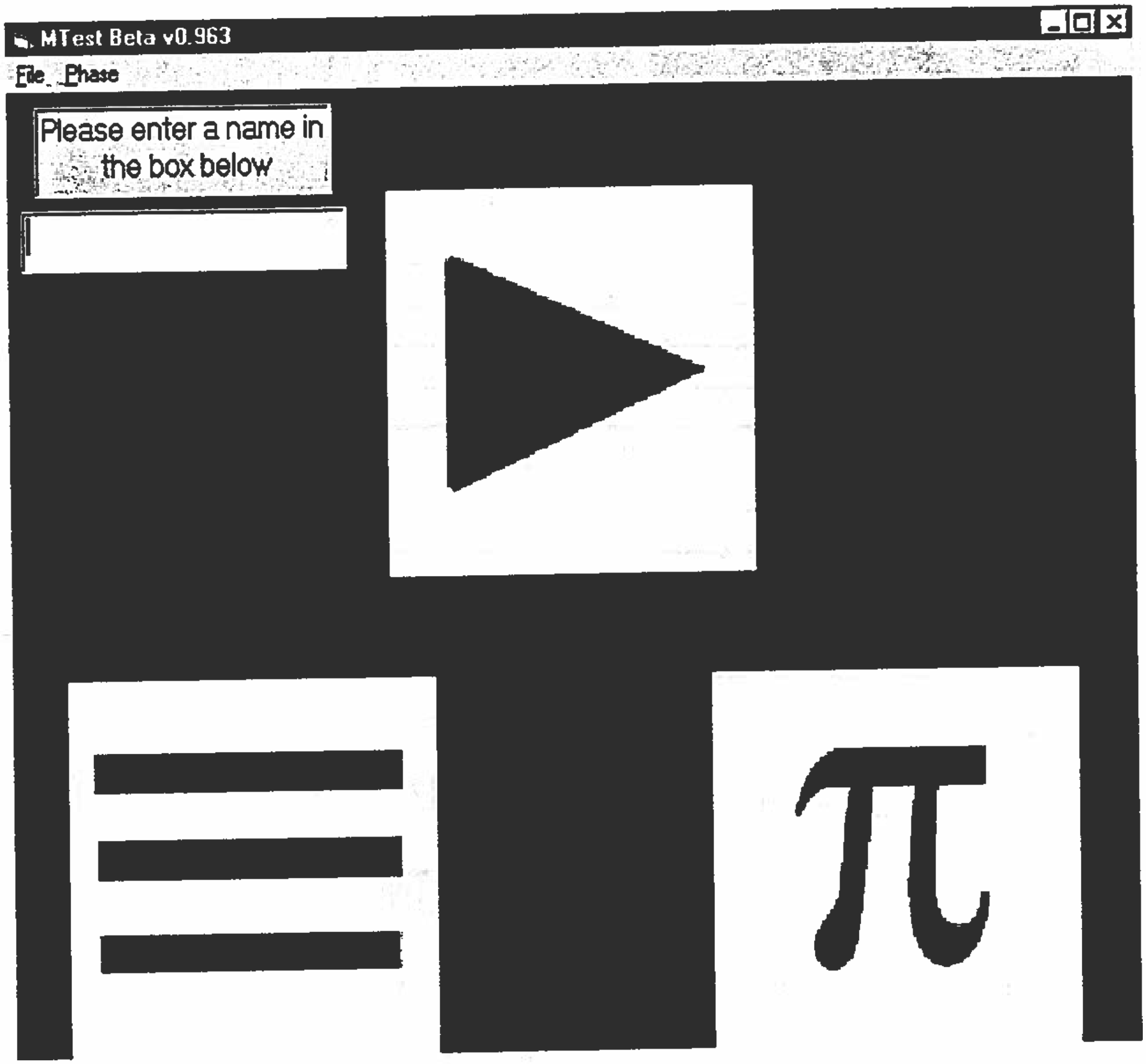


MTest Beta v0.963
File Phase
Please enter a name in the box below
β
σ

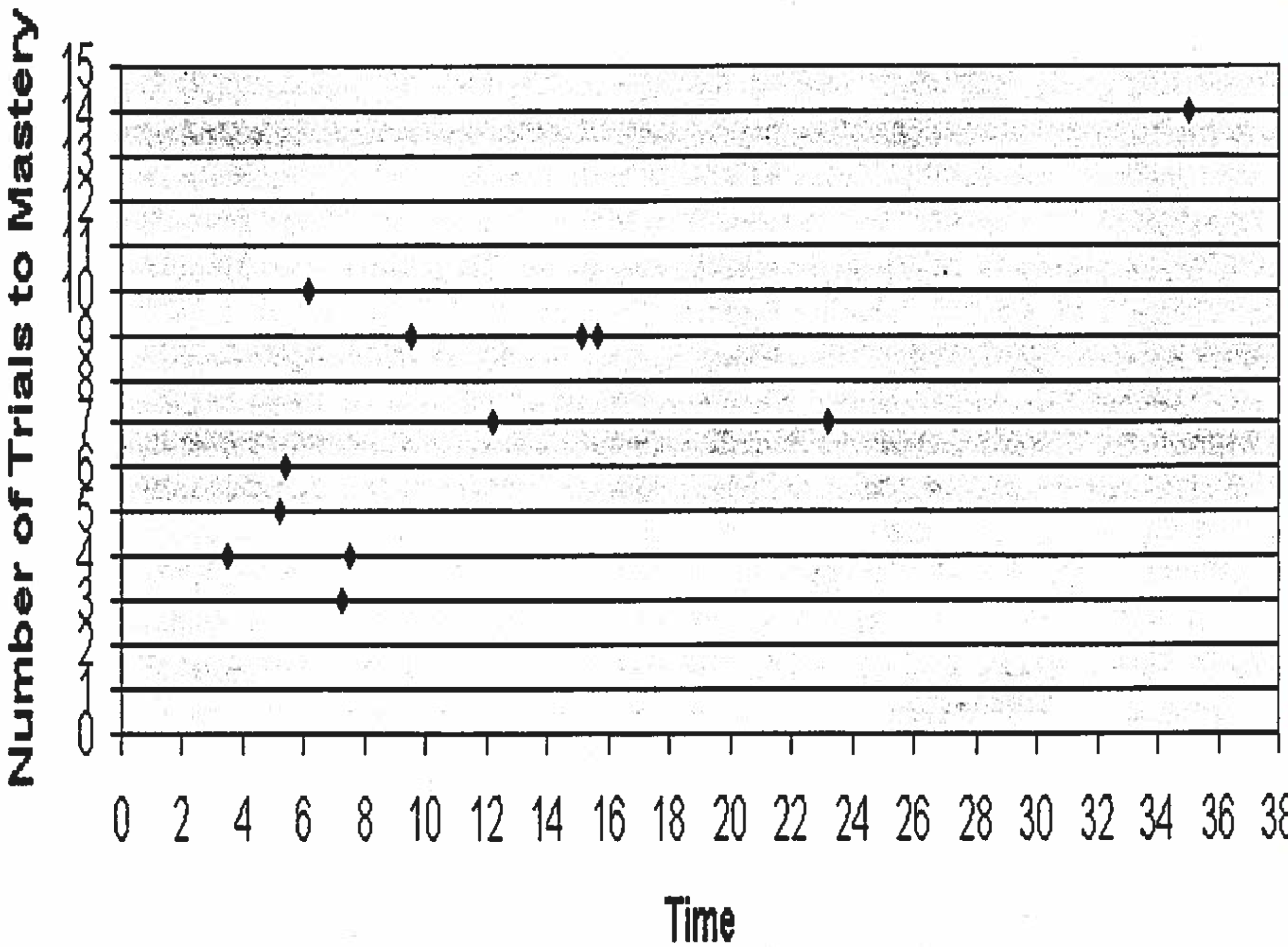
Train


MTest Beta v0.963
File
Phase
Please enter a name in the box below

Test

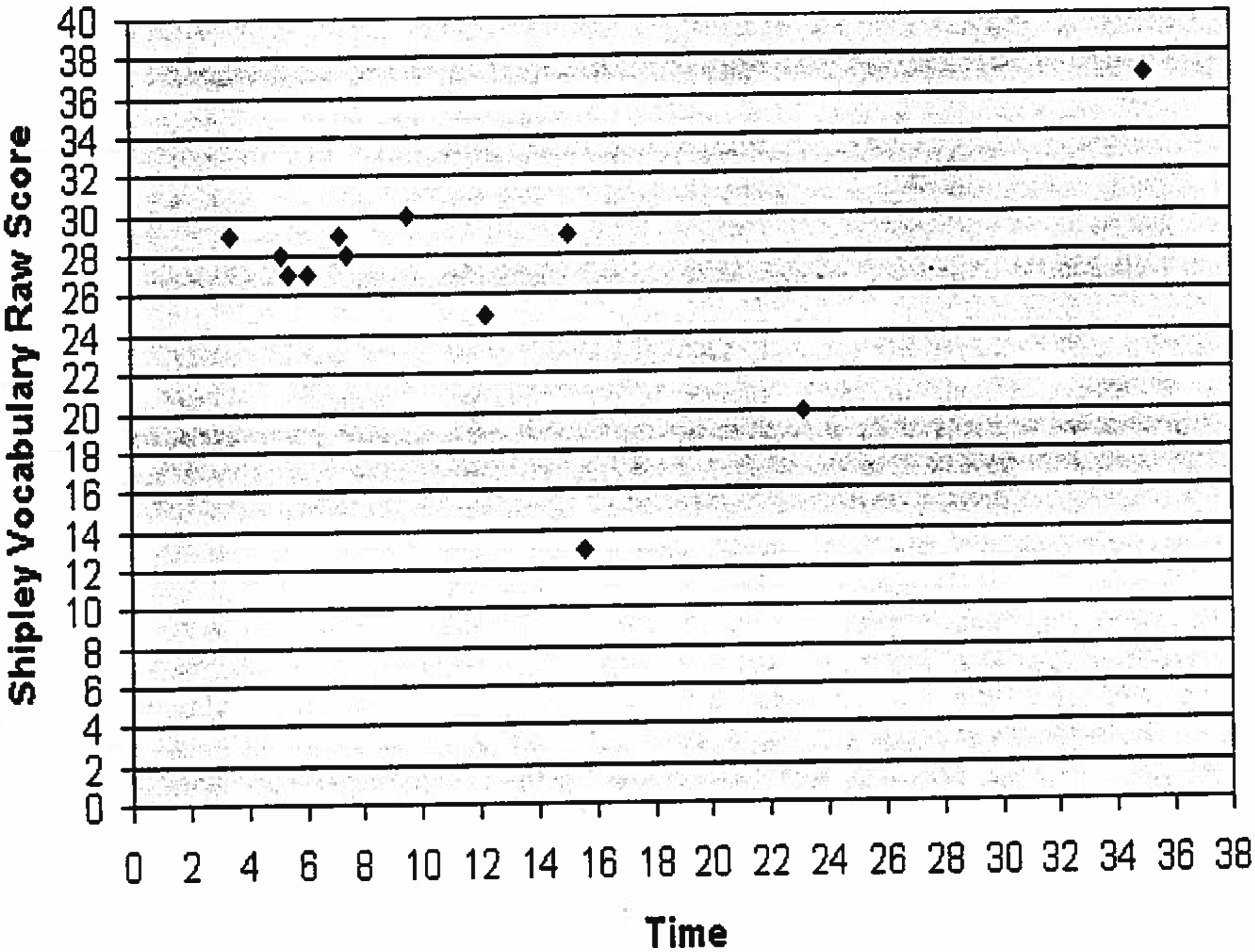

MTest Beta v0.963
File
Phase
Please enter a name in the box below

Appendix M

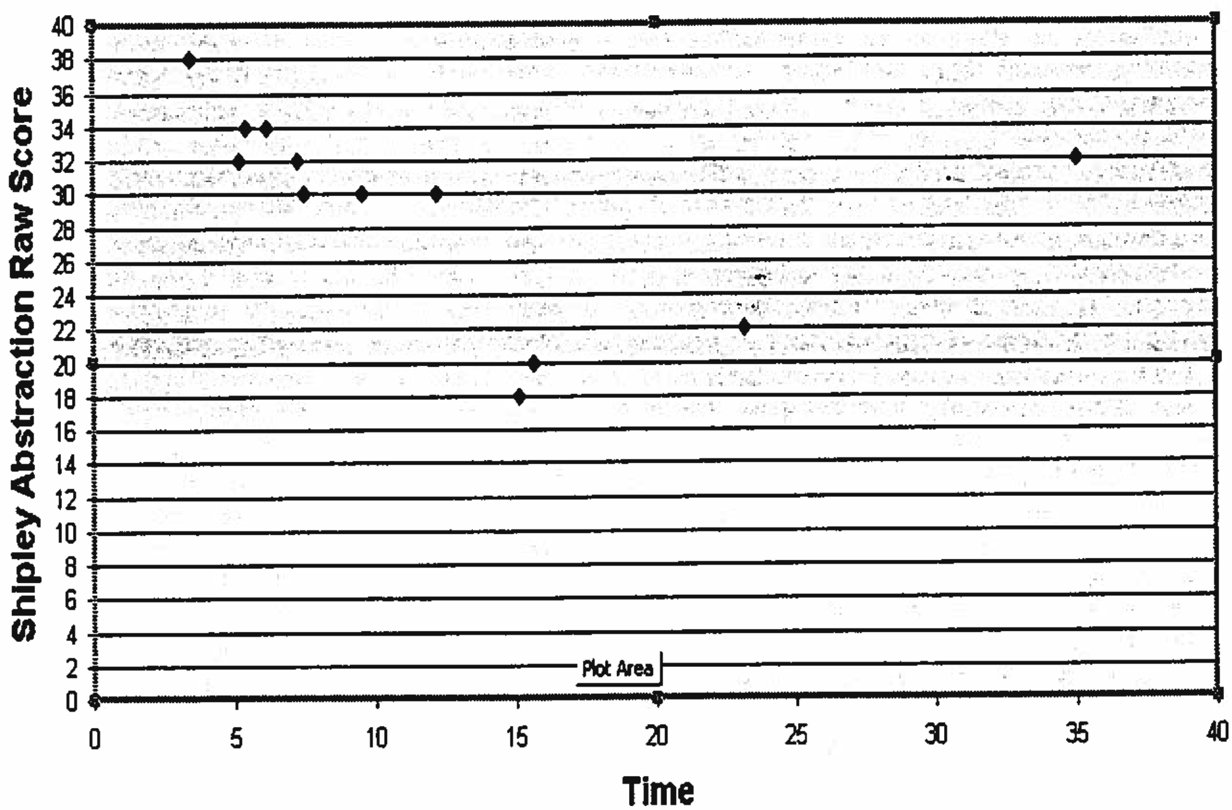


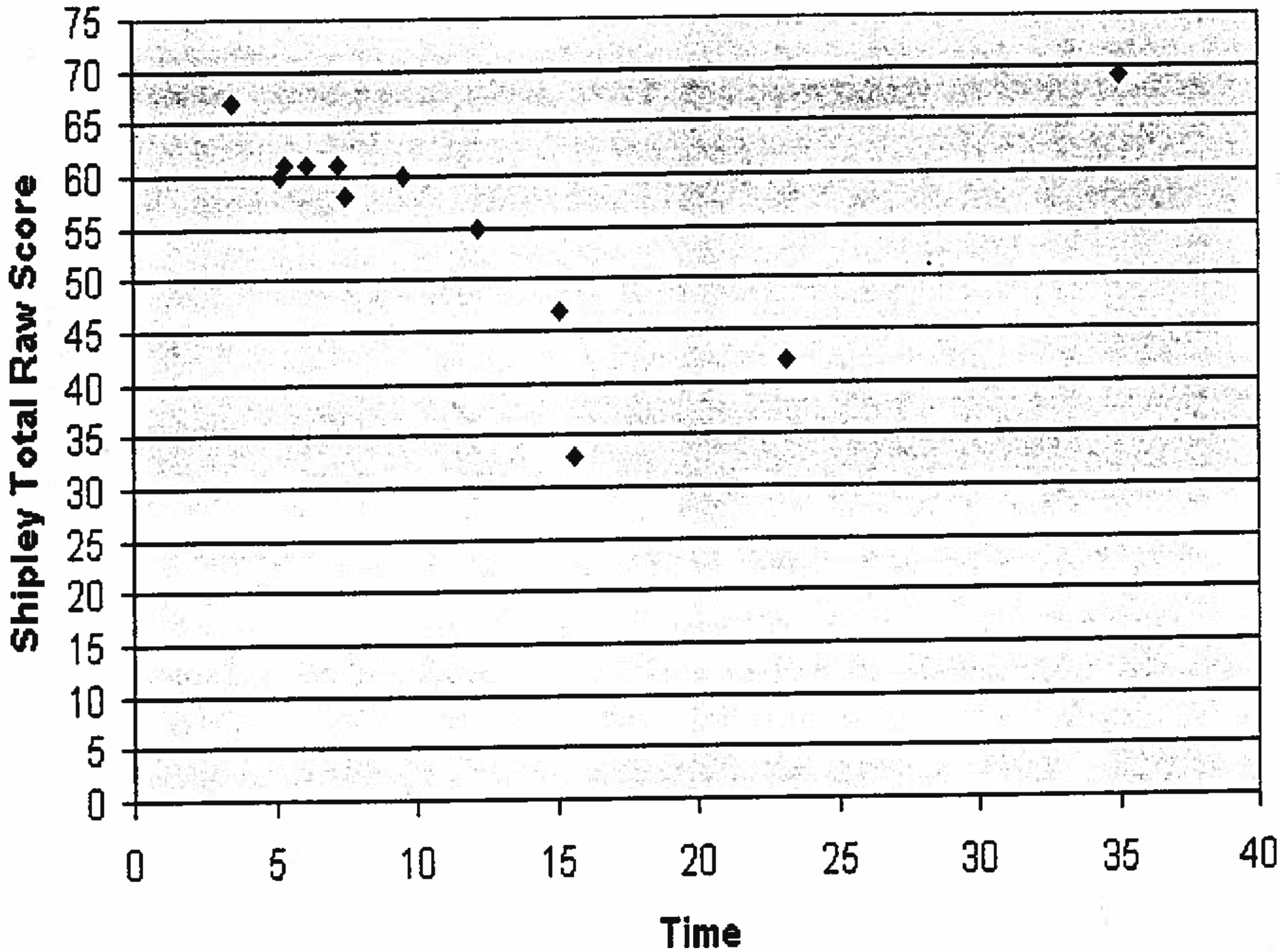
Number of Trials to Mastery
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38
Time

Appendix N

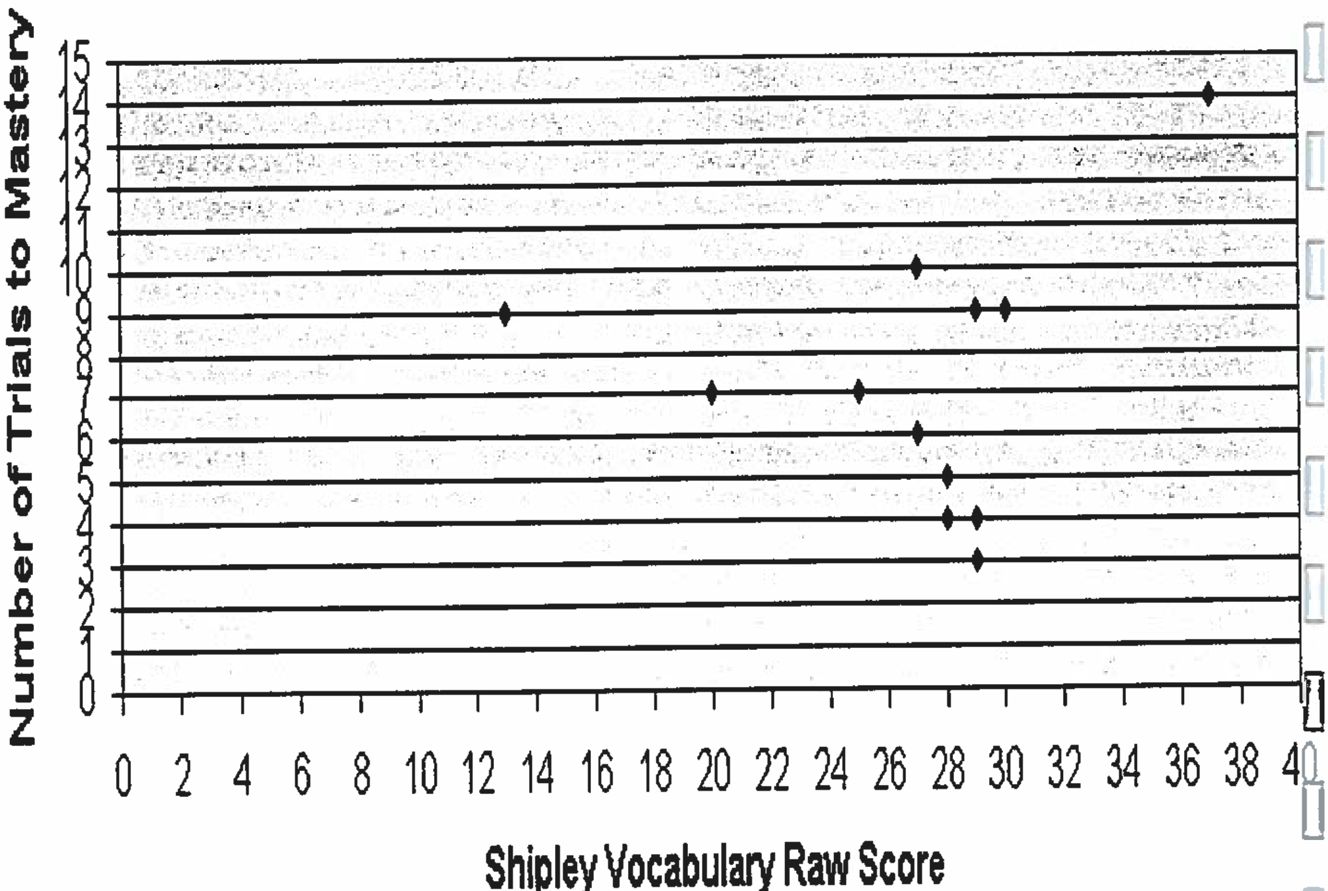


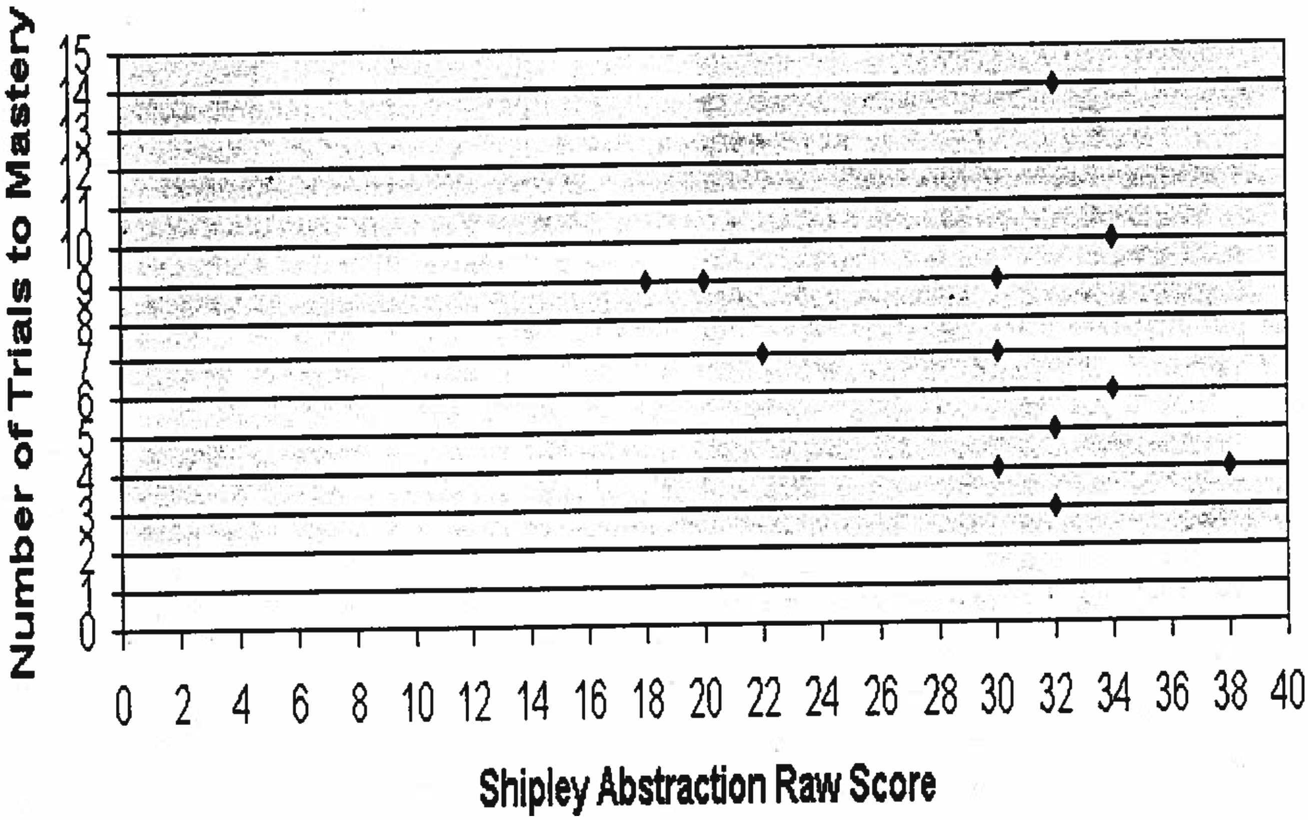
Shipley Vocabulary Raw Score
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38
Time

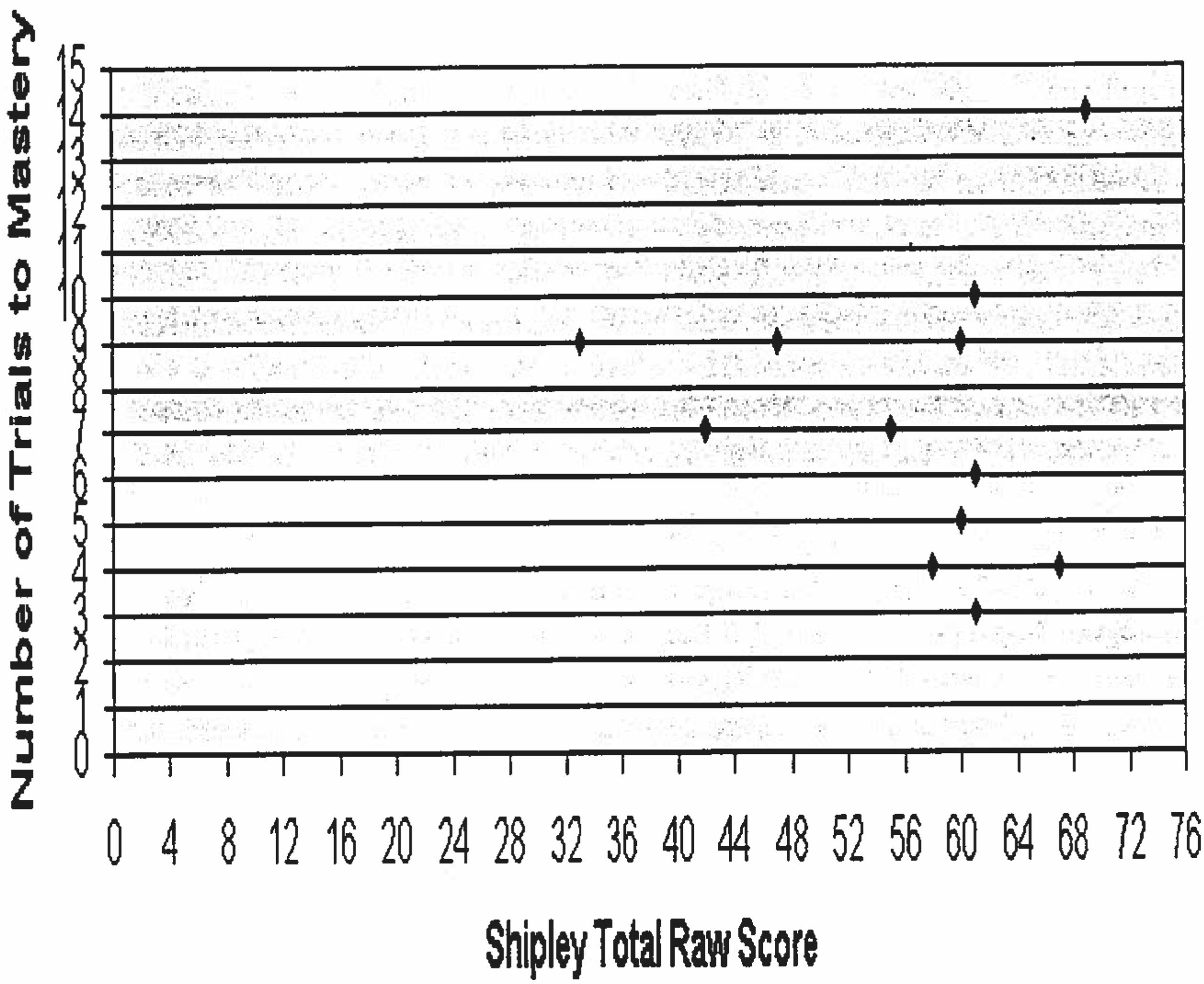

Shipley Abstraction Raw Score
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Plot Area
0
5
10
15
20
25
30
35
40
Time


Shipley Total Raw Score
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
Time

Appendix O


Number of Trials to Mastery
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
Shipley Vocabulary Raw Score


Number of Trials to Mastery
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
Shipley Abstraction Raw Score


Number of Trials to Mastery
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68 72 76
Shipley Total Raw Score

Soil Development and Soil Characteristics on a Reclaimed Mine Site

By: Aven Sizemore, Professor Jan Westerik, and Dr. Joe Manzo

Abstract

The purpose of this study is to determine if it is feasible for reclaimed surface mine sites to be restored to their natural habitat. After careful inspection of the study and control site, we determined the best course of action would be to examine and compare the soils of these two sites. We compared soil texture, water infiltration, soil temperature, soil compaction, pH levels, soil chemistry, soil moisture content, and overall fertility evaluation.

Overall, this study shows that the Birch River Coal Company restored the reclaimed mine site to a relativity productive pastureland according to the West Virginia Division of Environmental Protection's standards. Our research suggests that the West Virginia Division of Environmental Protection's policies might need reevaluated.

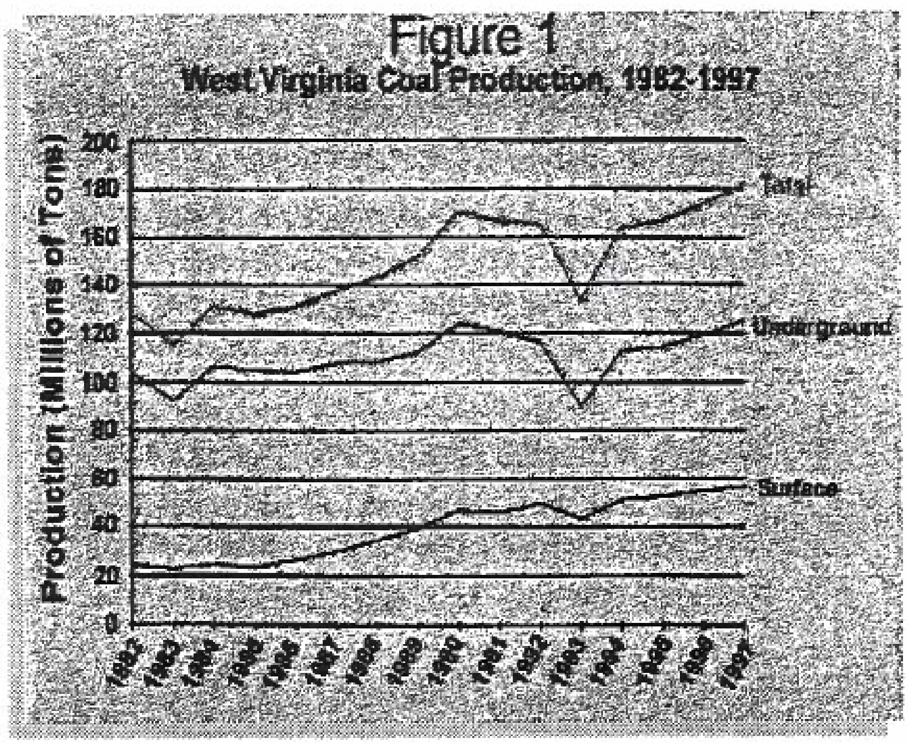
Introduction

Mountain top removal coal mining, a variant of strip mining, has become a controversial environmental and political issue in West Virginia. Mountain top removal consists of bulldozing down hilltops to uncover valuable, low- sulfur coal seams, which cannot be economically mined otherwise. This form of mining is a variant of strip mining.

The overburden removed from mountain top removal mine sites is normally dumped into the stream valleys that previously drained the area. In 1998, the West Virginia State Legislature passed a bill allowing coal companies to fill in larger streams and a greater cumulative length of stream channel with mine waste, without compensating the State for the loss. The applicable Federal Surface Mining Control and Reclamation Act (title 38 series 2 and title 47 series 30) generally requires that strip mined land be reclaimed to its approximate original contour (AOC). Ward (1999) states that mountain top removal mines can be exempted from this requirement because the additional costs so incurred might keep coal companies from (strip) mining in West Virginia altogether. There have been sixty-one active mountain top removal sites in West Virginia that have been exempted from AOC requirements to date (Ward, 1999).

In their media defense of the practice, coal companies maintain mountain top removal is the one mining method that will allow them to continue to operate and that only so can they continue to contribute to growth and development in West Virginia. Zerbe (1998) noted that statistics compiled by the Office of Miners Health, Safety and Training show that in 1948 there were 125,669 miners employed in West Virginia. By

1960 this number had dropped to 48,696. The general downward trend in coal mining employment continued after 1960. In 1987, there were 28,885 miners and in 1996, only 21,296. By 1997 the number of coal miners employed in West Virginia had declined to18,165. In spite of the decline in coal mining employment over the last several decades coal production is the highest it has ever been in West Virginia, as Figure 1 shows. Figure 1 also shows an increase of surface mined coal and a decrease in underground mined coal. Since underground mining employs more individuals than surface mining it would indicate than there would a decrease in employment rather than an increase.



**Source: West Virginia Geological Survey

So, when coal companies claim they need to remove the tops of mountains and destroy the trees and landscape, to recover the coal; and when they claim they can restore mine sites back to natural habitats, I became concerned. I decided to try to determine how feasible it really is to restore reclaimed surface mine sites to a reasonably productive habitat.

The first task in pursuit of the project was to locate reclaimed mountain top removal mine sites that could be studied. This was more complicated than had been anticipated. Mr. Worley Brown, a retired coal miner from Nicholas County, helped me locate several reclaimed surface mine sites and provided information about the history of these sites. The real problem encountered was receiving permission from a coal company to do research of any kind on a reclaimed mountaintop mine site. Three different coal companies refused us access to their reclaimed mountaintop mine sites before we contacted and received permission from the Birch River Coal Company to study one of their reclaimed mine sites. This reclaimed mine study site is located on Mill Creek Road East of US Route19 north of Summersville in Nicholas County, in relatively close proximity to several sites where the Birch River Coal Company currently operates a coal cleaning plant and is mining coal.

After an inspection of the reclaimed mountain top mine site, we decided to study the surface material's plant growth medium – i.e., soil – characteristics. We also decided to select a control site for comparison purposes. This site has not been mined, and its vegetation cover is similar to that of the study site. Upon completion of the study, we expect to be able to evaluate the ability of the soil or soil-like material to support adequately the growth of a plant community.

Factors to be Studied

We proposed to compare soil texture, water infiltration rates, soil temperature profiles, soil compaction and pH levels, soil moisture content, and various aspects of soil chemistry relating to soil fertility for the two sites selected. Equipment used will be mentioned below in the paper. Finally, by comparing the various readings for these two sites we can evaluate and perhaps project the rate at which the mined area is returning to a natural habitat.

When studying soils in a field setting, the texture of the soil is typically the first thing you notice and is an important property to determine. Soil texture is defined as the percentage by weight of the soil separates - sand, silt, and clay – size particles – that make up the mineral portion of the soil. To determine soil texture, you need to ascertain the mix of particles present. The largest of the soil separate particles, coarse sand, have a maximum diameter of 2 millimeters ($2x\ 10^{-3}m$). Particles larger than sand size may be present, but they are considered chemically inert in a soil because they cannot take part in chemical reactions between plant roots and the soil's mineral material. (Foth, 1990; Singer and Munns, 1996). Soil texture significantly affects the productivity and usability of the soils. Coarse-textured soils are often not the best for agricultural use. They can not easily hold and supply sufficient water or plant nutrients to produce high-quality crops every year without regular and substantial applications of fertilizer.

Factors that affect water infiltration include the amount of water already present in the soil. Obviously wet soils have slower infiltration rates than dry soils. This is because pores / cracks are fewer and smaller as clays become moist and swollen. Further, warm soils can take in water faster than cold soils can. Soil compaction, caused by vehicle traffic or trampling by cattle due to heavy grazing, reduces pore space, slows rainfall infiltration rates and speeds up water run off. In turn, this speeds up soil erosion. Although a soil's infiltration capacity is not consistent over time, it generally decreases during an irrigation or rainfall episode.

Another soil property to consider is the degree of compaction a soil has experienced. Placing a weight on the soil surface rearranges the soil particles and causes soil compaction. Soil compaction causes major problems for plants because plants cannot readily push their roots through dense compacted soil. Ellis and Mellor (1995) state, that under these conditions, plant growth may be restricted, particularly during the early stages of germination, and emergence and the main phase of root network development. (White, 1997; Winegardner, 1996). Foth (1990) states that soil compaction results in: (1) a decrease in total pore space, (2) a decrease in micropore space and (3) an increase in macropore space (Singer and Munns, 1996; Steila and Pond, 1989). Soil compaction also has adverse effects on other soil characteristics. An increase in compaction and a consequent decrease in porosity may cause waterlogging and poor aeration; these in turn have a detrimental effect on a soil's thermal characteristics.

Soil temperature and a soil's response to solar energy receipts is still another aspect of soil study. Soil temperature influences seed germination, root growth, the microbial population of the soil, the soil water supply, the temperature of the air above the soil, mineral weathering, and organic matter accumulation in soil. Thus, temperature is of great importance to the character of a soil. Brady and Weil (1999) state that mineral soil particles conduct energy faster than water. Therefore when particle-to-particle contact is increased by soil compaction, heat transfer rates are increased in that compacted soil (Ellis and Mellor, 1995; Hausenbuiller, 1985). Soils that warm up rapidly encourage early beginning to plant growth. The optimum growth for tropical species occurs at 30° C or more, while for temperate species it occurs at 20°C (Foth, 1970). The minimum temperature for plants to germinate and/or grow is around 32 to 38°C (Sopher and Baird, 1982). The soil cover provided by plants growing in and on the soil and any organic residue or other type of mulch also influences the temperature of the soil. A soil surface shaded by plant leaves is cooler than a soil surface that gets direct sun light. Dry soils are normally hotter than wet soils because a significant share of the energy received by a moist soil is used to evaporate some of the water it contains.

A very important soil property in relationship to plant growth is soil pH, a measure of its acidity or basicity. Otherwise stated, soil pH is a measure of the relative concentration of hydrogen (H^+) and hydroxyl (OH^-) ions in the soil solution. Hausenbuiller (1985) states pH is specifically a measure of the effective concentration of H^+ ions in equivalents per liter of solution. Indirectly, pH is also a measure of the OH^- ion concentration. Their relative concentrations determine whether the soil is acidic, basic, or neutral. If the concentration of H^+ ions is greater than the concentration of OH^- ions a solution is acidic. If the concentration of OH^- ions is greater than the concentration of H^+ ions it is basic, and if there is an equal concentration H^+ ions of and OH^- ions it is neutral. (Tan, 1994; Miller and Gardiner, 1998). The most favorable soil pH values for good plant growth conditions range from 5.0 to 8.5.

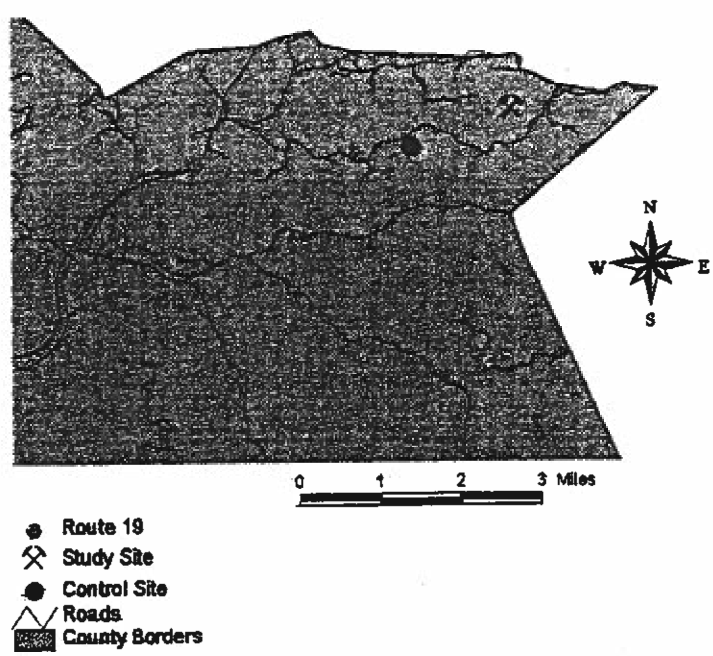
<u>Location and Description of Study and Control Sites</u>

The mined study site is located East of US Route 19 on Old Mill Creek Road, in northern Nicholas County (Figure 2). Its approximate geographic grid coordinates are

38°31.616′ N, 80°39.009′ W as determined through using a Garmin-GPS III unit. The site was reclaimed fifteen years ago, for a pasture land use (Workman, 1999). It has an approximately level to gently rolling topography, and its vegetation consists of a variety of planted grass species including a yellow flowering vetch-like plant, which seems to be the dominant species present, as shown in Figure 3. It also has a coarse textured layer of surface material (Figure 4). There are no trees growing on the mined site (Figure 5), and no tree seedlings are obviously present.

The control site, shown in Figure 2 and also located east of US Route 19 on Old Mill Creek Road, is somewhat closer to US Route 19 than the study site. Its approximate geographic grid coordinates are 38°31.596′ N, 80°39.006′ W. The control site is now abandoned, but was used to pasture cattle sometime within the past fifteen years (Brown, 1999). This site has a gently sloping topography, and its vegetation consists of a variety of grass, weed plant and wild flower species, as shown in figure 6. This site is undergoing ecological succession as shown by tulip poplar and other seedling trees present.

Figure 2. Northeastern Nicholas County, WV



Both the study and control sites, as shown on the USGS 7.5 minute series Little Birch Quadrangle published in 1967, exhibit a relatively level to gently sloping topography with forest as its vegetation cover. The Nicholas County Soil Survey shows that the soil type of both sites, prior to mining, belonged to the Dekalb and Gilpin soil series. The soil characteristics for the specific soil types originally present in the area of the study and the control sites are given in Table 1. The study site was mined and reclaimed after the dates of publication for the Little Birch Quadrangle and the Nicholas County Soils Survey Bulletin, so the topographic and soils description above obviously

Table 1: Soil Type Characteristics of the Study and Control sites.

Soil Type	Soil Characteristics
DeKalb (DeC)	Channery sandy loam, three to fifteen percent slopes, very stony, slight erosion hazard, moderate seedling mortality, moderate plant competition, and approximate soil pH of 3.6 to 6.5
DeKalb (DeF)	Channery sandy loam, fifteen to thirty-five percent slopes, very stony, severe erosion, hazard, moderate seedling mortality, moderate plant competition, and approximate soil pH of 3.6 to 6.5
Gilpin (GnC)	Silt loam, three to fifteen percent slopes, stony, slight erosion hazard, moderate plant competition, and approximate soil pH of 3.6 to 5.5

*Soil type and soil characteristics are derived from the United States Department of Agriculture—Soil Conservation Service – Nicholas County Soils Survey.

no longer apply to the study site. In the reclamation process, the Fiveblock soil type replaced the original soils at the study site. This reclaimed soil-like surface is described as channery sandy loam. Channery soil is a soil that has more than 15 percent thin, flat fragments of sandstone, shale, slate, limestone, or schist. (United States Department of Agriculture, 1992)

<u>Procedure</u>

Once a week beginning June 8, 1999, until July 27, 1999, I traveled first to the reclaimed mine site. After my arrival, I used a slotted soil sampler tube to collect a soil sample and bagged it in a Ziploc® bag. The bags were identified with stickers color-coded for each site. The sample collection date was noted on the sticker. Following this procedure I used a Reo-Temp heavy-duty steel soil thermometer to read soil temperatures at depths of 2.5, 5.0, and 7.5 cm, respectively. I next took an air temperature reading using the dry bulb on a Taylor-psychrometer. Subsequent to that I soaked a small area of soil with one gallon of water to calibrate a portable soil moisture meter for the soil of that site. After calibration I obtained compaction test, using a Dickey – John soil compaction meter. Also, I used a Cronus-Pro Survivor stopwatch and a set of Ben Meadows infiltration rings to measure water infiltration rates at the two sites.

After collecting the field data, the soil samples were transported to the laboratory for subsequent analysis. When I arrived at the laboratory I first took the soil samples out of the Ziploc® bags, crumbled them up, and put them in open dishes so the samples could air dry. After the samples had dried I used a LaMotte soil fertility test kit to do a chemical analysis of the soil samples. The equipment and supplies in this kit allowed me to test for soil pH. It also allowed me to determine the samples approximate content and/or concentration of the following: humus, nitrate nitrogen, phosphorous, potassium, calcium, ammonia nitrogen, magnesium, manganese, aluminum, nitrite nitrogen, ferric iron, sulfate, and chloride, content and concentration. The equipment and supplies in this kit made it possible to determine approximately the amounts of the elements and ions tested for that are present in the soils from which the samples were drawn.

Results and Discussion

The procedures described above provided the various soil temperature and soil moisture readings, along with soil compaction levels and water infiltration rates. There was a noticeable difference in the compaction rates of both sites. The study site had a compaction rate of 200 pounds per square inch, whereas the control site had a compaction rate of 100.5 pounds per square inch. Tables 2 and 3 show that there are no great differences in the relative soil moisture content between the reclaimed mine site and the control site. The difference in the soil temperatures (Table2 and 3) of the study and control sites are probably caused in part by the difference in the surface soil material of the study and control site. The readings of soil temperature, and soil moisture were only taken at the depths of 2.5 cm, 5.0 cm, and 7.5 cm because the soil layer at the study site was so compacted that it could not be penetrated any further without risking destruction of the equipment. The soil temperatures show a significant, although not a consistent, difference in temperature at various depths (Table 2 and 3) which can be at least explained partially by the shading of the plant matter coving the soils. The plant cover on the reclaimed study site, as Figure 6 shows, is not as dense and continuous as that at the control site shown in Figure 7.

TABLE 2: Soil Temperature, Relative Soil Moisture Content and Ambient Air Temperature at the Study Site on Selected Days in June and July, 1999

Field Observation Dates	6/8/99	6/15/99	6/22/99	6/29/99	7/6/99	7/14/99	7/20/99	7/27/99
Soil Temperature @ 2.5 cm	–	26°C	35°C	35°C	–	34°C	32°C	33°C
Soil Temperature @ 5.0 cm	25°C	24°C	26°C	26°C	–	27°C	28°C	29°C
Soil Temperature @ 7.5 cm	20°C	21°C	25°C	25°C	–	26°C	25°C	28°C
Soil Moisture @ 2.5 cm	–	–	–	7	4	1.9	6	6
Soil Moisture @ 5.0 cm	–	–	–	8	7	7	7.5	6.5
Soil Moisture @ 7.5 cm	–	–	–	9	8	0.4	7.5	6
Air Temperature	–	–	26.7°C	28.9°C	29.4°C	27.8°C	28.9°C	30.6°C
** Note: Soil moisture readings are relative rather than absolute. On the instrument used, a reading of 10 equals soil saturation								

1234

TABLE 3: Soil Temperature, Relative Soil Moisture Content and Ambient Air Temperature at the Control Site on Selected Days in June and July, 1999

Field Observation Dates	6/8/99	6/15/99	6/22/99	6/29/99	7/6/99	7/14/99	7/20/99	7/27/99
Soil Temperature @ 2.5 cm	–	25°C	26°C	–	32°C	28°C	28°C	32°C
Soil Temperature @ 5.0 cm	22°C	22°C	20°C	–	27°C	26°C	26°C	27°C
Soil Temperature @ 7.5 cm	20°C	20°C	19°C	–	25°C	25°C	25°C	25°C
Soil Moisture @ 2.5 cm	–	–	–	8.1	6	2	2	6
Soil Moisture @ 5.0 cm	–	–	–	8	9	5	5	6
Soil Moisture @ 7.5 cm	–	–	–	8	9	5	5	7.5
Air Temperature	–	–	26.7°C	28.9°C	29.4°C	27.8°C	28.9°C	30.6°C

** Note: Soil moisture readings are relative rather than absolute. On the instrument used, a reading of 10 equals soil saturation

The laboratory results for the soils at the two sites show the presence of comparable amounts of ammonia nitrogen, chloride, ferric iron, magnesium, nitrite nitrogen, and sulfates in the soils of the two sites, as shown in Table 4. Table 4 also shows a difference in the levels of pH; nitrate nitrogen, phosphorus, potassium, aluminum, calcium, and humus. The differences shown in the pH levels and nitrate nitrogen, phosphorus, potassium, aluminum and calcium contents between the two sites, as shown in Table 4, suggest that lime and fertilizer may still be being applied to the study site. The water infiltration test done at the study and control sites were inconclusive; the readings made could not be adequately interpreted because infiltration rates were very high due to the drought the area experienced this summer.

TABLE 4: Chemical Analysis

Factors	Control Site	Reclaimed Site
pH	6.6	5.2
Nitrate Nitrogen	10 lbs./acre	20 lbs./acre
Phosphorous	100 lbs./acre	25 lbs./acre
Potassium	100 lbs./acre	180 lbs./acre
Humus	2	1
Calcium	2800 PPM	1400 PPM
Ammonia Nitrogen	very low	very low
Magnesium	medium	medium
Manganese	medium	medium low
Aluminum	high	very high
Nitrite Nitrogen	<1 PPM	<1 PPM
Ferric Iron	<5 lbs./acre	<5 lbs./acre
Sulfate	1000 PPM	1000 PPM
Chloride	500 PPM	500 PPM

The study site has lower pH than the control site and only half the calcium content. The study site soil is more acidic, and so less productive. The higher nitrate nitrogen and potassium at the study site suggest the application of fertilizer. However, pH and calcium results do not suggest that lime is being added to the study site. The other significantly diferent reading is the free aluminum ion concentration. The fact that it is very high at the study site helps explain some of the low pH levels and also suggests that plants might have trouble on this site due to the possibility of aluminum toxicities.

Tables 5 and 6, show a significant difference in the soil texture between the study and control sites. For the study site Table 6 shows that 33% of the total sample weight of the soil has a soil particle size greater than 2 millimeters, which indicate a coarse – textured soil. Coarse – textured soils can not hold sufficient water or nutrients to support long – term agriculture use.

TABLE 5: Soil Texture at the Control Site

Soil Particle Sizes	Weight in Grams	% of Total Sample Weight
> 2 mm	26.0	17.7 %
2 mm – 1 mm	33.5	22.7 %
1 mm – 0.5 mm	32.5	22.1 %
0.5 mm – 0.25 mm	25.3	17.2 %
0.25 mm – 0.125 mm	17.0	11.5 %
0.125 mm – 0.075 mm	8.0	5.4 %
0.075 mm – 0.063 mm	2.5	1.7 %
0.063 mm – 0.045 mm	2.0	1.4 %
< 0.045 mm	0.5	0.3 %
Total	147.3	100 %

TABLE 6: Soil Texture at the Study Site

Soil Particle Sizes	Weight in Grams	% of Total Sample Weight
> 2 mm	39.0	33 %
2 mm – 1 mm	19	16.1 %
1 mm – 0.5 mm	15.2	12.9 %
0.5 mm – 0.25 mm	27.2	23 %
0.25 mm – 0.125 mm	11.5	9.7 %
0.125 mm – 0.075 mm	3.3	2.8 %
0.075 mm – 0.063 mm	0.7	0.6 %
0.063 mm – 0.045 mm	1.7	1.5 %
< 0.045 mm	0.5	0.4 %
Total	118.1	100 %

Summary and Conclusions

The purpose of this study was to determine how feasible it really is to restore reclaimed surface mine sites to a reasonably productive habitat. Due to time constraints and our area of interests we decided to look at the soil characteristics of a reclaimed area to see if it suited the purpose for which it was reclaimed. The reclaimed mine site which we used for our study site was reclaimed for pastureland. The results of our research show that the mined site has been reclaimed to possibly productive pastureland, although it is not being used for that purpose. The soil texture analysis showed a coarse texture soil at the study site. This might indicate the reclaimed site could not support crop production over the long term. Due to soil compaction levels at the reclaimed study site it will be unable to support the variety of vegetation types or tree growth that the control site supports because plants cannot readily push their roots through the dense compacted soil-like material of the study site. You could probably expect significant forest growth to have occurred on the control site in twenty to fifty years. Significant forest growth on the reclaimed study site should probably not be expected until twice that amount of time has passed. The possibility of aluminum toxicities and low pH and calium content make it difficult for plants to grow.

The Birch River Coal Company reclaimed the mined study site so that it would meet West Virginia Division of Environmental Protection reclamation standards. Nonetheless, the mined study site does not seem to be in use for any economic purpose now, and its ability to support the most common type of economic activity for the area other than mining will continue to be less than ideal for decades to come. Maybe the real conclusion of this study should be that the West Virginia Division of Environmental Protection is not meeting its mandate by being so quick to grant AOC variances to the mining companies it is supposed to regulate. A second conclusion to draw is that current reclamation standards are such that they need to be reviewed and revised to perhaps make it possible for reclaimed surface mine areas in thinly populated areas to recover to truly natural ecosystems much more rapidly.

References

Brown, Worley 1999. Personal Interviews .

Ellis, S.; Mellor A. 1995. Soils and Environment

Foth, Henry D. 1970. A Study of Soils Science.

Foth, Henry D. 1990. Fundamentals of Soil Science.

Hausenbuiller, R.L.1985. Soil Science: Principles and Practices.

LaMotte. 1994. LaMotte Soil Handbook.

McFerrin, John 1999. Haden, unlike DEP, followed the law. The Charleston Gazette. March 23, 1999.

Miller, Raymond W.; Gardiner, Duane T.1998. Soils in our Environment.

Nease, Janice. 1999. Miners' job security at whim of coal companies. The Charleston Gazette. April 12, 1999.

Radmacher, Dan.1999. Arch Coal's hypocrisy is Maddening. The Charleston Gazette April 9,1999.

Singer, Michael J.; Munns, Donald N. 1996. Soils: An Introduction.

Sopher, Charles D.; Baird, Jack V. 1982. Soils and Soil Management.

Steila, Donald; Pond Thomas E. 1989. The Geography of Soils: Formation, Distribution and Management.

Tan, Kim H. 1994. Environmental Soil Science.

United States Department of Agriculture.1992. Nicholas County Soil Survey.

Ward, Ken Jr.1999. Mining Legislation dodges big-picture debate. The Charleston Gazette –Sunday Gazette –Mail. January 17,1999

White, R.E. 1997. Principles and Practice of Soil Science: The soil as a natural resource.

Winegardner, Duane L. 1996. An Introduction to Soils for Environmental Professionals.

Workman, Mark.1999.Birch River Coal Company.

Zerbe, Carter. 1998. Mountaintop Nightmare. The Charleston Gazette –Sunday Gazette – Mail. November 16,1998.