ANALOGICAL REASONING IN CAPUCHIN MONKEYS (*CEBUS APELLA*)

by

ERICA HOY KENNEDY

(Under the direction of Dorothy Fragaszy)

ABSTRACT

Analogical reasoning involves recognizing similarities among object relations when the objects themselves are dissimilar. It has been argued that humans only share the capacity for this kind of reasoning with apes that have had prior token or language training. This study investigated whether capuchin monkeys can use analogical reasoning in order to solve a three-dimensional search task that was modeled from a similar methodology used in the developmental literature. The task involved hiding a food item under one of two or three opaque plastic cups of different sizes, and then allowing the subject to search for food hidden under the cup of analogous size in their own set of cups. Four monkeys were first trained to perform basic match-to-sample with three cups, and then were exposed to a series of relational matching tasks. If subjects reached criterion on these relational matching tasks, they were exposed to relational transfer tasks involving novel stimuli. Three of the monkeys failed to reach criterion on the basic relational matching tasks and therefore were not tested further. One monkey, however, revealed above-chance performance on all tasks, including the series of transfer tasks with novel stimuli. This evidence suggests that, contrary to previous arguments, a member of a New World monkey species with no language training has the capacity to solve an analogical problem.

INDEX WORDS: Analogical Reasoning, Capuchin monkeys, *Cebus apella*

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CHAPTER 1

INTRODUCTION

The ability to reason analogically is often considered one of the major hallmarks of human cognition. According to Anderson (2000) analogy can be defined as, "the process by which a problem solver maps the solution for one problem into a solution for another problem." The use of analogies makes categorization of new objects and solutions to novel problems more efficient because knowledge of similar objects/solutions can be used rather than attempting to solve problems or categorize items from scratch. It has been argued that the ability to comprehend analogies is linked to the use of language. To use language, one must understand that combinations of arbitrary symbols represent particular objects, actions, or concepts in the real world. The habitual use of such linguistic representations in daily life may have facilitated the use of higher order problem solving abilities, including the use of analogy in humans. The ability to reason analogically has clearly had a great effect on human advancement in terms of science and technology and thus has been one of the keys to human progress. The purpose of this study was to determine the degree to which the capacity to understand and use analogies is present in another species that does not use language. By studying the ability of non-human primates to use analogies to solve problems, we may gain a better understanding of our own reasoning ability and of the evolutionary pathways that may have led to the appearance of analogical reasoning in humans.

Developmental psychologists have examined the factors that influence the time frame in which children are able to comprehend analogies, as humans do not appear to be born with this understanding (it develops over time). It is argued that young children respond to literal (physical) similarity between objects in terms of color, shape, etc. (Gentner, Rattermann, Markman, & Kotovsky, 1995). Gentner argues that as children acquire greater knowledge, they go through a "relational shift" in which they gain the ability to understand *relational* similarities in addition to the physical object similarities they previously relied on. To illustrate this shift, Gentner gives the example of children asked to interpret the following metaphor: "A tape recorder is like a camera." In this case, 6-year-olds used object-based interpretations ("both are metal and black"), while 9-year-old children noticed the relational structure (the ability to record something for later) (Gentner et al., 1995).

There are two primary explanations for the "relational shift" given in the literature. One explanation is that children undergo a "global shift" in their cognitive abilities. In this case, the ability to understand higher-order relations is linked to Piaget's stages of cognitive development. Specifically, Piaget argued that children cannot complete relational analogies (non-object based) until they have reached the stage of formal operations at 11-12 years of age. An opposing explanation argues that children are able to focus on relational similarities as a function of their knowledge base (Gentner et al., 1995). According to this argument, younger children can perform analogies based on relational features if they involve a familiar context. In a 1977 study by Gentner, children of varying ages were asked, "If the tree had a knee, where would it be?" Children as young as four were able to solve this analogy involving relational features, suggesting that children do not need to reach the formal operations stage before they can reason in this way (Gentner et al., 1995).

If children are able to solve complex relational analogies as their knowledge increases, is it possible that other species with experience solving certain kinds of relational problems would also be able to solve similar, but novel, relational problems? It is argued that this may indeed be the case for chimpanzees. One chimpanzee in particular (Sarah) has shown much success in solving both functional and standard item analogies. In a 1981 study by Gillian, Premack, and Woodruff, Sarah was presented with a physical representation of an analogy in 2x2 matrix form. The analogy contained two relations, one between A and A,' and the other between B and B.' For example, Sarah was presented with a large blue triangle (A), a small blue triangle (A'), a large yellow crescent (B), and a small yellow crescent (B') in matrix form. Although the actual items being compared in this case are different (triangle and crescent), the *relation* between both pairs of items is the same (large to small). Sarah was presented with three stimuli in this form and was required to choose one item from a pair of objects to complete the analogy. One of the choices would complete a true analogy (i.e., maintain the same relationship between the pairs of objects), while the other item would not fit the analogy. It is important to note that the correct relation ("large" or "small") varied across trials, so that it was not possible to use one generalized size rule (i.e., "always choose the smallest item") to solve these problems. Sarah was also exposed to analogies that required some understanding of the functional use of household objects that she had previously encountered. In this case, she was exposed to items such as a padlock and key in relation to a tin can and can opener. In previous experiments, Sarah had learned to represent the concepts "same" and "different" with plastic tokens (Oden, et al. 2001). In this particular study, Sarah was required to use her prior knowledge of these concepts to label whether the two pairs of presented objects represented a "same" or "different" relationship. Sarah was successful at these tasks in both the geometric and functional forms, implying that she has the capacity to reason at the more abstract analogical level (Oden et. al, 2001).

Do other non-human primates show similar evidence of analogical reasoning? It has been argued by Premack that Sarah was successful at solving analogies because she had previous training with language, and that animals without this exposure to language would be unable to solve analogies (Shettleworth, 1998). A more recent study, however, revealed that chimpanzees that had no previous training with language, but did have experience using numerical symbols, were able to match "same" and "different" displays spontaneously (Thompson, Oden, & Boysen, 1997). For this reason, Thompson et al. (1997) argued that whereas training with abstract symbols is necessary for analogical reasoning to occur, the symbols not be linguistic.

According to Oden et.al (2001), there is no evidence to show that primates other than apes are able to perceive or solve analogies. Studies investigating analogical reasoning in rhesus macaques (*Macaca mulatta*) and capuchin monkeys (*Cebus apella*) using conceptual match-to-sample and dishabituation paradigms have produced negative results in terms of the ability of these species to comprehend analogies (Thompson et al, 1995; Thompson, Oden, Hyle, Hoy, Rapuano, & Safro, 2000). Results from analogical reasoning studies with monkeys suggest that there may be a fundamental difference between monkeys and apes in terms of their capacity to understand analogies.

A more recent study by Spinozzi, Lubrano, and Truppa (2004), however, provided evidence that monkeys are able to reason about abstract relations. In this study, five capuchins were tested on their ability to perform a MTS task that involved matching the spatial relations "above" and "below". In this case, subjects were required to match an image of a horizontal line with a dot situated either above or below the line to another image representing the same spatial relationship ("above" or "below") between the line and the dot. The monkeys were successful in matching the images when the choices included an image that matched the sample in terms of the relation between the line and the dot, but the distance between the dot and the line were varied so that there was no choice that was an identical match to the sample. The authors argued that these results provided evidence that capuchin monkeys can reason about abstract spatial relations (“above” vs. “below”). The current study aimed to determine whether capuchin monkeys were capable of solving a complex analogical task that more closely mirrored those that have been solved by young children and chimpanzees.

The capuchin subjects in the current study were chosen because they have had many years of experience solving experimental problems, particularly spatial relational problems such as navigating two-dimensional mazes and using a variety of tools. There has been much evidence from the developmental literature that suggests that prior knowledge plays a key role in forming effective problem-solving strategies (Gaultney, Bjorklund, & Schneider, 1992; Alexander & Schwanenfluegel, 1994; Woloshyn, Pressley, & Schneider, 1992; Scheneider, Bjorklund, and Maier-Bruckner, 1996). If the capuchins in this study were able to solve spatial analogies, it would suggest that analogical reasoning is not limited to apes and is not a function of training with symbols, but instead may be linked to extensive problem-solving experience.

This study makes use of a task that has previously been used to test the analogical reasoning abilities of children. In the 1991 study by Rattermann and Gentner, 3 and 4-year-old children were asked to complete what they called a “perceptual matching task” (Gentner & Rattermann, 1991). In this study, both the child and the experimenter had a set of three objects (such as flower pots) that decreased in size in a continuum from left to right. The experimenter would hide a sticker under one of her three objects, and then ask the child to use this information to find a sticker hidden under the child’s own set of objects.   The correct response in all cases was to search under the object of the same *relative* size as that revealed by the demonstrator (i.e., smallest object to smallest object, or largest object to largest object, varying across trials). The purpose of this study was to determine if the children would rely on a strategy dependent on object similarity or relational similarity. Thus, both sets of stimuli also included some degree of object similarity. For example, if the experimenter's set of stimuli included flower pots of sizes 4, 3, and 2, then the child's set would include pots of sizes 3, 2, and 1 (Gentner & Rattermann, 1991). Pots of size 3 and 2 occur in both sets (and are physically identical), but they do not share relational similarity between the sets (size 2 serves as the smallest for the experimenter, but as the middle size for the child). If children are able to use the rule based on relational similarity to find their sticker, then they should not be confused by the object similarity. Overall, it was found that younger children (3-year-olds) showed poorer performance on this task in comparison with 4-year-olds, suggesting that the ability to reason about relations develops over time.

In the current study, capuchins with no language training were required to use the experimenter's demonstration of retrieving a hidden food item in order to find hidden food in the analogous location under the subject's set of objects. The current study expanded on the Gentner and Rattermann (1991) design by including a series of four different testing phases that were presented in an order that was hypothesized by the experimenter to increase in difficulty based on the demands of the tasks. This design feature was included in order to examine whether experience with similar kinds of problems (i.e., Match-to-Sample) affects the microdevelopment of relational reasoning. This design allowed for the examination of the conditions that support the emergence of analogical reasoning rather than simply determining whether capuchins can spontaneously solve relational reasoning problems.

It was believed that the extensive prior problem-solving experience of the subjects would provide the knowledge base needed for the monkeys to solve both physical matching and relational problems. In addition, it was believed that the specific experience with the physical matching task should aid the monkeys to acquire the skills needed for the relational matching task. Previous work with these subjects (Hoy & Fragaszy, 2004) revealed that capuchins that were exposed to computer mazes in order of increasing difficulty performed significantly better than those that received the same mazes in random order. This suggests that initial exposure to relatively simple problems (i.e., a physical matching task) may aid in the solution of more difficult problems presented later (relational problems).

Three were three primary predictions concerning the performance of capuchins solving both physical identity and relational matching problems. 1) As previous research has shown that relational problems are more difficult than physical matching problems, subjects should require more trials to reach criterion for the relational matching task in comparison with the physical matching task. 2) Capuchins should be able to reach criterion on both the relational matching task with the distracter and the relational transfer task if they reached criterion on the initial relational matching task (without the distracter). 3) The frequency of errors and errors that are repeated should decrease as a function of experience for all testing phases. As none of these subjects has had prior language training, it was also predicted that these capuchins would require a greater number of trials to solve these problems in a qualitative comparison with apes that have completed similar analogical tests. If capuchins are ultimately able to perform this task using a strategy based on relational similarity, then it can be argued that the ability to reason analogically is not limited solely to symbol-trained apes and humans.

CHAPTER 2

METHOD

Subjects

Four male capuchin monkeys (*Cebus apella*) participated in this study. These monkeys ranged in age from 10-20 years old. All subjects had several years of experience with instrumental spatial problem-solving tasks (including use of computer joystick problems, touchscreen and tool-use tasks). (For more detailed descriptions of the previous experience of these subjects, see: Leighty and Fragaszy, 2003; Fragaszy et al., 2003; Rosengart and Fragaszy, 2005; Cummins-Sebree and Fragaszy, 2005). All subjects also had experience with a food search task as part of a study investigating the A-not-B error (Rosengart and Fragaszy, 2003). The monkeys were pair-housed at the University of Georgia. None of the animals were food deprived during testing, although testing occurred prior to either their morning or afternoon feedings. The monkeys received a diet of Purina monkey chow and fruit. The care and experimental treatment of the monkeys followed local and federal regulations concerning humane care and treatment.

Materials

Subjects were transported to a room adjacent to their housing area for testing. Subjects were tested in a cage (64 x 47 x 78 cm) composed of metal mesh and two Plexiglas side panels. One of the Plexiglas panels contained a rectangular hole in the lower half of the panel that allowed subjects to extend their arms outside of the cage in order to manipulate objects. The stimuli were presented to the subjects on a metal cart that was pushed up to the Plexiglas panel of the test cage. This cart was the same height as the floor of test cage. A small step-like tiered platform was placed on top of the cart in order to display the stimuli. Both "steps" were 15.24 x 20.32 cm in dimension and contained five evenly spaced markings to indicate the locations for stimulus placement. The second tier was approximately 2.54 cm higher than the bottom tier (see Figure 1). During testing subjects were rewarded with a food item (dried fruit, nuts, or cereal) upon completion of a successful search. A white poster board that was 60.56 x 81.28 cm in dimension was used as a barrier to obstruct the subjects' view while the experimenter hid the food for each trial. A video camera was used to record testing sessions to allow playback for scoring purposes.

The experimental stimuli consisted of two sets of eight plastic stacking cups (children's toys), spray-painted black. The cups in these sets ranged in diameter from 5.08 to 8.89 cm. A new set of stimuli was used for the final relational matching transfer testing phase. These stimuli consisted of two sets of eight plastic stacking cubes that were painted yellow, and ranged in width from 4.13 to 7.30 cm. Thus, these two stimulus sets differed in shape and color.

Procedure

Preliminary Training

All subjects were exposed to a series of trials to familiarize them with the search task. For all phases, an assistant read aloud the size of the cups to be used in each trial, their position, and the relative size of the cup that was to serve as the hiding location ("big" or "small"). Upon the start of a trial, the experimenter called the subject's name to gain the subject's attention. For preliminary training, a single cup was placed on the bottom tier of the stimulus platform. The experimenter then lifted the cup and pointed to the food item hidden under it. The experimenter then once again covered the food with the cup, while keeping a finger on top of the cup hiding

Figure 1. Picture of stimulus platform.

the food. The cart and platform were then pushed up to the test cage allowing the subject the ability to search under the cup and retrieve the food item. Until the monkey chose a cup, the experimenter fixed her gaze at a designated point on the wall above the testing cage.

If the food was not retrieved in 30 seconds, the trial was repeated. The size of the cup used in each trial was randomized, although no cup was used for more than two consecutive trials. Each subject was exposed to twenty initial training trials. This same training procedure was then repeated using two cups of different sizes. In this case, the experimenter revealed a food item hidden under one of two cups which were placed side by side on the lower tier of the platform. The subject was then given immediate access to the platform and allowed to search. In all testing phases, if the subject chose the wrong cup, the cart was removed from the subject's reach and the trial was repeated from the beginning after a five second inter-trial interval. The trial was repeated until the correct cup was chosen and the subject did not receive a food reward until this time. The size of the cup that was used to hide the food was randomized, except that no cup served as the correct choice for more than two consecutive trials. The position of the cup used to hide the food was counterbalanced in order to eliminate any potential side bias. Subjects completed a minimum of thirty trials with two search locations. Subjects progressed to the Match-to-Sample phase after finding food on the first trial on 80% of the preliminary training trials.

Match-to-Sample

After completing the initial training trials, subjects were exposed to basic match-to-sample (MTS) trials. (See Table 1 for a description and Figure 2 for a diagram of the stimulus arrangement for each testing phase). For these trials, a pair of cups of different sizes was placed on the lower tier of the platform (hereafter the "subject's set"). A single cup that matched the size of one of these two cups was placed in the center of the higher tier (hereafter the "experimenter's set"). The manipulation of the cups and the food for all testing phases was done with the partition blocking the subject's view of the platform. Prior to the start of a trial, the experimenter hid food under the appropriate cups, out of the subject's view. The experimenter then gained the subject's attention and revealed a food item that had been hidden under the cup on the higher tier. The platform was then pushed within the subject's reach and the subject was permitted to search under one of the two cups on the bottom tier. In order to find the hidden food, the subject had to choose the cup that matched the size of the cup where the food was hidden on the higher tier. (Note: For all testing phases, the cups on the higher tier of the stimulus platform were very difficult, but not impossible, for the subjects to reach due to the distance of these items from the testing cage. If a subject managed to reach a cup on the higher tier, this was considered an incorrect response and the trial was repeated. This happened on less than 1% of trials.) Each subject continued testing until it reached a criterion of 9/11 correct trials in two consecutive testing sessions. MTS training continued until subjects were successful with this task or until they reach 1200 trials.

Relational Matching

After reaching criterion on the MTS phase, subjects were exposed to Relational Matching trials. In this case, all four cups used were different sizes. In this phase, a food item was first hidden under one of two cups in the subject's stimulus set and the cup of the same relative size in the experimenter's set, out of the subject's view. At the start of a trial, the experimenter revealed and pointed to the food item hidden under the cup in the experimenter's set with the same size relation (i.e., "large" or "small") to that of the cup hiding the food in the subject's set. In order to find the hidden food, the subject needed to recognize the relation of the cups in the

Table 1. Description of testing phases.

Test Phase	Description
Match-to-Sample (MTS)	Two cups of different sizes were placed on the lower tier of the stimulus platform (in the “subject’s set”). One cup that physically matched one of these two cups was placed in the middle of the upper tier of the stimulus platform (in the “experimenter’s set”). After seeing hidden food revealed under the sample cup in the experimenter’s set, the subject was successful if he searched under the cup that matched the size of the sample in the subject’s set.
Relational Matching	Two cups of different sizes (“big” and “small”) were placed in different positions on the lower and upper tiers of the stimulus platform. None of the cups were physically the same size. The experimenter revealed food hidden under one of the two cups on the upper tier, and the subject had to search under the cup that matched the size relation (“big” or “small”) of the sample cup on the upper tier.
Relational Matching with Distracter	Procedure was identical to Relational Matching, except that there was a cup of identical size in the subject’s and experimenter’s set that served as a “distracter”. The distracter cups did not serve same size relation in the two sets. Upon seeing food hidden under the sample cup, the subject had to choose the cup that matched the size relation of the sample (ignoring the physical match). Half of trials involved sets of two stimuli, while half involved sets of three stimuli.
Relational Matching with Distracter Transfer	Procedure was identical to Relational Matching with Distracter, except that trials involving novel stimuli (yellow cubes) were interspersed with familiar trials. Half of trials involved sets of two stimuli, while half involved sets of three stimuli.

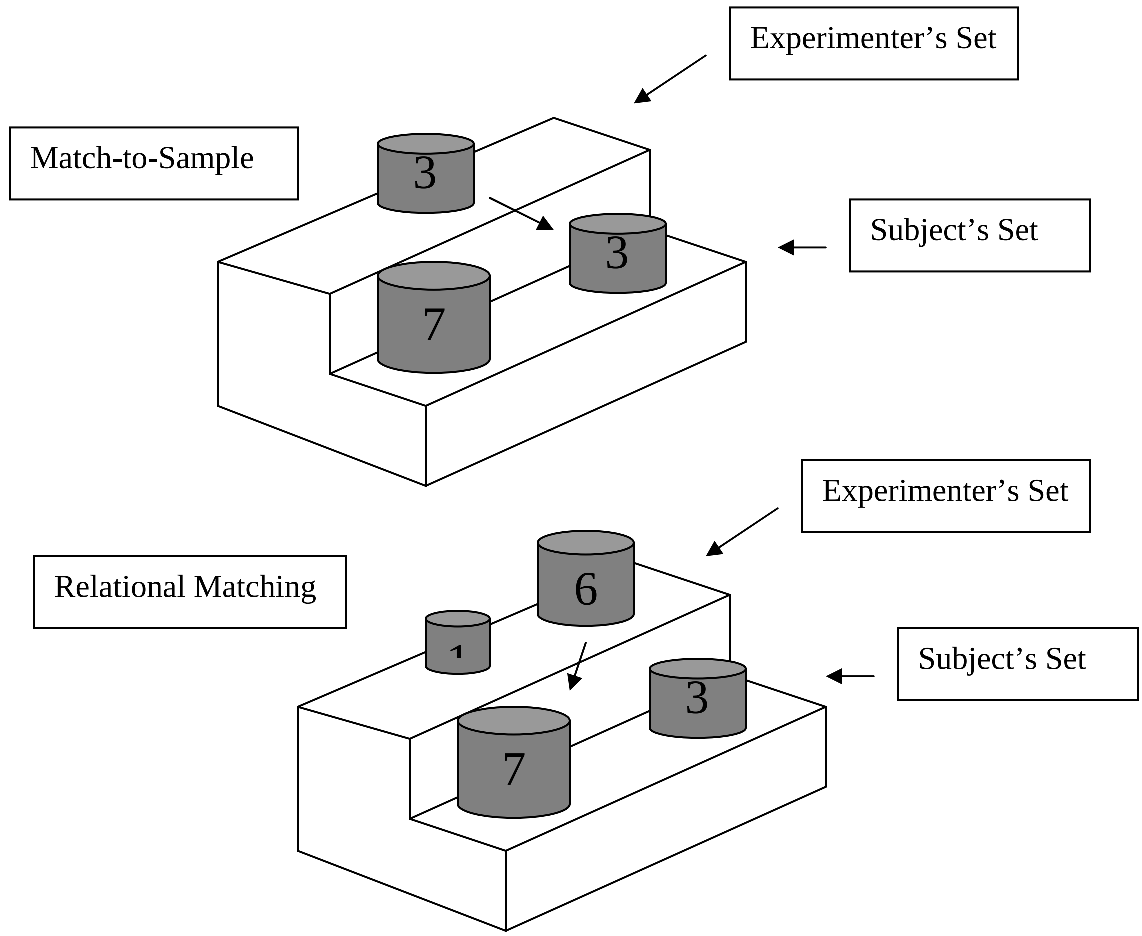

Figure 2. Diagram of stimulus arrangement for Match-to-Sample and Relational Matching phases. An arrow is drawn between the cup hiding the food in the experimenter's set and the correct choice in the subject's set.

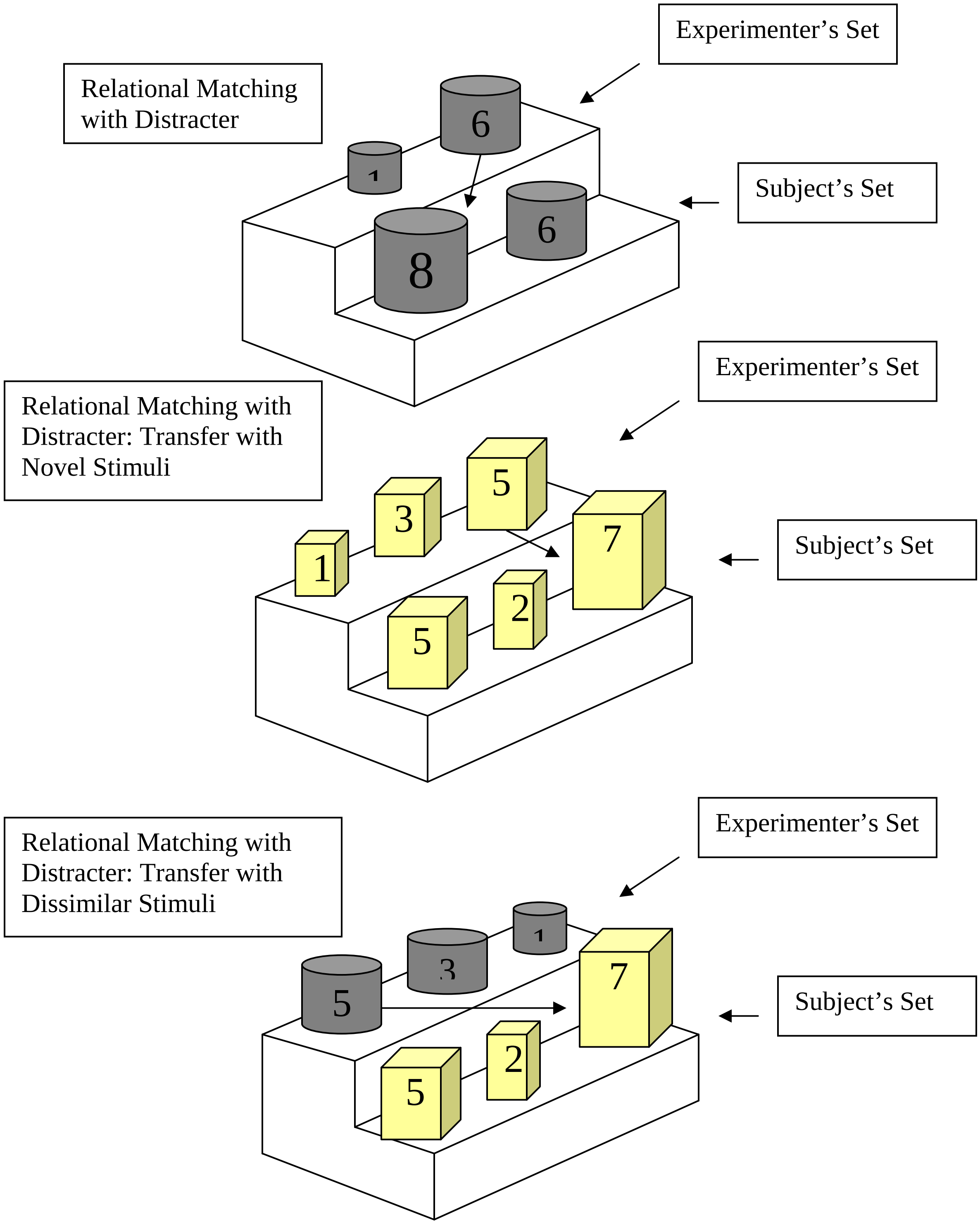

Figure 3. Diagram of stimulus arrangement for testing phases involving distracter stimuli. An arrow is drawn between the cup hiding the food in the experimenter's set and the correct choice in the subject's set.

experimenter's set, and use the assessment of this relation to search under the cup of the same relative size in his own set. If the subject made an error on his first search attempt, the trial was repeated until the subject searched in the correct location. Subjects continued testing until they reached a criterion of 9/11 correct trials in two consecutive testing sessions or completed 600 trials. If a subject failed to reach criterion after 600 trials, testing was discontinued.

Relational Matching with Distracter

The procedure in this phase was identical to that used in the Relational Matching phase. The primary difference between the two phases was that the experimenter's stimulus set and the subject's set contained a cup of identical size. The cups in the two sets did not share the same size relation, however. For example, if both sets contained the same size "3" cup, in the experimenter's set this cup served as the largest of the set, while in the subject's set this cup served as the smallest. Therefore, if the experimenter hid the food under the largest cup (size 3) in her set, the subject had to ignore the identical cup in its set and choose the largest cup (size 5) based on a relational size rule. Another difference in this phase was that half of the trials involved using two sets of two cups, while half involved using two sets of three cups. Trials involving two and three cup sets were randomly interspersed within each testing session. The subject continued testing until he reached a criterion of 9/11 correct trials in consecutive testing sessions for the two-cup trials. The subject continued testing until he reached criterion of 7/11 correct in consecutive testing sessions for the three-cup trials.

Relational Matching with Distracter: Transfer Test with Novel Stimuli

Once a subject reached criterion on the Relational Matching with Distracter task, he was exposed to a transfer test involving novel stimuli. For transfer trials, two sets of yellow cubes were used. These transfer trials were interspersed randomly with trials from the previous testing phase (Relational Matching with Distracter) using the familiar stimulus set (black cups). As with the previous phase, half of the trials involved sets of two stimuli, while the other half involved sets of three stimuli. Four transfer trials were randomly included in each testing session that consisted of 11 total trials (four transfer trials and seven familiar trials). The subject completed testing in this phase after completing a total of 60 novel transfer trials (30 trials involving sets of two stimuli and 30 involving sets of three stimuli).

Relational Matching with Distracter: Transfer Test with Dissimilar Stimuli

In the final transfer phase, the subject was presented with Relational Matching with Distracter trials that had an additional modification. In this phase, the experimenter's set of stimuli differed in color, shape, and size from the subject's set. For example, for each trial in a session, the experimenter's set of stimuli consisted of three black cups of varying sizes while the subject's set consisted of three yellow cubes of varying sizes. In this phase, all trials involved sets of three stimuli (or three choices). A correct search required using a relational size rule to match physically dissimilar stimuli (i.e., the largest black cup with the largest yellow cube). (Note that the intermediate sized cup never served as the sample in any testing phase). The subject was presented with three of these transfer sessions, for a total of 33 trials.

Testing Criterion

For all testing phases, 11 trials were conducted per session. A maximum of two sessions (22 trials) were conducted per day. For testing phases involving sets of two cups (MTS and Relational Matching), the subject reached criterion when he chose correctly on 9/11 (or more) trials in two consecutive testing sessions. This distribution of scores (9/11) represents a significant difference ($p<.05$) in the number of correct responses in relation to the total number of choices made according to the binomial distribution with chance responding of 0.50. For testing phases involving sets of three cups (Relational Matching with Distracter), the subject reached criterion when he chose correctly on at least 7/11 trials in consecutive testing sessions ($p<.05$ according to binomial distribution with chance responding of 0.33). For this testing phase, trials involving two cups were mixed with those containing three cups, therefore criterion was calculated by totaling correct responses over a period of four testing sessions (with 5 or 6 three cup trials occurring per session). In the MTS test phase, if a subject did not reach criterion after completion of 1200 trials, testing was discontinued for that subject. If a subject did not reach criterion after 600 trials in the Relational Matching phase, testing was discontinued for that subject.

Control for Experimenter Cues

To determine if subjects were making choices based on inadvertent cues from the experimenter during testing (i.e., gaze direction, body tilting), a second video camera was positioned next to the monkey's testing cage in order to film the experimenter from the subject's perspective. This additional camera view was used to film the two transfer phases. Following testing, three human observers watched 29 randomly selected trials from these phases from the subject's perspective. The observers were instructed to determine the position of the correct choice ("right", "middle", or "left") based solely on the actions of the experimenter as she presented each trial to the subject. The observers (like the subject) were blind to which cup was baited and were unable to see the cups as the experimenter hid the food. If the observer was unsure of their choice, they were asked to guess a location, and indicate that they were "not sure" of their choice. The observers indicated that they were "not sure" of their choice based on the actions of the experimenter in nearly 100% of the trials scored. The observer's choices were compared to the correct choices for each trial, and binomial tests revealed that the observers chose the correct position at or below chance levels. This indicates that the experimenter provided no reliable cues that humans could detect, as to the location of the correct choice other than showing the subject the hidden food in experimenter's stimulus set.

Analysis

Performance was measured in terms of the number of trials required to reach criterion. Only first choices were considered when determining whether subjects reached criterion. Correction trials were only used in determining the frequency of repeated errors as a function of experience. Spearman rank order correlation coefficients (r_s) were calculated to examine the relationship between experience and frequency of errors committed for each testing phase in which a subject reached criterion. Experience was measured in terms of blocks of 33 trials for the MTS phase, and blocks of 11 trials for all additional phases. Spearman rank order correlation coefficients were also calculated to examine the relationship between experience and the frequency of errors that were repeated for each phase in which a subject reached criterion. A binomial test was used to determine whether subjects preferred to choose the stimulus that was the exemplar's physical match if an error was committed in the Relational Matching with Distracter phase. Performance for the two Relational Matching Transfer tasks was measured solely in terms of whether the subject committed fewer errors than expected by chance according to a binomial test. Chance was conservatively set at 0.50 for both transfer phases.

CHAPTER 3

RESULTS

Match-to-Sample

All four subjects reached criterion on the Match-to-Sample task. Subjects required between 309 and 1113 trials to reach criterion on this task (see Figure 4). As experience increased, frequency of errors decreased. There was a significant negative correlation between experience (measured in terms of blocks of 33 trials) and frequency of errors for all subjects other than Nick, who required the fewest trials to reach criterion (see Table 2 for significance values). There was a significant negative correlation between experience and the frequency of errors that were repeated at least once for all subjects (see Table 2, and Figures 6-10 in Appendix B). The frequency of errors that were repeated more than once was negatively correlated with experience for all subjects (p<.05, with correlation coefficients ranging from –0.745 to –0.460) (see Figure 5 for Mickey's performance). Nick was the only monkey that appeared to show evidence of a side bias for MTS, with 63% of his choices (202/322) being made to the right side.

Relational Matching

Three monkeys (Nick, Leo, and Solo) failed to reach criterion for the Relational Matching phase after completing 600 trials and were not tested further. Mickey was the only monkey to reach criterion on this task. He reached criterion on this phase after completing 143 trials. There was no significant correlation between experience (in this case measured in terms of blocks of 11 trials) and frequency of errors for Mickey in the Relational Matching

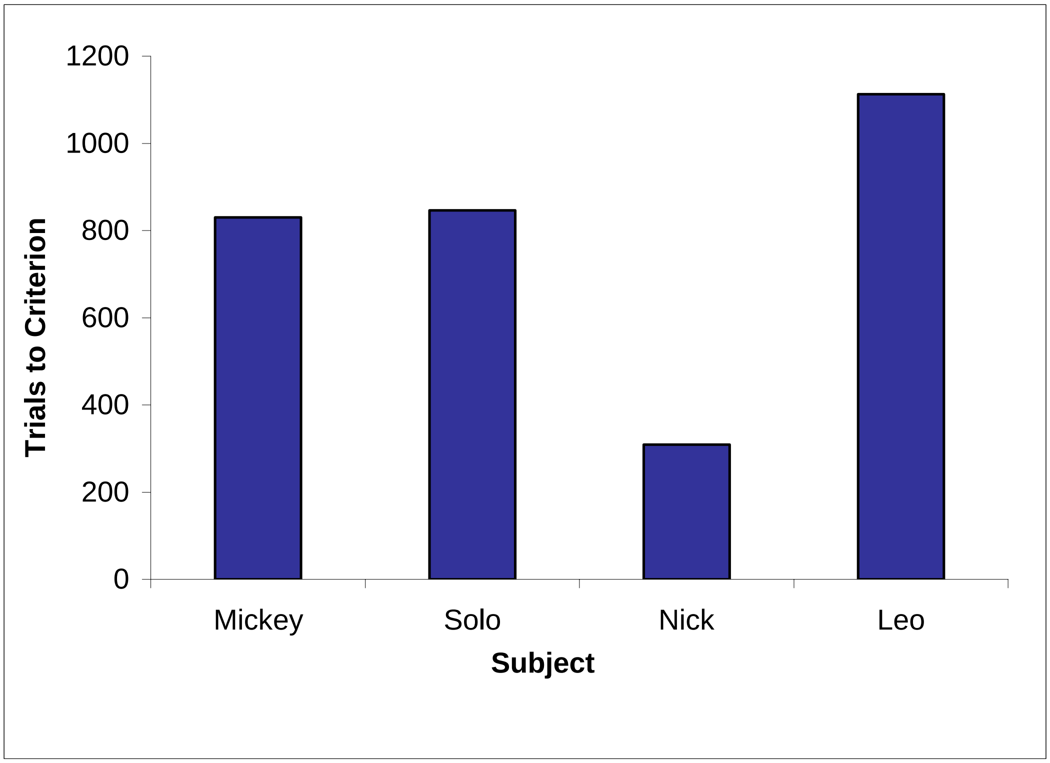

Figure 4. Number of trials required to reach criterion for the Match-to-Sample phase.

Table 2. Significance values for Spearman Rank Order Correlation Coefficients for MTS.

Subject	**Correlation**	**Spearman Rank Order Correlation Coefficient (r_s)**	**p value**
Mickey	Trial Block and Error Frequency	- 0.459	0.024*
	Trial Block and Repeated Errors	- 0.723	0.001*
Solo	Trial Block and Error Frequency	- 0.449	0.024*
	Trial Block and Repeated Errors	- 0.673	0.023*
Nick	Trial Block and Error Frequency	- 0.397	0.290
	Trial Block and Repeated Errors	- 0.857	0.003*
Leo	Trial Block and Error Frequency	- 0.541	0.001*
	Trial Block and Repeated Errors	- 0.826	0.001*

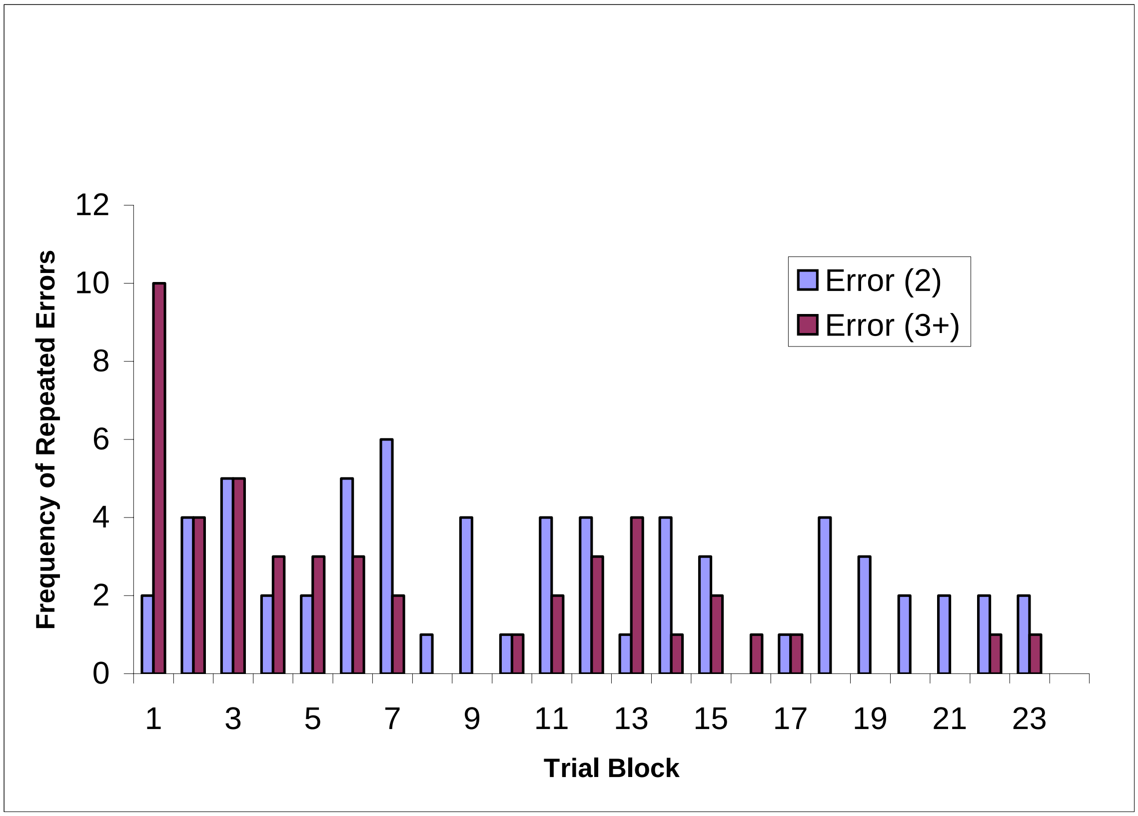

Figure 5. Frequency of errors that occurred two times (repeated once), and frequency of errors that occurred three or more times as a function of trial block for Mickey. Each trial block represents 33 trials from the Match-to-Sample phase.

phase, r_s = -0.104, p = 0.735. There was also no significant correlation between experience and frequency of errors that were repeated, r_s = -0.129, p = 0.673.

Relational Matching with Distracter

Mickey reached criterion on the Relational Matching with Distracter phase after having completed 28 of the two-cup trials and 55 of the trials involving sets of three cups.

For both two-cup and three-cup trials, there was no significant correlation between experience and frequency of errors (r_s = 0.409, p = 0.116; r_s = -0.21, p = 0.939). There was also no correlation between experience and frequency of repeated errors for two and three-cup trials (r_s = 0.015, p = 0.957; r_s = -0.084, p = 0.758). For trials involving sets of three cups, Mickey chose the cup that was not the exemplar's physical match on 46 of 72 trials that resulted in error. The binomial test revealed that Mickey preferred the cup that was *not* the physical match to the exemplar at levels above chance when he committed an error ($p<.05$).

Relational Matching with Distracter: Transfer Test with Novel Stimuli

In the first transfer phase, Mickey was presented with familiar Relational Matching with Distracter trials that were mixed with transfer trials involving novel stimuli of different color, shape and size. Mickey searched in the correct location on 38/60 of the transfer trials, with correct searches occurring on 60% (18/30) of trials involving two search locations and 67% (20/30) of trials involving three search locations. Mickey was correct on 86% (42/49) of familiar trials involving two search locations and 63% (35/56) of familiar trials involving three search locations. There was no significant correlation between experience and frequency of errors for the transfer trials involving two search locations (r_s = -0.384, p = 0.158), and no correlation between experience and frequency of repeated errors (r_s = 0.433, p = 0.107). For transfer trials involving three search locations, there was also no significant correlation between experience and frequency of errors (r_s = -0.472, p = 0.076). There was, however, a significant negative correlation between experience and the frequency of errors that were repeated more than once for the transfer trials involving three search locations (r_s = -0.565, p = 0.028). There was no significant correlation between experience and frequency of errors and repeated errors for the familiar trials involving two and three cups. Mickey made errors on 28/105 (27%) of the familiar trials and made repeated errors on 10/28 (36%) of these trials. He made errors on 23/60 (38%) of the transfer trials and repeated errors on 10/23 (43%) of these trials.

Relational Matching with Distracter: Transfer Test with Dissimilar Stimuli

For the final transfer phase, Mickey was presented with Relational Matching with Distracter trials in which the experimenter's stimulus set and the subject's stimulus set were different from one another (i.e., the experimenter's set was composed of black cups while the subject's set was composed of yellow cubes). All of these trials had three possible search locations (setting chance performance at 33%). If, however, Mickey learned to avoid the stimulus that was the physical match, chance performance would be at 50%, as he would have only two choices after having ruled out the stimulus serving as the physical match. In this phase, Mickey searched in the correct location on 70% (23/33) of trials. He chose the correct location on 7/11 trials in the first testing session and 8/11 on the final two sessions. This performance is significantly above chance according to the binomial distribution ($p<.05$), with chance conservatively set at 50% to allow for the possibility of the use of strategy that involves ruling out the physical match and choosing from the remaining two search locations.

CHAPTER 4

DISCUSSION

The results of this study provide evidence that capuchin monkeys can solve analogical problems similar to those solved by young children and chimpanzees. Although only one subject of the four tested reached criterion on the relational matching task with a distracter, he did so after completing relatively few of these trials (143). It was originally predicted that subjects would require fewer trials to reach criterion on the physical matching (MTS) task in comparison with the tasks requiring the use of a relational rule, as it has been shown that relational reasoning develops later in children (Gentner et al., 1995). This was not the case in this study, as the subject who solved the Relational Matching task (Mickey) did so in many fewer trials than was required for him to reach criterion on the MTS task (more than 800). The difference in difficulty of these tasks is unclear, however, because one subject (Nick) solved the MTS task in relatively few trials (300), but failed to reach criterion after completing 600 trials on the Relational Matching task. Although the sample size for this experiment was small, it is apparent that there are individual differences in the ability to solve these problems.

The most significant finding of this study was evident in Mickey's performance on the final transfer phase that involved using a relational matching rule to match items from two physically dissimilar sets of stimuli. This transfer phase involved a problem that was most clearly analogical in nature because solving the problem involved assessing the relative size of the exemplar in comparison to the other items within one set, and then using that assessment to choose the stimulus of the same relative size in the subject's set which was comprised of entirely different items. While it could be argued that Mickey could solve the Relational Matching with Distracter task by excluding the physical match and then choosing the cup that is "most similar" to the exemplar, this strategy would not result in above-chance performance for the final transfer phase. In the final transfer phase, there was no true physical match to exclude (since the items in both sets differed in color, shape, and size), and choosing the stimulus that was the "most similar" in size to the exemplar would not result in above chance performance with three choices. Therefore, the results of this final phase of testing provide strong evidence that Mickey was using analogical reasoning to solve this problem. As Gentner et al. (1995) discuss evidence that young children have greater difficulty solving analogical problems when the stimuli to be matched differ greatly in appearance, it would be interesting to conduct additional tests to if determine if making the items in each stimulus set more different from one another also decreases performance for capuchins.

Although only one subject in this study reached criterion on the Relational Matching tasks, this subject provided compelling evidence that a member of a New World monkey species can solve a problem involving analogical reasoning. Moreover, he was able to do so without language or token training. Premack (1997) argued that only apes (such as Sarah) that had prior training with language were able to solve analogical problems. This was later refuted by a study by Oden, Thompson, and Boysen (2001) that showed evidence of analogical problem solving in chimpanzees that had exposure to simple token training, but no language training. It was argued that training with symbols or tokens allowed these animals to reason at a level that they could not otherwise attain without this kind of training. The current evidence suggests that token training is not necessary for solving analogical problems, and that there is no firm divide between apes and monkeys in their capacity to reason in this way. Gentner (1995) has argued that analogical reasoning abilities in children develop as a function of increasing general knowledge of the world rather than as a function of age. I would argue that it is specifically experience solving a wide range of problems that facilitated the analogical reasoning abilities of the non-human primates that have shown the ability to complete these tasks. The chimpanzees that have solved these problems, and the capuchins in the current study, have had years of experience solving a wide range of experimental problems including three-dimensional search tasks. As there is much evidence to suggest that prior knowledge plays a key role in problem-solving in humans (i.e., Gaultney, Bjorklund, & Schneider, 1992; Alexander & Schwanenfluegel, 1994; Woloshyn, Pressley, & Schneider, 1992; Scheneider, Bjorklund, and Maier-Bruckner, 1996), it is possible that the knowledge gained from the exposure to other similar tasks aided these non-human primates to reason analogically.

The findings of the current study correspond with those of Spinozzi et al. (2004) who demonstrated that capuchins could match images based on abstract spatial relations ("above" and "below"). Although there are similarities between the Spinozzi et al (2005) study and the current study, I believe that the methodology used in the current study allows for a more direct comparison of analogical tasks performed by children and chimpanzees and therefore allows for a more accurate comparative perspective. I would also argue that the analogical task solved by Mickey in the current study was more challenging than the spatial task performed by the monkeys in the Spinozzi study for two primary reasons. First, the subjects in the current study were required to learn to direct their attention to the location of hidden food that was unattainable (in the experimenter's stimulus set), and use this information to search under the object of analogous size in their own set. This is arguably more difficult as it requires that the subject attend to a series of events (i.e., seeing hidden food revealed that is out of reach, and using the location of this hidden food to search in the analogous location). Second, the current experiment included testing phases that involved sets of three choice stimuli rather than two (as Spinozzi's task only involved binary choices). In the relational matching with distracter phase, Mickey was presented with three cups of different sizes that made up the sample set, and a choice set that was also composed of three stimuli of different sizes. This is significant because there is a reduced probability (.33) of the subject guessing the correct choice correctly, and the task also requires that the subject be able to assess the relative size of a greater numbers of objects. For these reasons, this task represents a more difficult analogical problem.

Although there are differences between the Spinozzi (2005) study and the current study, there is also an important similarity. In both studies, subjects were first trained to perform a match-to-sample task that involved use of a physical matching rule before they were exposed to a matching task that required use of a relational rule. It is possible that having experience with the relatively simple physical matching task prior to the relational task facilitates learning to reason analogically. Although the results of the current study were inconclusive in terms of determining the extent to which exposure to the physical matching task prior to the relational task facilitates learning to use a relational rule, the one subject that solved the relational matching problem required few trials to do so after mastering the physical MTS problem. I believe that the relatively few trials required by this subject to solve the relational matching task (relative to the large number required to solve the basic MTS task) indicates that the most difficult aspect of solving these problems involved learning the demands of the task itself. As the subjects in this study had no prior exposure to MTS tasks, it was necessary for them to learn the series of rules associated with solving this novel kind of problem. I believe one of the most difficult aspects of this task was for the subjects to learn to focus their attention on information given to them by a human demonstrator (i.e., showing them where the food is hidden), and using this information to make a decision about where they should search.

One of the goals of this study was to compare qualitatively the performance of capuchin monkeys and chimpanzees on similar analogical reasoning problems. With only one capuchin monkey reaching criterion on the Relational Matching tasks in this study, only a limited comparison is possible between the performance of capuchins and chimpanzees. However, this study provides evidence that one capuchin monkey was able to solve an analogical problem similar to those solved by young children and chimpanzees. Although Mickey required a relatively large number of trials to learn the MTS task (over 800), he reached criterion on all of the other tasks involving use of a relational rule in relatively few trials (150 or less). This suggests that extensive training is not necessarily needed to teach a capuchin to use a relational rule, but that extensive training is needed to teach the animal the rules of the task in general. With exposure to similar, but increasingly more complex tasks, (MTS followed by Relational Matching, followed by Relational Matching with Distracter, etc.), Mickey was able to rapidly transfer and modify the relational rule he was using to solve each task in the series. Previous studies have not presented monkeys with analogical problems in this “scaffolded” way. Future studies should directly compare the performance of monkeys presented with analogical problems in this manner to the performance of monkeys that are required to solve the problem with no other prior training.

In summary, one capuchin monkey solved an analogical problem presented in the form of a three-dimensional search task despite having no previous exposure to language or token training. It is possible that exposure to a simpler physical matching task prior to the exposure to the relational problem may have facilitated Mickey’s ability to learn to use a relational rule. The degree to which general problem-solving experience affects monkeys' and apes' ability to solve analogical problems deserves further investigation. Thus far, it appears that only experimentally experienced monkeys and apes have been successful at solving analogical problems. In order to determine whether knowledge gained from exposure to experimental tasks contributes to the success of these animals, it is necessary to compare experimentally naïve apes and monkeys with their experienced counterparts on the same task. Although the analogical reasoning abilities of chimpanzees have been tested using a variety of methods, the specific methodology used in this study (and adapted from the developmental literature) has not been used with chimpanzees. It would be interesting to compare experimentally naïve and experienced apes and monkeys on the same task in order to determine what factors contribute to an animal's ability to reason analogically.

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APPENDIX A

SUPPLEMENTAL FIGURES

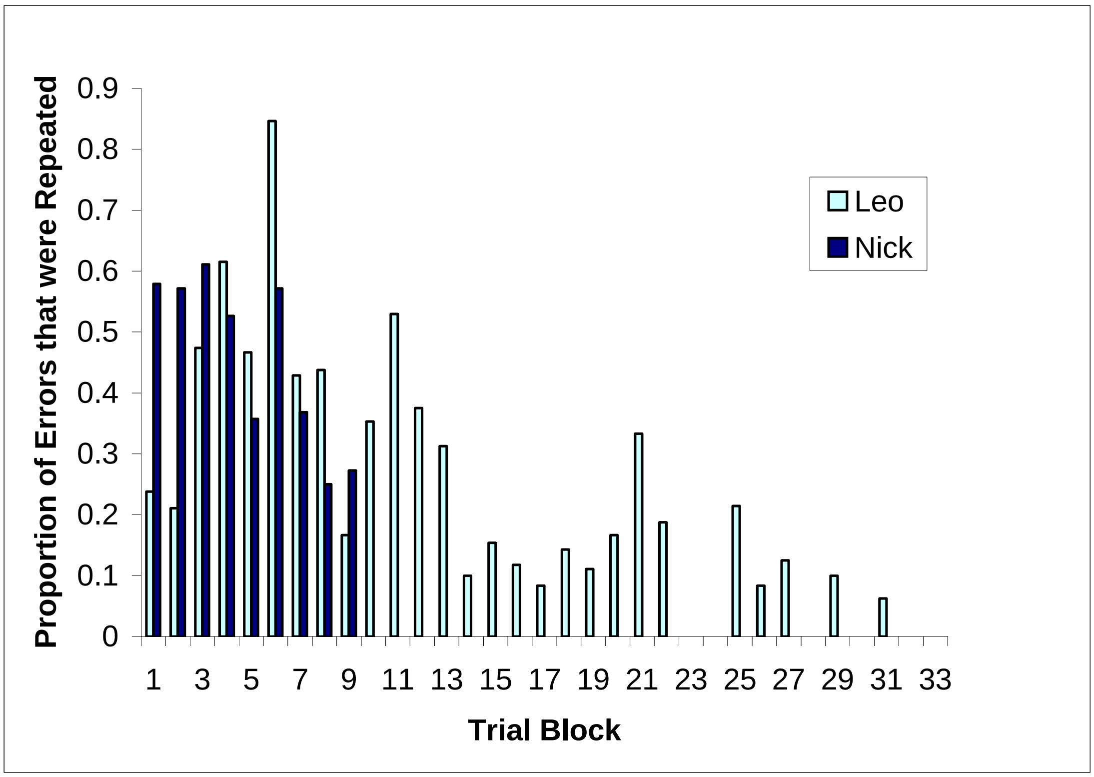

Figure 6. Proportion of errors that were repeated as a function of trial block during the MTS phase for Nick and Leo. Each trial block represents 33 trials.

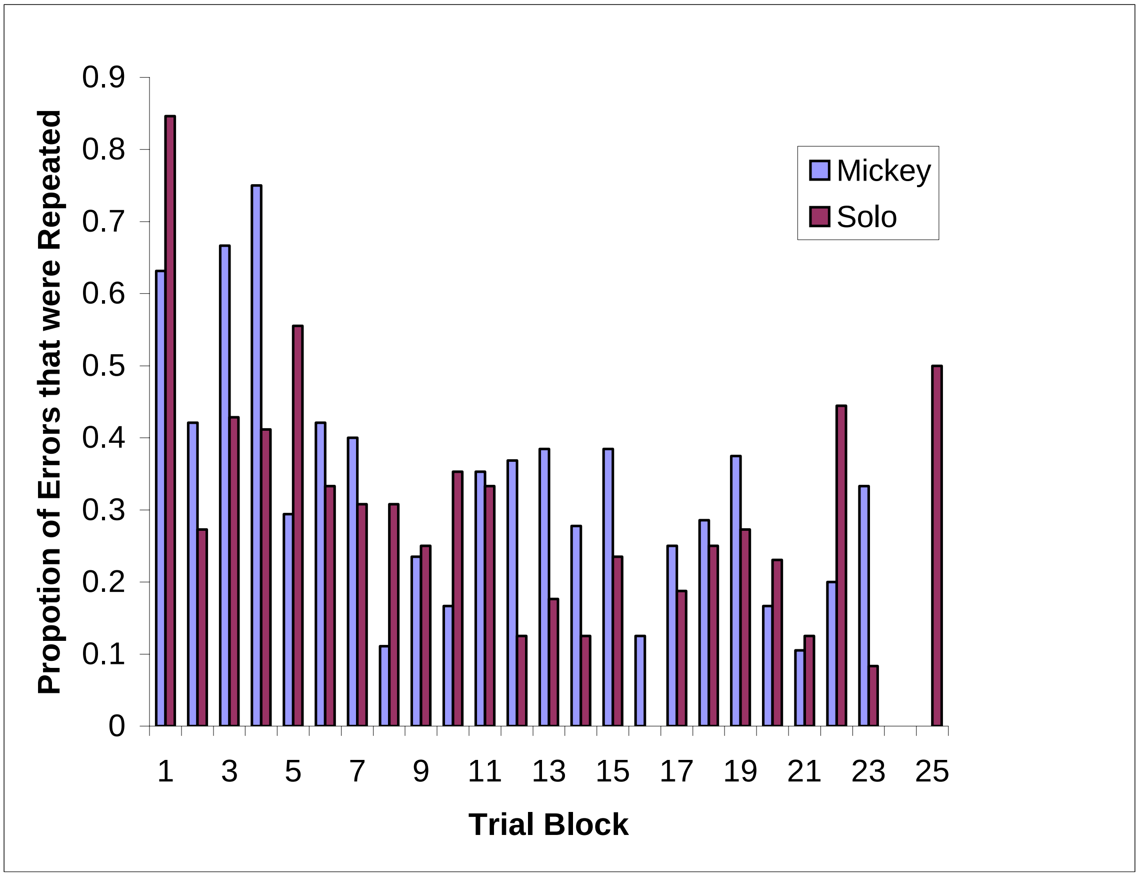

Figure 7. Proportion of errors that were repeated as a function of trial block during the MTS phase for Mickey and Solo. Each trial block represents 33 trials.

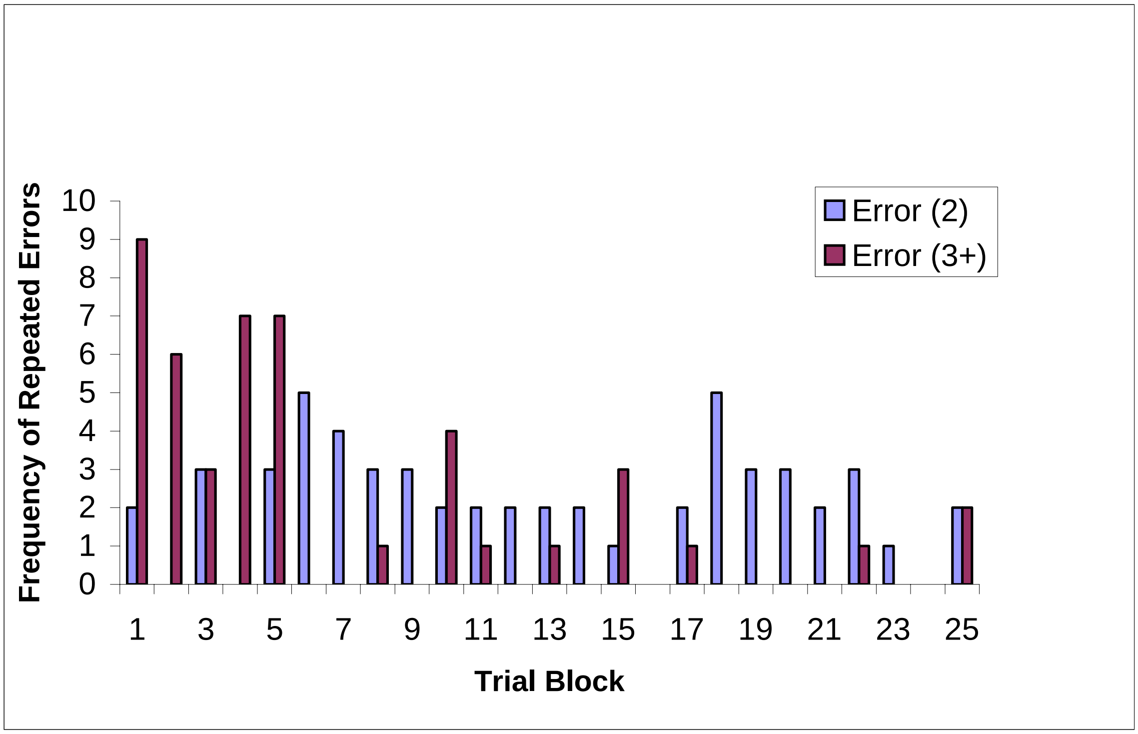

Figure 8. Frequency of errors that occurred two times (repeated once), and frequency of errors that occurred three or more times as a function of trial block for Solo. Each trial block represents 33 trials from the Match-to-Sample phase.

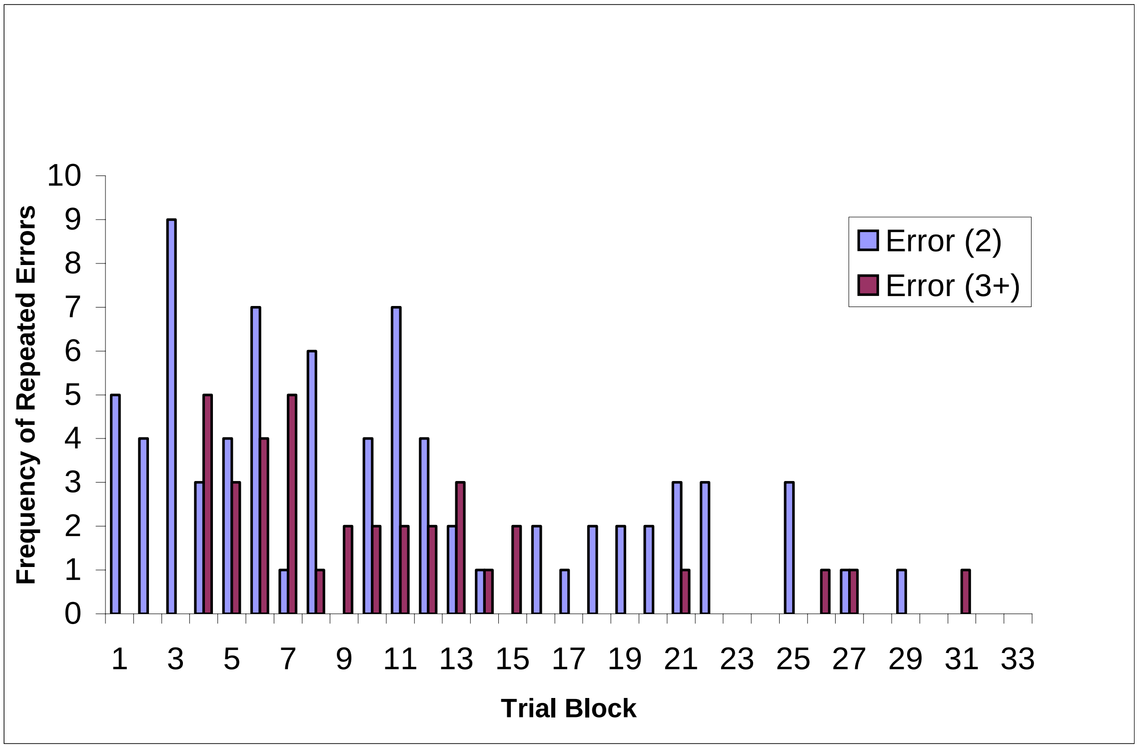

Figure 9. Frequency of errors that occurred two times (repeated once), and frequency of errors that occurred three or more times as a function of trial block for Leo. Each trial block represents 33 trials from the Match-to-Sample phase.

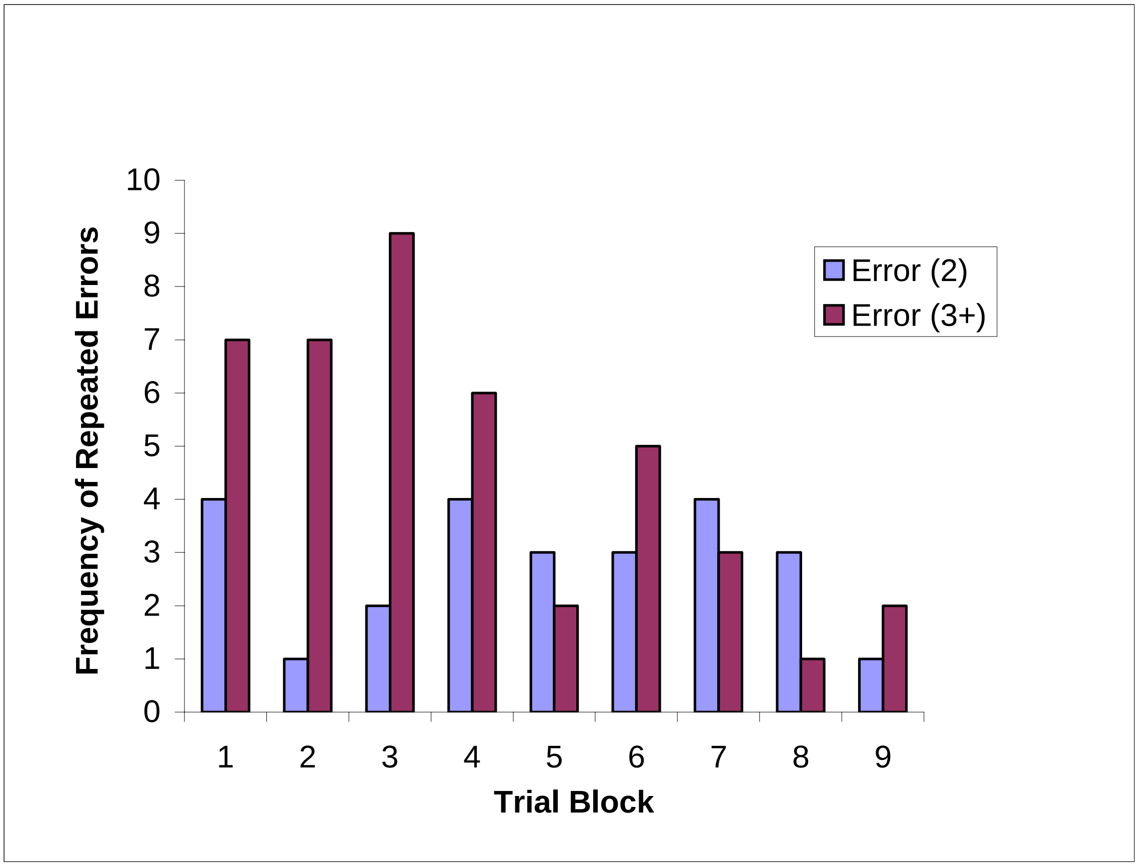

Figure 10. Frequency of errors that occurred two times (repeated once), and frequency of errors that occurred three or more times as a function of trial block for Nick. Each trial block represents 33 trials from the Match-to-Sample phase.

APPENDIX B

REVIEW OF THE LITERATURE

The ability to construct and use analogies has been a key factor in human progress. Using analogies involves recognizing similarity between objects or ideas that are otherwise dissimilar. Analogies are useful in teaching complex concepts and in scientific discovery. It can be argued that much of science involves building analogies between previous explanations and new questions and, for this reason, relatively few discoveries are entirely “new”. General problem-solving also greatly relies on the use of analogies. Those that are best at reaching solutions to problems are often those who are able to retrieve knowledge from the solution of a previously encountered problem that was similar and use that information to solve a novel problem. The use of analogical reasoning therefore allows for more efficient problem-solving because similar problems do not need to be solved “from scratch”.

Because analogical reasoning plays such central role in human cognition, there has been much research investigating the development of this kind of thinking in children. There is also some debate as to whether humans are the only species capable of this kind of thought. Studies have examined analogical reasoning in a wide range of species and have produced mixed findings. Some argue that only language-trained chimpanzees can reason analogically while others believe that the precursors to analogical thought can be found in species such as pigeons. The goal of this paper is to summarize some of the key findings relating to the development of analogical reasoning in humans and also to review and clarify the evidence found by studies attempting to determine if non-human species share the ability to reason by analogy.

The course of the development of analogical reasoning in humans, and the factors that contribute to it, remains a source of debate. Piaget argued for a “structural” theory of the development of analogical reasoning and claimed that children were not capable of this type of reasoning until a relatively late age (11-12 years) (Goswami, 1992). His theory of the development of analogical reasoning rests on the assumption that there are “lower-order” and “higher-order” levels of reasoning. “Lower-order” relations are thought to be relatively simple attributes of the analogy elements while “higher-order” relations relate the “lower-order” relations to one another and are therefore more complex. Piaget argued that younger children can comprehend “lower-order” relations but do not have the ability to understand how these relationships relate to each other at a higher level. Piaget believed that younger children have the necessary knowledge about the basic relations in analogy problems and that they recognize the goal of the task, but that they are simply unable to use this information to solve analogies until they reach early adolescence.

More recent theories concerning the development of analogical reasoning argue that the ability of children to solve analogical problems is dependent on their general knowledge and the difficulty of the relations that comprise the analogy (Goswami, 1992). According to these “knowledge-based” theories, there is no global shift in children’s ability to reason analogically at a particular age. Instead, children can theoretically comprehend analogies at a very young age as long as they have acquired the necessary knowledge about the world. Proponents of these theories argue that even infants may be capable of basic analogical reasoning if the problem is presented in an appropriate manner. Although there has been evidence in support of both structural and knowledge-based theories of the development of analogical reasoning, there is growing evidence that suggests that relational knowledge is the key factor in successfully solving analogies (Goswami, 2001).

There are several methods of testing analogical reasoning in children. The most commonly used method is the "item analogy" task (Goswami, 1992). In this task, a child is verbally presented with two items "A and B" and a third item "C" and is required to complete the analogy by choosing a fourth item "D" that relates to "C" in the same way that "A" and "B" relate to each other. For example, a child could be asked "light is to dark as hot is to ____?" The child could be asked to create their own answer or to choose from a selection of answers that are presented. This same task can also be presented in a pictorial form that potentially allows younger children to be tested with the same analogies as older children. Another method used to test analogical reasoning in very young children involves the use of "problem analogies" (Goswami, 1992). In this case, a child or infant must apply knowledge obtained from solving a previous problem in order to solve a novel problem that is similar. Such tasks may involve using a tool that is similar to one previously used to obtain an item or searching for a hidden object in a location analogous to the original place where they saw something hidden. Additional research has investigated the relational knowledge of infants using "dishabituation" tasks. In these experiments, infants are repeatedly exposed to pairs of visual (or auditory) stimuli until they habituate to these stimuli. The infants are then exposed to novel pairs of stimuli that either represent a similar relation to the original set or represent a different relation. If infants dishabituate to the stimuli that represent novel relations, it is argued that they have at least a rudimentary version of analogical reasoning.

In order to determine the extent to which analogical reasoning can be found in non-human species, it is important to examine the age at which it is evident in human development.

If analogical reasoning requires much knowledge of the world and is highly dependent on language, then it would be expected that the ability to reason in this way would emerge relatively late in children. If, however, this kind of reasoning does not depend on language and is not explicitly learned, then it is possible that the precursors for analogical reasoning can be found in very young children and possibly other species. As was previously mentioned, Piaget was one of the first to study children's ability to solve analogies. His analogy tasks involved asking children of different ages to sort pictures of objects first into pairs, and then into groups of four (forming an "analogy") (Goswami, 1992). Based on the results of these studies, Piaget divided the development of analogical reasoning into three age-based stages. During the first stage (at 5-6 years of age), children were not able to successfully pair the pictures based on their relational features and were not able to group the pairs together in order to form an analogy. Children in the second stage ranged from 7-11 years of age and were better able to match objects based on their relational properties. At this stage, children appeared to form analogies primarily by trial-and-error and were quick to change their minds about their pairings when the experimenter offered a counter-suggestion (Goswami, 1992). It was argued that children at this stage could reason about the relations of pairs of objects in succession but still did not have the ability to successfully reason about these relations in combination. By age 11-12 (stage 3), however, children appeared to be able to form analogies relatively easily (not by trial-and-error) and were not persuaded to incorrectly change their pairings based on suggestions from the experimenter (Goswami, 1992). Since younger children reliably produced errors in their construction of analogies, Piaget believed that children weren't truly capable of reasoning by analogy until a relatively late age.

There has been evidence to suggest that the conclusions that Piaget drew from his analogy experiments may have been flawed and that children may in fact be able to use analogical reasoning at a much younger age than he suggested. It has been argued that Piaget's experiments required general knowledge of relations that older children were more likely to have as the result of experience, putting the younger children at a disadvantage (Goswami, 2001). It was also argued that younger children may have been more likely to accept the incorrect counter-suggestions from the experimenter because they were less willing to disagree with an adult than the older children. For these reasons, a large amount of research has been conducted in order to test Piaget's claims that younger children are not capable of analogical reasoning.

More recent studies have provided evidence that children, whose age would have placed them in stage 1 according to Piaget, do have the ability to reason about relations and solve analogies. One such study by Goswami and Brown (1989) used a picture-based analogy task similar to that used by Piaget. The primary difference in this study, however, was that the experimenters were careful to choose pictures of objects to use in their task that were very familiar to the children. In this case, children were shown a pair of pictures (a bird and a nest) and a third picture (a dog) and were asked to choose the object that completed the pattern from a selection of four pictures (in this case, a doghouse). The authors tested children that were four, five and nine years of age, and each of these age groups performed at levels above chance for this task. This finding suggests that younger children can solve analogies if they are familiar with the items that make up the problem.

An earlier study by Gentner (1977) also provided evidence that children younger than 11 years of age can reason analogically. In this experiment, participants ranging in age from 4-5, 6-7, and adults were asked to solve spatial analogy problems. This task involved asking subjects to assign human body-part labels to pictures of objects. For instance, when shown a picture of a tree, the subjects would be asked, "If this tree had a knee, where would it be?" (Genter,1977). In order to answer correctly, the subject would point to the location on the picture that was analogous to the location of that body-part on a person. The pictures of the objects were presented to the subjects in varying positions (upright, horizontal, and upside-down). The results showed that there was no significant difference in correct responses among the age groups, even when the pictures were presented in an unusual orientation. Gentner argued that this is evidence against Piaget's proposed stages of analogical development. These findings once again suggest that familiarity with the items involved in analogies plays a vital role in children's ability to solve these problems.

A number of studies have investigated young children's ability to solve spatial analogy tasks, partially due to the fact that these tasks rely less heavily on language than standard item analogies. One such study investigated the ability of three and four year old children to find a hidden item after seeing it hidden in an analogous location by the experimenter. In this study (Rattermann, Gentner, & DeLoache, 1994), the experimenter had a set of three blue boxes that varied in size (sizes= 1, 2, 3) and the child also had a set of boxes that varied in size (sizes=3, 4, 5). The boxes in both sets represented the same size relations ("small, medium, and large"), although only one of the boxes in each of the sets overlapped in true physical size (size 3 in this case). At the start of the experiment, the child watched as the experimenter hid a sticker under one of the three boxes in the experimenter's set. The child was then told that there was a sticker hidden in the same place in their set of boxes. In order to find the sticker, the child had to choose the box of the analogous size from their own set of boxes. If the sticker was hidden under the box that has an identical physical match in the child's set, then the child must ignore this physical similarity and make their choice solely on the basis of relative size. The results of this study showed that both age groups performed at near-chance levels when presented with this task.

These authors later conducted a variation of this same study in which verbal labels were given to the stimuli in order to potentially stimulate use of the relational size rule in a new group of three-year-olds. The objects in this study were given labels that were familiar to the children, with the large object being referred to as “daddy”, the medium object as “mommy”, and the small object as “baby”. In this case, the child was told, for example, that the sticker was hidden under the “daddy” object in both the experimenter’s set and the child’s set. After watching the sticker being hidden under the object in the experimenter’s set and after hearing this verbal cue, the child was permitted to search in their set of objects. The results showed that the children performed much better on this task (79% correct) than in the previous task without labels (54% correct) (Rattermann et al, 1994). This finding appeared to suggest that language plays an important role in facilitating the use of analogical reasoning at an early age. It has been argued, however, that the children in this study may have been making their choices by matching the object labels or the spatial location of the objects rather than truly relying on a relational rule to solve this problem (Goswami, 1995).

In order to further investigate young children’s performance on spatial analogy problems, Goswami (1995) performed a study similar to Rattermann et al’s in which some potential confounds were eliminated. As in the previous study, Goswami investigated the ability of three and four year old children to solve spatial analogies. In this case, the experimenter and the child each had a set of stacking cups that varied in size (with the absolute sizes of the sets being different). The children were told that, in order to play a game, they had to choose the cup in their set that was the same as the cup that the experimenter had chosen in her own set. The primary difference between this and the previous study was that Goswami varied the spatial position of the cups in each array, while Rattermann et al used the same spatial arrangement throughout testing. In addition, Goswami introduced the use of verbal size analogies based on the children's story "Goldilocks and the Three Bears". In this condition, children heard the story and then the experimenter related the different size cups in her set to the characters in the story (for example, the large cup belonged to "Daddy Bear"). The children were then instructed to choose the cup in their own set that matched the experimenter's cup based on the analogy from the story. Unlike the procedure of Rattermann's study, this procedure involved only giving verbal labels to the items in the experimenter's array and not to the items in the child's array. Goswami argued that this difference forced children to make their choice on the basis of the transitive relations of the items rather than simply matching labels. The results showed that children of both ages performed well (approximately 80-90% correct) on this spatial analogy problem. In addition, the results showed that children who received the verbal labels based on the children's story did not perform significantly better than those who did not receive the labels. Contrary to Rattermann et al's initial findings, these results suggest that children as young as three have the ability to solve spatial analogy problems. The conflicting results of these studies also indicate that the method of presenting analogies to children clearly has an effect on their performance.

The studies that have been described provide evidence that children as young as three have the capacity for analogical reasoning, but to what extent do infants share this ability? Several studies have provided evidence that infants possess at least the precursors to analogical reasoning. One way in which this capacity has been examined in infants is to test whether they can generalize the solution of one problem to the solution of another. In one such study, the authors tested whether 10 and 13-month-old infants could apply a technique used to attain an out-of-reach toy to a similar problem (Chen, Sanchez, & Campbell, 1997). In the task, there was a toy that was out of the child's reach but was attached to a string. In order to reach the string, the child would have to pull on a piece of cloth that the string was resting on. There were two strings and pieces of cloth, but only one of the strings was attached to the toy. In order to successfully solve this problem, the infant had to choose the correct piece of cloth to pull in order to reach the string that was connected to the toy. Each infant was successively presented with three of these problems in which the general task remained the same, but the component parts differed. For instance, the toys were different in each task and the kind of string and color of the cloth differed for each problem. The results showed that the performance of the 13 month-olds improved with the repeated presentation of the isomorphic problems. The performance of the 10 month-olds was worse, with successful attempts primarily occurring only after repeated problems and if the components of the problems were very perceptually similar (Chen et al, 1997).

As previously mentioned, the capacity for basic analogical reasoning is also studied in infants using habituation paradigms. One such study by Cooper (1984) investigated infants' ability to recognize relationships based on numerosity. In this study, infants were presented with arrays of items that represented a numerical relationship, including "greater than", "less than", and "equal". They were repeatedly presented with one of these relationships until the infants habituated. The infants were then presented with a novel relationship in order to determine if dishabituation occurred. Evidence of dishabituation would suggest that the infants recognize differences in the array relationships. The results showed that 10-12 month old infants showed dishabituation only when the differences between the arrays changed from one of equality to inequality (or vice versa). Only 14-16 month old infants showed dishabituation when presented with changes in the arrays from “greater than” to “less than” (or the reverse). Thus, although the older infants were more sensitive to changes in relations of numerosity, infants as young as 10 months showed the ability to detect differences among the relations, which is a requisite for analogical reasoning.

It appears that there is sufficient evidence that counters Piaget’s claim that children only show evidence of analogical reasoning in early adolescence. Studies have shown that children can use analogies to solve problems at ages as young as three. Growing evidence suggests that even infants as young as 10 months are sensitive to changes in object relations. These findings suggest that analogical reasoning may be an inherent way in which we process the world around us and not an advanced ability that only emerges after much training and experience. If this is the case, it is likely that at least the rudiments of analogical reasoning can be found in non-human species. To what extent do other species reason about the world in this way? What species show evidence of analogical reasoning and what are the ecological pressures that would contribute to the development of this kind of thinking? The answers to these questions are still highly debatable. Analogical reasoning has been studied in animals using methods similar to those used in developmental research. Much of the research has involved dishabituation or match-to-sample paradigms, as these tasks do not rely on language. Some studies with non-human primates have more closely replicated studies performed with children. These studies have investigated analogical reasoning by requiring animals to solve problems through use of analogy. Other studies have involved the presentation of standard “item-analogy” tasks to primates with varying degrees of language training. The purpose of the remainder of this paper is to review the performance of non-human animals on analogical reasoning tasks in attempt to clarify how this way of thinking emerged and why.

At this time, the clearest evidence of analogical reasoning in non-human species has been provided by apes. Early studies by Premack with chimpanzees provided the groundwork for more recent analogical reasoning research. Premack's initial experiments tested the analogical reasoning abilities of four eighteen-month-old chimps using a habituation/dishabituation paradigm (Premack & Premack, 2003). In this test, pairs of objects were attached to a board and then each pair was presented to the subject for a period of fifteen minutes. These object pairs consisted of objects that represented either "identity" or "non-identity" relations. In "identity" pairs (AA), both objects were the same (such as two spoons). In the "non-identity" pairs (BC), the objects were different (such as a ball and a plastic ice cream cone). The subject was given one pair (AA) for fifteen minutes and was then immediately given a novel pair of objects (BB or CD) for a second fifteen minute interval. Subjects were also initially given a "non-identity" pair followed by either a novel "non-identity" or "identity" pair. The amount of time subjects spent handling the pairs were then compared. The results revealed that subjects preferred to spend more time handling object pairs that represented a novel relationship (identity or non-identity) in relation to the original pair of objects they encountered. Premack argued that this finding is evidence that these chimps were able to recognize differences in relations, which is a precursor to analogical reasoning.

Later analogical reasoning studies by Premack incorporated language training. Premack trained three chimpanzees to use plastic symbols to represent the concepts of "same" and "different" (Premack & Premack, 2003). The subjects were trained by presenting them with two objects in a horizontal line separated by a space. The subjects were required to place the token for “same” or “different” in between the two objects based on their relationship to one another. Once subjects correctly completed this task, they were presented with a transfer task using novel objects. One subject who had difficulty with the transfer test was presented with all of the objects in a random (non-linear) format and was permitted to arrange all of the items (including the tokens for “same” and “different”) in any way she wished. The results of this small experiment showed that this subject spontaneously paired the two same objects (two spoons) and separated the one different item (a piece of clay) and labeled it with the token for “different”. In repeated trials, this subject (“Peony”) always paired like objects and separated them from the objects that were different. By the end of training, all three subjects were reliably able to use the plastic tokens to label same and different objects. Following this training, these subjects were presented with relational match-to-sample problems in which they were required to match pairs of objects with the sample pair that shared the same relation (i.e., “same” or “different”). For instance, if the subjects were presented with a pair of triangles, the correct match would be a pair of circles rather than a pair that represented “non-identity” such as a square and an octagon. If presented with a probe pair that represented “non-identity” (a triangle and oval), then subjects were required to choose the pair from the sample that also represented “non-identity” (a square and circle). Although these three subjects were unable to solve relational match-to-sample problems prior to their symbol training, all three were able to reliably solve these problems after this training (Premack & Premack, 2003). For this reason, Premack argued that prior exposure to symbol/language training is required for analogical reasoning.

Premack and colleagues also tested one chimp (Sarah) with arguably more difficult “functional” analogy problems. In this case, Sarah was presented with a pair of objects (such as a lock and a key) and presented with a third object (a paint can) and required to choose between one of two objects (a can opener and a paint brush) in order to complete the analogy. In order to correctly solve this problem, the subject must choose the object to complete the analogy based on the equivalence of function of the object pairs. For these tests, all of the objects comprising the analogies were items that were familiar to the subject in her daily life. The results showed that Sarah was able to solve these problems as successfully as she solved the more basic perceptual analogy problems.

As the result of this series of studies, Premack argued that there was a great disparity in the analogical reasoning abilities of chimpanzees who had received language abilities and those who had not. He believed that some degree of language training was necessary in order to reason in this way. A more recent study by Thompson, Oden, and Boysen (1997) revealed that chimpanzees with previous token training, but no language training, are able to solve relational match-to-sample problems. In this study, one juvenile and four adult chimps were required to match pairs of objects to sample pairs that represented the same relation (“identity” or “non-identity”, as described above). One of these subjects (Sarah) had prior language training and had taken part years earlier in Premack’s initial analogical reasoning studies. Three of the subjects had experience with discrimination tasks using token, while one of the subjects had no prior experience with language or tokens. The results showed that four of the subjects performed at levels above criterion, while the subject with no prior training did not perform at levels above chance. The authors also note that the subjects that were successful at these problems showed above-chance performance after very few trials and with non-differential reinforcement, suggesting that extensive training with these problems was not necessary. The authors also argue that the results of this study provide evidence that language training is not necessary for analogical reasoning, but rather that it is experience with tokens that provides the basis for this kind of reasoning (Thompson, Oden, & Boysen, 1997).

It seems clear that chimpanzees have some degree of analogical reasoning ability, but to what extent do other non-human primates (or other animals) share this capacity? Thompson and Oden (1995) argue that apes are capable of analogical reasoning while monkeys (and all other animals) are not capable of analogical reasoning. They argue that only apes (and human children) with some degree of token/language training can reason in this way. Tests that have attempted to replicate analogy tasks used with children and apes with monkey subjects have shown that these species have been unsuccessful in solving these problems. Thompson and Oden (1995) tested adult rhesus macaques (*Macaca mulata*) using a dishabituation test previously used with children. As previously described, this test involved presenting the subject with a pair of objects for a period of time and then presenting the subject with two new pairs of objects, one representing the same relation as the original pair and the other representing a novel relation. If the subject looks longer at the pair representing the novel relation, then this is seen as evidence that the subject can recognize differences among relations. When this test was performed with rhesus monkeys, there was no significant difference in the amount of time the monkeys spent looking at the pair of objects representing a novel relation in comparison with the other sample pair (Thompson & Oden, 1996). These monkeys did, however, show a preference for physical novelty using the same test but without the use of abstract relations (i.e., single objects were used instead of pairs). This suggests that the negative results of the test involving abstract relations were not a result of the inappropriate use of this methodology with this particular species. A similar dishabituation test (this time using handling time as the dependent measure) has also been performed with capuchin monkeys (*Cebus apella*) (Thompson, Oden, Hyle, Hoy, Rapuano & Safro, 2000). The results of this study revealed that there was no significant difference in the handling time of object pairs representing novel relations, suggesting that this species of monkeys is also unable to recognize relational differences.

Although studies such as these appear to support the argument that only humans and apes with symbol training are capable of analogical reasoning, a series of recent studies suggests that even species such as pigeons are sensitive to differences in relations. These studies also test subjects using a dishabituation paradigm, but they differ in that subjects are presented with two-dimensional arrays of many (same or different) objects. For instance, subjects could initially be presented with an array of 16 identical umbrellas, and then be presented with two new displays, one with 16 identical paperclips and the other with a mixture of 16 different items. A series of studies (e.g., Wasserman, Hugart, & Kirkpatrick-Steger, 1995; Young & Wasserman, 1997; Gibson & Wasserman, (2003) have provided evidence that pigeons can label displays of identical or non-identical icons as “same” or “different” using different colored computer keys.

A study using this paradigm has also been conducted using baboon (*Papio papio*) subjects (Fagot, Wasserman, & Young, 2001). In this case, two subjects were required to choose one of two sample arrays of 16 identical or non-identical icons whose relations matched those represented by the original object array. Although the subjects were successful with this task using arrays of 16 items, their performance suffered when the number of items in the arrays were reduced (Fagot et al., 2001). There appears to be evidence that subjects tested using this paradigm make discriminations largely on the basis of the amount of variability (“entropy”) which is evident in the displays. For this reason, there has been some debate as to the extent to which these studies truly provide evidence that these species are sensitive to abstract relations.

A more recent study by Spinozzi, Lubrano, and Truppa (2004) provided evidence contrary to the claim that monkeys are unable to reason about abstract relations. In this study, five capuchins were tested on their ability to perform a MTS task that involved matching the spatial relations “above” and “below”. In this case, subjects were required to match an image of a horizontal line with a dot situated either above or below the line to another image representing the same spatial relationship (“above” or “below”) between the line and the dot. The subjects were first trained to solve a basic MTS task in which one of the choices provided to the subject was an identical physical match to the sample image. All subjects were able to solve this task relatively rapidly (with an average of 198 trials needed to reach criterion). The monkeys in this study were also successful in matching the images when the choices included an image that matched the sample in terms of the relation between the line and the dot, but the distance between the dot and the line were varied so that there was no choice that was an identical match to the sample. The authors argued that this study provided evidence to suggest that capuchin monkeys can reason about abstract spatial relations (“above” vs. “below”).

The extent to which species other than apes and humans can reason analogically remains unclear. Although the majority of studies performed with monkeys have suggested that these species are insensitive to relational differences, I believe that further research is necessary before this conclusion can truly be made. Although studies with apes suggest that some degree of token/language training is necessary for analogical reasoning, it is also possible that the performance of these animals was linked to their extensive exposure to problem-solving tasks over the course of their lives as research subjects. To my knowledge, there has been no comparison of the performance of animals with and without extensive problem-solving experience on these tasks. In addition, I would argue that the monkeys that have been tested with analogical problems have not had comparable experience with problem-solving tasks in relation to the apes that have been successful with these problems. In addition, it is possible that the monkey species that have been tested were exposed to experimental paradigms that were not ideal. For instance, in the Thompson et al. (2000) study that investigated the dishabituation of capuchins to pairs of objects representing novel relations, it is possible that some of the objects composing the pairs were more interesting than others. As capuchins are destructive foragers, they appear to have preferences for items which they can easily damage. In the case of this study, it is possible that the subjects preferred to handle some objects over others not because they were attending to the relations of the objects, but were simply more interested in destroying some over others. For this reason, I believe that it is important to test species using a variety of different paradigms before reaching a conclusion that a species lacks the capacity for analogical reasoning.

Theoretical support for the notion that experience in a particular domain can facilitate the development of novel forms of reasoning can be found in the developmental literature. Relatively recent developmental research has focused on the “microdevelopment” of reasoning abilities in children. Rather than examining how cognitive abilities develop over long periods of time, microdevelopmental studies investigate the factors that influence how novel skills or reasoning abilities are attained within short time intervals (Granott & Parziale, 2002). These studies allow for the detailed analysis of how knowledge is acquired by focusing on changes in strategies used throughout the course of exposure to a particular problem. As experience with a problem can potentially play a large role in a child’s choice of strategy, studies have investigated the extent to which factors such as the ability to explain one’s strategies or the use of a knowledgeable partner affect the ability to learn within short periods of time (Kuhn, 2002;

Siegler, 2002). The current comparative study stems from this microdevelopmental framework because it investigates the extent to which experience with a similar problem (i.e., physical matching) facilitates the ability to solve novel problems involving the use of a more complex strategy (in this case, relational matching).

The capuchin subjects in the current study are of particular interest as they have had many years of experience solving experimental problems, particularly spatial relational problems such as navigating two-dimensional mazes and using a variety of tools. There has been much evidence from the developmental literature that suggests that prior knowledge plays a key role in forming effective problem-solving strategies (Gaultney, Bjorklund, & Schneider, 1992; Alexander & Schwanenfluegel, 1994; Woloshyn, Pressley, & Schneider, 1992; Scheneider, Bjorklund, and Maier-Bruckner, 1996). As Scheneider et. al (1996) report, “When children have detailed information about a topic, they are able to process information about a domain more efficiently, identify relations among items more easily, and incorporate new information into already existing schemas more readily than children with less detailed knowledge structures.” I argue that having general problem-solving experience should have the same effects on the ability of non-human primates to solve analogical reasoning problems. Thus, if the capuchins in this study are able to solve spatial analogies, it would suggest that spatial analogical reasoning is not a function of training with symbols, but is instead dependent on extensive problem-solving experience.

It was predicted that the extensive knowledge base of the subjects in this study would allow them to solve both physical matching and relational problems. It was also believed that the experience that the monkeys would gain while solving this particular task would aid their ability to reason analogically. Specifically, it was predicted that the experience with the physical matching task should aid the monkeys to acquire the skills needed for the relational matching task. Previous work with these subjects (Hoy & Fragaszy, 2004) revealed that capuchins that were exposed to computer mazes in order of increasing difficulty performed significantly better than those that received the same mazes in random order. This suggests that initial exposure to relatively simple problems (i.e., a physical matching task) may aid in the solution of more difficult problems presented later (relational problems). There is evidence from the developmental and education literature that presenting increasingly more difficult aspects of a problem in sequence (referred to as "scaffolding") greatly facilitates the ability to learn (Frisk, Jakobson, Knight, & Robertson, 2005; Rittle-Johnson & Koedinger, 2005; Reiser, 2004; Case, 1991). Although scaffolding usually involves a social component (involving a skilled teacher guiding a student through increasingly more difficult problems), recently various forms of computer technology have been used to guide learners in a step-like manner through complex problems and this is considered scaffolding (Puntambekar & Hubscher, 2005). Therefore, although the current study does not involve the social aspect of scaffolding, it does present problems to the subjects in a similar step-like manner.

To summarize, the current study aimed to investigate the capacity for analogical reasoning in capuchin subjects using a novel testing paradigm. More importantly, this study involved subjects whose experience with research involving a wide range of problem-solving tasks (i.e, tool-use and computer joystick tasks) more closely mirrors that of the apes that have been successful with analogical problems. This study's methodology was based on three-dimensional search tasks that rely on analogical reasoning and have been used in developmental studies (Rattermann et al., 1994; Goswami, 1995). The current study, however, expanded on these previous studies by also investigating the conditions that support the microdevelopment of analogical reasoning by first exposing subjects to a physical matching task followed by a relational matching task. Through the use of this novel paradigm and test-savvy subjects I hoped to attain a clearer understanding of the extent to which species other than humans and apes share our capacity for analogical reasoning.