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AN ANALOGICAL PARADOX FOR NONHUMAN PRIMATES:
BRIDGING THE PERCEPTUAL-CONCEPTUAL GAP

by

TIMOTHY M. FLEMMING

Under the Direction of Dr. David A. Washburn

ABSTRACT

Over the past few decades, the dominant view by comparative psychologists of analogical reasoning in nonhuman primates was one of dichotomy between apes, including humans, and monkeys: the distinction between the *analogical ape* and *paleological monkey* (Thompson & Oden, 2000). Whereas evidence for analogy proper by representation reinterpretation in monkeys is sparse and debated, the gap between that which is analogic and paleologic has been narrowed by the studies presented here. Representation of relational concepts important for analogy proves difficult for rhesus and capuchin monkeys without the ability to rely on a greater amount of perceptual variability, implicating a perceptually-bound predisposition in problem-solving (**Chapters 2-3**). A shift in attention from perceptual features to abstract concepts for employment in relational matching is again difficult, but not impossible given cognitive incentive in the form of differential outcomes to refocus attention on conceptual properties (**Chapter 4**). Finally, chimpanzees unlike monkeys appear more apt to reason by analogy, perhaps due to a more default conceptual focus (**Chapter 5**). Taken together, these studies provide an account for the emergence of analogical reasoning skills throughout the primate lineage in contrast to views regarding analogy a hallmark of human intelligence.

INDEX WORDS: Analogical reasoning, Relational concepts, Relational matching, Monkeys, Nonhuman primates

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by

TIMOTHY M. FLEMMING

A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy

in the College of Arts and Sciences

Georgia State University

2010

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2010

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An analogical paradox for nonhuman primates:

Bridging the perceptual-conceptual gap

Chapter 1: Introduction and Literature Review

Analogical reasoning serves as the “core of cognition,” providing a seminal foundation upon which logical inference, problem-solving, decision-making and other higher-order reasoning can be built (Hofstadter, 2001, p. 499; see also Halford, 1992). According to Halford (1992) and Hofstadter (2001), its role is central to many aspects of thinking, at least for humans, which were the focus of those studies. What then of analogy for nonhuman animals? Animals solve problems, make decisions, and manifest higher-order reasoning, at least in some situations; so should we predict that nonhuman animals have the capacity for analogical reasoning, perhaps even as the foundation of these other competencies? With some researchers arguing cogently for the existence of rudimentary reasoning by analogy in nonhuman primates (e.g., Premack & Premack, 2003; Fagot & Parron, 2010; Thompson & Flemming, 2008; Thompson & Oden, 2000), the study of analogy seems to have much to offer in the debate over the continuities and discontinuities between human and animal minds.

Overview

Analogy can be defined as shared structural abstraction (Gentner, 1983; Hofstadter, 2001; Premack, 1983) or the judgment of relations-between-relations (Thompson & Oden, 2000). The mapping of knowledge from one domain to another is central to the assumption in formal analogical reasoning that relational concepts are held constant from one domain to the other. A formal theory of analogy (Gentner, 1983) assumes the formation of mental representations of

base (sample) and target (choice) relations, with the alignment of these relations across domains being considered analogy.

Analogical reasoning is a cognitive process through which previously learned rules are applied to novel situations. As a cognitive heuristic, reasoning by analogy is a form of representativeness wherein judgments are based on how much the structure of one event resembles that of another (Goldstein, 2011). Allowing us to apply flexibly common rules and bringing to the forefront the underlying structure of a problem, analogy enables the avoidance of relearning upon every new set of instances encountered. For all of these cognitive savings, analogies allow us to be efficient, and thus are functionally adaptive as an accurate and sometimes rapid process by which we make decisions about our surroundings. Further, in the words of Gentner (1999), they are thought to lay the foundation for critical thinking.

It [analogy] is central in the study of learning and discovery. Analogies permit transfer across different concepts, situations or domains and are used to explain new topics... Analogies are often used in problem solving and inductive reasoning because they can capture significant parallels across different situations. Beyond these mundane uses, analogy is a key mechanism in creativity and scientific discovery (p. 17).

In the most basic instantiation, an analogy involves establishing a relationship between two given elements and subsequently seeking out that same relationship between two novel elements (e.g., Goswami, 1995; Premack, 1976; Thompson & Oden, 2000). Mechanistically, this process involves perception of relational information and computation of conceptual equivalence between these relations; in other words, it is the ability to judge relations-between-relations. In this vein, concepts are equated to one another, rather than simply put to use for purposes of object identification.

Humans across cultures have been shown to have this universal ability to reason by analogy (Bellack, 1992; Dunbar, 2001; Hofstadter, 2001; Nehaniv, 1999). In fact, there is little

evidence to the contrary. Notably though, this skill does continue to emerge throughout development from only limited recognition of relations in early years to a full mapping of underlying structure later in cognitive development (Gentner, 1988; Goswami & Brown, 1989). By approximately age 7, humans typically show proficiency in most problems involving employment of analogy (Rattermann & Gentner, 1998a). Given the rather late emergence in human development of a full capacity for analogical reasoning compared to other cognitive abilities, it remains unclear whether analogical reasoning is present in other animals.

Whether analogy is unique to humans has been the subject of debate for more than 30 years—a debate that has become more active as of late. Premack (1976) initiated this debate when he provided evidence that a language-trained chimpanzee (*Pan troglodytes*) was capable not only of completing by also of creating analogies. Several primate species without language training have subsequently been reported to have the ability to reason by analogy (e.g., Fagot & Parron, 2010; Kennedy & Fragaszy, 2008; Spinozzi, Lubrano & Truppa, 2004; Thompson, Oden & Boysen, 1997) or to exhibit analogical precursors (e.g., Fagot, Wasserman & Young, 2001). In the present chapter, I will review this distinction between *analogy proper*, the mapping of mental representations for relations, and *analogical precursors*, which are relational discriminations and any matching of relations measured behaviorally, and build an argument that analogy has emerged throughout the primate lineage from basic perceptually-bound relational judgments. Specifically, I will explore whether failure to match relations reflects an inability to manifest higher-level abstraction or the potency of the lower-level abstraction and being overwhelmed by the perceptual features of stimuli.

If there is a discontinuity across species in the evidence for analogical reasoning, it remains unclear whether it is a difference of degree or kind. Dunbar (2001) describes and

analogical paradox wherein human subjects tend to focus on superficial rather than structural features to solve problems particularly in the laboratory setting. This may be analogous to patterns of behavior observed in nonhuman primates. Because some non-ape species possess the requisite knowledge of relational concepts, but subsequently fail to apply those relational concepts to match the relations-between-relations (e.g., in relational matching-to-sample tests like those described later), analogy might seem to be driven by an intervening cognitive variable different from that used to learn relational concepts (e.g., Marcus, 2001; Penn, Holyoak & Povinelli, 2008). This operational difference, however, does not necessarily imply a qualitative difference in the cognitive abilities between apes and non-apes. Rather, the level of representativeness or meaning of which the thinker is capable is likely involved in observable differences in analogical abilities between species.

Consider one useful task – the labeling of stimuli as being either the *same* or *different*. This ability emerges around age 4 in children, and adult humans make such judgments rapidly and seemingly with little or no cognitive effort. However, comparative assessments of sameness and difference judgments provide a radically different picture. Ontogenetic and phylogenetic shifts in performance based on *same/different* judgments prompts questions regarding the origin of such competencies. Comparative studies with nonhuman animals gather evidence for the evolution of the cognitive mechanisms of analogy. More generally, by examining differences in the cognitive abilities of several species researchers are able not only to determine the behavioral capabilities of each species but also perhaps better to identify alternate cognitive approaches that manifest as similar behavioral outcomes. In addition, the cognitive phenomena as they develop within the individual, both human and nonhuman, can be better understood. In the case of analogy, comparative studies including those to be discussed here provide empirical evidence for

a shift from perceptual to conceptual learning in the acquisition of these skills both throughout the evolutionary history of primates and developmentally within humans.

Behaviorally, analogical reasoning is observed in most instances whereby an individual correctly matches relations (Thompson & Oden, 1996). Cognitively though, for reasoning to be considered analogical by definition, the mental representation of concepts is required (e.g., Gick & Holyoak, 1980; Gentner, 1983). Where the metaphorical line is drawn between that which is considered analogy proper and an analogical prerequisite is the subject of some debate with some drawing species distinctions (human/nonhuman or ape/non ape; see Penn et al., 2008; Thompson & Oden, 2000) and others drawing cognitive (levels of representation) lines. I will discuss the integral role that several cognitive processes and requisite types of knowledge play in enabling analogical reasoning or behavior and the implications that each have for the discontinuity observed in analogy proper and analogical prerequisites.

Learning relational concepts and analogies: Methodology

One must consider critically all of the differences in methodology utilized to assess analogical reasoning. The following tasks presented to human and nonhuman animal subjects are illustrative of increasing levels of conceptual complexity: matching-to-sample (MTS), generalized match-/nonmatch-to-sample, transpositional learning, *same/different* discrimination, conditional *same/different* (S/D¹) discrimination, within-set relational matching and *same/different* (S/D) relational matching-to-sample (RMTS). A taxonomy of these tasks and associated descriptions of conceptual complexity is presented in Table 1.1. Relational-conceptual judgments of identity and nonidentity are not entirely removed from the matching or

¹ The S/D notation will be used throughout this manuscript to refer to knowledge of both *same* and *different* as complimentary opposites of the same conceptual coin. S/D will also be used commonly as referring to the types of tasks and discriminations involving this complimentary knowledge of both concepts.

Table 1.1.

Tasks in order of increasing complexity of relational computations

	1.	2.	3.	4a. 4b.	5.	6.	7a. 7b.	
	<u>Matching-to-Sample</u>	<u>Match/Nonmatch</u>	<u>Transpositional</u>	<u>Same/Different</u>	<u>Conditional</u>	<u>Within-Set</u>	<u>Relational</u>	
	(MTS)	(MTS/NMTS)	<u>Learning</u>	<u>Discrimination</u>	<u>S/D Discrim.</u>	<u>Relation Matching</u>	<u>MTS (RMTS)</u>	
				>2 items 2 items			>2 items 2 items	
Example Problems								
Relational Computations	=	= or ≠	≈	= and ≠	If ★, than = If ●, than ≠	If ≈ (e.g., smallest), than choose ≈	If =, than = If ≠, than ≠	
Capable Species								
Pigeon	1. & 2. Zentall & Hogan (1976)	3. Angermeier et al. (1965)	4b. Blaisdell & Cook (2005)				7a. Wasserman et al. (2002)	
Sq. Monkey	1. & 2. Burdyn & Thomas (1984)				5. Burdyn & Thomas (1984)			
Capuchin	1. & 2. Katz et al. (2002)	3. Scanlon et al. (1976)			5. Chapter 3	6. Kennedy & Fragaszy (2008)		
Baboon	1. Wilde (1994)			4a. Fagot et al. (2001)			7b. Fagot & Parron (2010)	
Rhesus	1. & 2. Harlow (1943)	3. Gentry et al. (1959)			5. Chapter 2-3		7b. Chapter 4	
Orangutan	1. Vonk (2003)						7b. Vonk (2003)	
Gorilla	1. Vonk (2003)						7b. Vonk (2003)	
Chimpanzee	1. & 2. Finch (1942)	3. Köhler (1938)		4b. Woodruff et al. (1978)		6. Chapter 5	7b. Thompson et al. (1997)	
Human	1. Weinstein (1941)					6. Gentner (1983)	7b. Flemming et al. (2008)	

Note. For example problems, samples are presented above choices; + indicates a correct selection. For relational computations, = reflects an identity/*same* relation, ≠ reflects a nonidentity/*different* relation, and ≈ reflects an otherwise “is relative to” stimulus generalization.

nonmatching-to-sample paradigm, but involve an additional level of assessment and computation. In a matching-to-sample (MTS) paradigm, subjects make one such equivalence computation (Thompson & Oden, 1996). Transpositional learning studies (e.g., Gentry, Overall & Brown, 1959; Köhler, 1938; Spence, 1937) address relations through simpler mechanisms of featural stimulus generalization. Transpositional learning requires an evaluation of one stimulus relative to another and subsequent choice of one stimulus that follows a consistent rule relative to that sample (e.g., darker than/lighter than) akin to generalized matching. In a S/D discrimination task one can use a similar singular equivalence computation. Finally, in a conditional S/D discrimination task wherein the subject makes responses to both identity and nonidentity based on specific discriminative cues present, two separate cognitive computations (one for identity and one for nonidentity) are required (Burdyn & Thomas, 1984). These computations are no more complex individually than are those utilized for matching to sample.

Tasks designed to assess knowledge of analogies add an additional level of conceptual complexity. Within-set relational matching tasks often presented to children wherein subjects must attend to the physical attributes of one item as it relates to the others in a given set are exemplary of the mapping of relations required by analogy (Goswami, 1995; Rattermann & Gentner, 1998a). These tasks require only attention to and selection of one item after an evaluation of its terms of relatedness amongst others, allowing for a focus on more local properties of stimuli. Relational matching-to-sample (RMTS) tasks on the other hand require the evaluation of sets of two or more items as they relate to one another and the subsequent selection of another entire set of stimuli, necessitating a focus on global properties of stimulus sets. Whereas both of these tasks are commonly used as measures of analogical reasoning ability in

human and nonhuman primates, neither necessitates the use of mental representations *per se* as required in analogy proper.

Step one: Concept learning

By definition, analogy first requires the determination of terms of similarity between two or more items (Gentner, 1983; Gillian, Premack & Woodruff, 1981; Premack, 1976; Thompson & Oden, 2000). This determination implies knowledge of relational concepts. Essential to analogy, concepts provide the framework upon which a relationship between items can be represented. The ability to sort items into classes allows one to transfer knowledge of these terms of relatedness to novel stimulus sets. Thus, applicable to humans and nonhuman animals alike, “concepts are the glue that holds our mental life together” (Murphy, 2002, p. 1).

Concepts are adaptive and cognitively efficient, and thus are likely to be observed at least in rudimentary form in nonhuman animals. There are several types of concept learning. In his learning-intelligence hierarchy, Thomas (1980) placed conceptual abilities in the highest three levels of an increasingly complex eight-level ordinal scale of “intellective abilities.” (p. 459). Table 1.2 outlines Thomas’ hierarchy. Levels 1-5 include more basic stimulus-response learning from habituation to discrimination learning. Levels 6-8 outline a continuum of conceptual abilities from the ability to make class distinctions based on physical similarities, a skill present in many nonhuman animals. At the highest end of this continuum lies the capability to act on class distinctions based *not* on physical or functional similarities, but on relations-between-relations that form the necessary foundation for analogical reasoning.

Perceptual concept learning. If concepts are the “glue” that cements our mental lives (Murphy, 2002) then sameness is the metaphorical glue that holds together all concepts. Perceptual similarity and stimulus generalization are the roots of all conceptual behavior

Table 1.2.

Thomas' (1980) learning-intelligence hierarchy

	<u>Conceptual Complexity</u>	<u>Example</u>
Level 8: <i>Biconditional Concept</i>	Relational Concepts	RMTS (if AA, choose BB, not CD)
Level 7: <i>Conditional Concepts</i>	Relational Concepts	Conditional S/D Discrimination (if ♦, choose AA, if ●, choose CD)
Level 6: <i>Class Concepts</i>	Feature-based Concepts	Transpositional Learning (if ■, choose ■, not □)
<hr/>		
Level 5: <i>Discrimination Learning</i> (multiple, concurrent S-R connections)		
Level 4: <i>Chaining</i> (two or more S-R connections)		
Level 3: <i>Stimulus-Response Learning</i> (Operant Learning)		
Level 2: <i>Signal Learning</i> (Classical conditioning)		
Level 1: <i>Habituation</i>		
<hr/>		

(Harnad, 1987). For example, the matching concept and identity matching-to-sample (MTS) paradigms require that one make a cognitive computation of perceptual equality between stimuli.

Early studies requiring “matching-from-sample” in rhesus monkeys, *Macaca mulatta*, (Harlow, 1943) inspired investigations of the most basic of perceptual concepts. By mapping individual stimulus features from a sample, rhesus monkeys learned an important generalizable rule that applied to a wide variety of stimulus arrangements from one trial to the next. In addition to a matching rule (perceptual similarity), Harlow (1943) also trained his monkeys to choose an object containing no stimulus features in common with a sample, or an oddity rule. These rules of nonmatching and matching-to-sample (MTS) serve as important foundations for concepts.

In an effort to examine concept acquisition for both sameness and difference, Zentall and Hogan (1976) investigated the generalization of the matching and nonmatching rule for pigeons (*Columba livia*). Pigeons initially trained to choose a shape that matched a sample (MTS) generalized the rule more rapidly to stimuli of novel colors on subsequent trials than did pigeons trained to choose shapes that were different from the sample (nonmatching-to-sample, NMTS). This first and most basic kind of concept learning is of perceptual concepts (Zentall, Wasserman, Lazareva, Thompson & Rattermann, 2008). Perceptual concept learning is accomplished when one sorts objects on the basis of shared physical features, akin to featural categorization. No level of abstraction is necessary; rather only a single cognitive computation of matching or stimulus generalization is needed.

Pioneering work by Herrnstein in the 1960s with pigeons provided evidence for perceptual concept learning in nonhuman animals. Pigeons learned several different concepts (e.g., trees, people, water, fish) based on generalization of stimulus features included in photographic slides (see Herrnstein, 1985, for review). Pigeons successfully discriminated slides

from disparate classes by pecking when certain stimulus features were present. Further, these discriminations based on stimulus features in common generalized to sets of novel photographs. Whereas all concepts are initially based on perceptual judgments such as these, it is likely that perceptual similarity guides several levels of conceptual behavior, including applications in analogy.

Whereas a go/no-go paradigm such as the one used by Herrnstein (1985) provides evidence for generalized knowledge of a single stimulus feature, concurrent knowledge of several stimulus features specific to different perceptual categories is indicative of both within and between conceptual knowledge. In an experiment that required pigeons to peck at one of four colored keys arbitrarily designated as the correct response when viewing a photographic slide from one of four categories (cats, flowers, cars and chairs), Wasserman and colleagues provided evidence for this between and within-class conceptual knowledge in a nonhuman animal (Bhatt, Wasserman, Reynolds & Knauss, 1988). Of course, true conceptual understanding cannot be proven without generalization to novel stimuli from the same classes. Because generalization to novel slides was not achieved at levels significantly above chance when pigeons viewed ten exemplars of each class, further investigations revealed that a more difficult training regime increased accuracy in generalization to novel stimuli. By increasing the number of training exemplars, Wasserman and Bhatt (1992) believed the likelihood of resemblance between training and generalization stimuli was increased, thus enhancing overall conceptual knowledge. Whereas accurate generalization of behavior toward novel stimuli provides evidence for knowledge of perceptual concepts one might argue that it is no different from a simple matching concept.

Roberts and Mazmanian (1988) investigated concept acquisition at varying levels of abstraction in three different species: humans, pigeons, and squirrel monkeys (*Saimiri sciureus*).

Utilizing concepts at three levels of abstraction similar to those described above (Thomas, 1980) Roberts and Mazmanian (1988) employed a two-choice discrimination task that required animals to differentiate one slide from another. Subjects viewed photographic stimuli of animals within predetermined categories, choosing keys corresponding to in-category and not-in-category. Slides were presented two at a time to the animals. Humans, not surprisingly, were able to acquire concepts at the basic, low-abstraction, as well as the high-abstraction levels. Humans correctly chose the in-category slides with around 90% accuracy for all three levels. Monkeys and pigeons, however, were less successful at certain levels of abstraction. Monkeys were significantly better at making the discriminations at low (e.g., kingfisher vs. other bird) and high (e.g., animal vs. nonanimal) levels. Pigeons only successfully acquired the most basic concept: they discriminated only kingfishers from all other slides. When the problem was made more abstract by requiring subjects to identify birds in general, or animals in general, the category may have become too broad or abstract for the subjects to learn a simple rule for identifying individual exemplars (Roberts & Mazmanian, 1988). These findings support the theory that nonhuman animals, and to the greatest extent pigeons, learn concepts by responding to a small set of features in pictures that look similar (Premack, 1983; Zentall, Edwards, Moore & Hogan, 2002).

Associative concept learning. Associative concept learning is a second type that relies on qualities other than equating or generalization of stimulus features. Without reliance on perceptual features on which to base judgments of identity, how is it that one identifies objects as belonging to the same class? The sameness that holds together members of associative concepts is arbitrary (Zentall, et al., 2008). Associative concepts are of interest in consideration of symbolic representation. For instance, spoken and written words are arbitrary designations for

concrete objects that they name and thus are associatively in the same class as that object. This utility of arbitrary stimuli belonging to the same associative class as a concrete object allows them to serve as symbols, representing all others in class whether present or not.

In many-to-one associative concept learning paradigms (i.e., Katz, Wright & Bodily, 2007), several stimuli are paired with one arbitrary stimulus, thus creating a discriminative cue. Through the common mapping of stimuli to a discriminative cue, all stimuli eventually come to represent the others that share an associative history with the same discriminative stimulus. For instance, by requiring the selection of circles and triangles when shown a patch of gold color and rectangles and ovals in the presence of a patch of blue color, an experimenter can effectively create associative classes of these rather arbitrary geometric shapes.

The treatment of two arbitrary stimuli as functionally similar is the foundation for stimulus equivalence (Cook, Katz & Cavoto, 1997; Harlow, 1943; Herrnstein, 1990). By establishing equivalence between stimuli, one can begin to understand the relations instantiated between them, an essential aspect of analogy that will be discussed at length in the next section. Formalized stimulus equivalence, according to Sidman and Tailby (1982) requires three properties: reflexivity (generalized identity matching – acquisition of the matching concept as discussed previously), symmetry (bidirectionality) and transitivity (mediated learning). These three properties specifically allow for what Sidman and Tailby (1982) refer to as emergent relations. For instance, by separately training an A-B association and an A-C association, subsequently finding an emergent B-C association provides evidence for an implicit relation, akin to transitive inference. An associative concept including all three stimuli has been created with only two explicitly trained and one implicit relation.

Step two: relational concepts

As is the case with associative concepts, relational concepts are not derived from the physical characteristics or perceptual properties of stimuli themselves. Unlike both physical and associative concepts, singular stimuli cannot be sorted into a relational class. Rather, relational concepts require the existence of at least two items. Relational concepts, such as *same/different* and *above/below* involve a comparison of the relationship between (or among) two or more objects. These concepts do not depend on any absolute perceptual properties of stimuli (Zentall et al., 2008), but rather are entirely based on the relation between them. Unlike most natural concepts, relational concepts are abstract in that classification based upon shared physical features of stimuli is impossible (Katz & Wright, 2006).

For the majority of this dissertation the relational concepts of *same* and *different* will remain the focus of attention because of their frequent utilization in problems of analogy. Like other relational concepts, *same* and *different* cannot be accounted for by associative learning alone. A particular stimulus can be used as part of either a *same* pair or a *different* pair, and thus cannot alone provide cues for relational concept learning. Only the relation between stimuli can define a relational concept. Because the relational classification of items requires a level of abstraction beyond that which one might need for other types of concept formation, successful discrimination of *same* from *different* has proven difficult for several nonhuman animal species from pigeons to chimpanzees (e.g., Fagot et al., 2001; Thompson & Oden, 1996; Vonk, 2003; Wasserman, Frank & Young, 2002; Wright & Katz, 2006; Young & Wasserman, 1997).

Same vs. different or uniformity vs. chaos. In one of the first investigations of *same/different* relational concepts utilizing multiple-item arrays, Wasserman et al. (1995) provide evidence that pigeons could learn the relational concept by generalizing the rule to novel

stimuli. Pigeons viewed arrays of 16 computer icons and responded to one of two keys designated for either same or different. Whereas the inclusion of 16 icons in each array is more than the amount of perceptual information necessary for a relational concept, the successful discrimination of these displays still provided convincing evidence that a perhaps more generalized concept for sameness and difference has been learned.

Katz et al. (2007) argued against a conceptual interpretation of these data. They believed a more parsimonious explanation to be a strategy in which pigeons based their judgments on global perceptual features of stimulus arrays such as orderliness. Katz and colleagues claimed that rather than a concept of *same*, it was more likely that the pigeons perceived and subsequently discriminated orderly from disorderly spatial organization of the visual arrays. If this argument were true, however, pigeons would not show any decrements in performance in transfer trials with novel stimuli. Pigeons did show small decrements in performance on transfer trials, indicating that along with a generalizable S/D rule their behavior was also guided to a small extent by memorization of individual icons (Wasserman et al., 1995).

Wasserman and colleagues conducted several experiments over the next decade designed to refute these spatial organizational arguments by presenting the pigeons with arrangements of icons that were spatially more random (Young & Wasserman, 1997), that were staggered and rotated (Young & Wasserman, 2001), and that were somewhat occluded via Gaussian blur (Young, Wasserman & Ellefson, 2007). Pigeons in all of these studies succeeded in making S/D discriminations without any decrement in performance predicted by alternate interpretations. Wasserman and colleagues then turned their collective attention to the display variability as a controlling factor in these S/D discriminations.

Variability refers to a computed amount of change in uniqueness from one stimulus to another rather than their spatial organization. A more plausible explanation of pigeons' behavior is that they show a graded change in discriminative responding as the amount of sameness and difference varied along a continuum. During their investigations of defining characteristics for categories, Shannon and Weaver (1949) quantified the amount of change within a categorical variable with a term they called entropy. Entropy, the amount of change between stimulus boundaries in a given display, is a measure of variation within in these relational categories. For stimulus-stimulus comparison purposes, it is calculated on a logarithmic scale by the number of discrete pieces of information necessary to predict the conceptual nature of that relational category, where $H(A)$ is the entropy of the categorical variable, or in this case, *same/different* stimulus array and p_a is the proportion of observed values within that category:

$$H(A) = - \sum_{a \in A} p_a \log_2 p_a$$

Thus, all displays of identical images, no matter the number, have entropy equal to zero; there is no change from one stimulus to another no matter how many are present within the array. Displays of all nonidentical images have entropy that increases on a logarithmic scale as the number of items contained within them increases (i.e., 2 nonidentical, entropy = 1.0; 4 nonidentical, entropy = 2.0; 6 nonidentical, entropy = 2.5). Discrimination tasks involving comparisons of entropy-infused *same* and *different* displays often receive criticism as subjects may detect general orderliness or disorderliness of the display rather than extracting relational-conceptual information, making a two-item S/D discrimination (entropy = 0, same vs. entropy = 1, different) the most plausible truly “conceptual” strategy.

Whereas humans (Young & Wasserman, 2001) and great apes (Vonk, 2003) appear less sensitive to and not dependent upon entropy of stimulus displays for the mental representation of

relations, pigeons, baboons (*Papio papio*) and rhesus monkeys are all species for which entropy is critical. Pigeons appear to be especially sensitive to changes in entropy in the acquisition of the S/D concept (e.g., Wasserman & Young, 1997). That pigeons appear to have considerable difficulty discriminating *same* from *different* with low levels of entropy contrast suggests a predisposition to attend to perceptual stimulus features over the conceptual. Rather than discriminating displays on the basis of their relational *identity/nonidentity*, pigeons default to a more item-specific strategy of attending to and perhaps memorizing large sets of individual stimulus features (Wasserman et al., 2002). Young, Wasserman and Garner (1997) decreased the number of items in each stimulus array to discover incremental depreciating effects on the pigeons' performance. Pigeons demonstrated marked difficulty in discriminating at all displays of less than 8 icons each. Entropy accounted for this variation in performance at each successively lower level. With each lower level of entropy contrast in discrimination of *same* from *different*, decrements in performance were observed to the point where with 8-item arrays responses were consistent with chance. In another study (Young & Wasserman, 1998), pigeons even ceased responding to trials containing entropy contrasts of 1 [2 nonidentical, entropy = 1.0; 2 identical, entropy = 0]. In addition, pigeons showed strongly asymmetric rates of acquisition for *same* displays over *different* displays (Young & Wasserman, 2002) and higher rates of overall success when discriminating *same* (S+) from *different* (S-) as compared to the reverse (*different* – S+, *same* S-).

Baboons also have been shown to exhibit sensitivity to entropy in the discrimination of *same* from *different* visual displays (Wasserman, Young & Fagot, 2001). Baboons tested on the multiple-item array S/D discrimination task were detrimentally impacted by a reduction in the number of icons from 16 to 8. Like pigeons, they mastered the task with 16, 12, and 10 icon

arrays and transferred their knowledge of the relational concepts to novel stimulus arrays. With arrays containing less than 8 items however, their discriminative performance was at chance levels. One considerable difference in the behavior of baboons was that they did not exhibit asymmetric discriminative preferences. That is, baboons were equally accurate on both *same* and *different* trials, indicating that their knowledge of the S/D concept was symmetrical albeit with strong perceptual dependency.

2 is better than 16? Wasserman and Young (2010) contended that a “single root process” (p. 11) guides the *same/different* discriminative abilities of pigeons and baboons. The graded decrement in discriminative behavior along with a reduction in item number gives no reason to believe that subjects employ any strategies of a different kind, but rather that their ability to use a strategy of variability detection is dependent upon a contrast of higher entropy distinction. Another argument (Katz et al., 2007) is that any *same/different* concept learning involving multiple-icon arrays cannot be attributed to conceptual learning because sameness and difference must be able to be defined between two items. Judgments based on more than two items are simply detections of perceptual entropy.

Wright and Katz (2006) reported that rhesus monkeys, capuchin monkeys (*Cebus apella*), and pigeons understand sameness and difference without the use of entropy-infused stimulus arrays. Both the primate and avian species used matching and nonmatching rules to judge relational sameness or difference and generalized these rules to novel stimulus sets with varying rates of acquisition, dependent on measures such as training set size, test stimuli and contingencies. The methodology used in this study required only a simple match or nonmatch rule in each subsequent trial. Whereas this study shed light on the employment of match/nonmatch rules independent of one another (see also Shields, Smith & Washburn, 1997),

the *simultaneous* discrimination of identical *from* nonidentical pairs of stimuli within a trial more was more difficult and more directly addressed conceptual knowledge of relations as opposite sides of the same coin.

Also in contrast to other S/D discrimination studies with pigeons (e.g., Wasserman et al., 2001), Blaisdell and Cook (2005) provided evidence for simultaneous 2-item S/D discrimination in pigeons. Performance was likely attributable to the use of geometric stimuli void of perceptual complexity that encouraged a focus on the relational information present, rather than a focus on specific stimulus features as might occur with more intricate clipart icons used in previous investigations. Blaisdell and Cook (2005) presented only 6 different geometric shapes of 6 different highly-discriminable colors. By creating 12,960 unique displays, memorization of specific stimulus combinations was considered impossible. Each pigeon was trained to peck only at *same* or *different* pairs within a testing session; nonetheless, they successfully discriminated *same* from *different* pairs, albeit not as opposite complimentary concepts. By simplifying the task and removing many perceptually-bound discrimination strategies, it is perhaps the case that relational information was more salient and thus conceptual strategies began to emerge. The utilization of trial-unique stimuli and a methodology encouraging a shift in attention away from perceptual features of stimuli likely allowed for the emergence of more conceptually-guided behavior. This brings to light questions of effects of the number and kind of exemplars utilized in the attainment of relational concepts.

Katz, Wright, and Bachevalier (2002) identified training stimulus set size as crucial to S/D abstract concept learning for both pigeons and nonhuman primates. An increased set size has the advantage of drawing attention away from aspects of individual exemplars and placing emphasis on the relation between them. With small set sizes, individual features of objects may

become the controlling cue, whereas in large stimulus sets individual features change frequently enough that stimulus relationships such as the S/D distinction are able to emerge as the basis for further discrimination (Katz et al., 2002). For both pigeons and monkeys, a larger training set of exemplars allowed for much greater success in the generalization of matching/nonmatching rules on subsequent novel transfer trials. However, the reverse is true for the speed of acquisition. With smaller stimulus training sets, rate of acquisition of matching/nonmatching rules was more rapid relative to larger sets. Regardless, generalization of the rule is the only measure that verifies conceptual acquisition.

Wasserman and Young (2010) argued, consistent with Goldstone and Barsalou (1998), that it is most appropriate to view S/D discrimination tasks as falling somewhere on a perceptual-conceptual continuum rather than being purely conceptual or perceptually-bound tasks. Goldstone and Barsalou (1998) stated that many phenomena we view as conceptual actually may be the result of perceptual processes becoming less bound to the perceptual features of the stimuli. Therefore, the degree to which a process is conceptual is dependent upon the degree to which it cannot be accounted for by perceptual features alone (Wasserman et al., 2002). In the case of *same* and *different*, conceptual control requires maintenance of the discriminative rule to persist even for two-item sets, with a minimal amount of perceptual sameness and difference present. Ideally, subjects could use the amount of perceptual variation in multiple icon arrays (higher entropy contrast) and flexibly apply a *same/different* rule to two-item sets if what was learned was truly relational in nature, rather than being bound to perceptual variation. However, there is great variability across species with regard to this ideal outcome. Figure 1.1 presents a taxonomic organization of species along which they likely fall along a perceptual-conceptual continuum in their ability to match relations.

CONTINUUM OF ANALOGICAL MECHANISMS

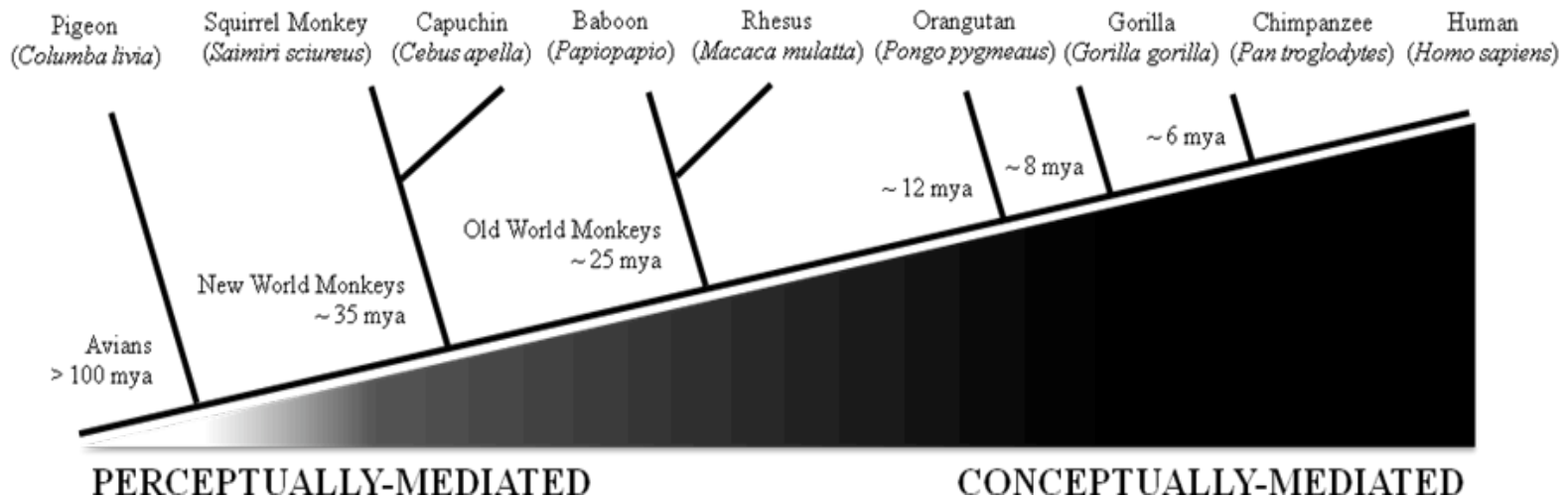


Figure 1.1. Continuum of mechanisms used in analogical reasoning and tasks of analogical prerequisites by human and nonhuman animals (Papini, 2008, p. 182; 659-690). Conceptually-mediated mechanisms such as representation and/or labeling of relations are inferred in species passing 2 x 2 relational matching to sample tasks. Conceptually-mediated mechanisms begin to emerge in capuchin monkeys and those primates sharing more recent common ancestors with humans. Perceptually-mediated mechanisms such as discrimination of relations and relational matching via perceptual variability emerge from avians onward.

Until recent studies (Fagot & Parron, 2010; Kennedy & Frigaszy 2008; Spinozzi et al., 2004) provided suggestive evidence that non-apes were capable of reasoning by analogy, failure to match relations in a *same/different* RMTS task by monkeys was attributed to a general cognitive discontinuity between their perceptual and categorical conceptual abilities. The hypothesized disconnect to process relational information, wherein formation of relational concepts is hampered by a natural predisposition of monkeys to attend to the perceptual qualities of the stimuli appears causal in their inability to match relations. This hypothesis is supported by the evidence from preferential handling and gaze studies that abstract relational properties are implicitly more salient for chimpanzee and child even at an early age than is the case for monkeys for whom physical elemental properties are more salient (Oden, Thompson, & Premack, 1990; Tyrrell, Stauffer & Snowman, 1991; Vauclair & Fagot, 1996). However, even for chimpanzees and children, these relational properties emerge from a reinterpretation of lower-order physical properties.

Whereas monkeys do not seem spontaneously to perceive 2-item relational sameness and differences, both chimpanzees (Oden et al., 1990) and 4-year-old human children (Tyrrell et al., 1991) preferentially attend to stimuli consisting of novel relations when habituated to another (e.g., *different* when habituated to *same*). Subsequent failures on the part of infant chimpanzees and 4-year-old human children seem not to reflect an inability to detect such relations, but rather are indicative of a failure in the application or voluntary accessibility of their existing perceptual competencies (Fodor, 1983; Oden et al., 1990). Thompson and Oden (2000) concluded from these results that monkeys are *paleologists*; their conceptual categories are based on shared predicates – absolute and relational features bound by perceptual and/or associative similarity, whereas symbol-trained apes are *analogical* in the sense that they perceive abstract propositional

similarities spontaneously. That some monkeys might appear to *behave* analogically may not, however, be attributable to reasoning by analogy proper.

Analogy: *Same* is the same as *same*

Whereas analogy is an extension of sameness (“choose the same relation as exemplified in the sample”) there is a significant gap in cognitive distance from physical similarity to analogy. A generalized ability to discriminate the relations of *same* and *different* is essential, albeit only the first step, in reasoning by analogy. As stated previously, analogy is dependent upon knowledge of first-order relational concepts, but requires an additional level of cognitive computation: that of relations-between-relations (Premack, 1976; Flemming, Beran, Thompson, Kleider & Washburn, 2008; Thompson & Oden, 1996; Thompson & Oden, 2000). The argument outlined here is not that this judgment is different in kind, but rather in degree, rendered difficult for nonhuman animals due to strategies that otherwise might be more accessible. For example, monkeys may have the cognitive capacity to perceive relations-between-relations, but they may instead employ a more accessible strategy of focusing their attention on local perceptual features of stimuli.

In addition to differences in attentional focus, Thompson and Oden (1996) further suggested that a relational matching-to-sample task is cognitively more demanding than either conditional or simultaneous relational S/D discriminations. In RMTS, there is required a greater number of both matching/nonmatching operations and number of encoded abstract relations to be retained for successful completion of a trial. In the RMTS task, the animal must first compare the physical properties of each item within the sample to identify the categorically abstract relation they represent (Premack, 1983; Thompson & Oden, 2000). It must then retain the encoded outcome of that operation while performing the same comparative operation on each comparison

stimulus pair and encoding those outcomes. Finally, the animal must compare the encoded abstract representations resulting from all of the former operations and judge these abstract representations to be the same or different before executing its decision response.

Representation in analogy. Hence, in order to make explicit *same/different* judgments of abstract relations as in analogical judgments, one must represent the abstract concepts in some way (Oden, et al., 1990; Premack, 1983). Little is known of the modality of such representations for nonhuman animals but one possibility is that the provision of physical symbols affords chimpanzees and children, if not monkeys, the opportunity to encode abstract S/D relations as iconic representations thereby functionally reducing the RMTS task to a covert physical matching problem (Penn et al., 2008; Thompson & Oden, 1996, Thompson & Oden, 2000; Thompson et al., 1997). Symbol systems appear to provide apes and humans the representational scaffolding for manipulation and expression of propositional knowledge in RMTS and related nonverbal analogy tasks (Gillan et al., 1981; Oden, Thompson & Premack, 2001). There is no evidence as yet that physical conditional cues associated with specific conceptual relations similarly acquire symbolic meaning for monkeys (Flemming et al., 2008).

The concepts of *sameness* and *difference* make possible analogies such as those in relational matching-to-sample (Premack, 2010). Moreover, whereas the computation of relational matching is of the same type, it must be processed concurrently with those of relational sameness or difference. The relational matching computation does however require a level of abstraction that other judgments of relational sameness and difference do not: no physical consistencies exist. As judgments of relation, these relations-between-relations are likely learned on a perceptual basis. Premack (1986) reported that although chimpanzees do not spontaneously

employ analogy, the animals gradually learned a relational matching-to-sample task with absolutely no feedback within 400 training trials.

An alternate belief (e.g., Penn et al., 2008) is that whereas perceptual similarity is based on relations between observed features, judgments of conceptual relational similarity are based only on the correspondence between symbols that abstractly represent the elements involved. This interpretation does not allow for the employment of perceptual comparison beyond the first computation of relational identity or nonidentity. Penn et al. (2008) stand alone both in their belief that analogy requires an altogether different cognitive faculty and that the ability to reason by analogy is uniquely human. With the recent evidence for “analogical animals” largely determined by how liberally one defines analogy, a discussion of alternate views on how analogical reasoning is accomplished is warranted.

Theories of analogy. In an attempt to define better what is meant mechanistically by analogy, Holyoak and Thagard (1995) proposed a multiconstraint model that, as its name implies, outlines several cognitive limitations that guide our use of analogy: similarity, structure and purpose. First, analogy is aided by a direct comparison of similarity of the elements involved. So, if there is any consistency between stimuli in base and target relations, a subject’s propensity to identify similarities between them may aid in the mapping of one relation to another. Second, the constraint of structure that helps guide analogy implies a pressure to identify parallels between base and target. That is, with all other options in a problem-solving process exhausted, a search for structural commonalities must take place. Like an extension of a search for similarity within sets, the same search for similarity between sets is an initiating force in the employment of analogy. Finally, and perhaps most noteworthy, there must be an inherent purpose to drive the goals of the thinker. In the case of nonhuman animals, this purpose might

take the form of motivation. Holyoak and Thagard (1995) state that this purpose serves to bias attention so as to favor the goal state. The role of motivation for nonhuman animals and the associated attentional shift will be discussed later.

Not entirely removed from the idea of a proposed shift in attention is Rattermann and Gentner's (1998a; see also Gentner, 1988) notion of a relational shift whereby subjects during development accomplish analogy only when terms of object similarity can be put aside in favor of relational similarity. Whereas 7-month old human infants spontaneously detect same and different relations (Tyrrell et al., 1991), the mapping of those relations emerges much later in development. Because several errors in analogical mapping by 4- and 5-year-old children were due to a focus on object-based similarity (i.e., attempted matching due to similar physical features of base and target), Rattermann and Gentner (1998a) contend that surface similarities drive reasoning skills until a point at which knowledge of the objects or situations therein is mastered, giving way to the search for possibilities beyond that which is already known. This relational shift from object properties to common relational structures is itself a shift in attention enabled by more generalized object expertise. Because the shift is dependent upon the amount and kind of knowledge a subject possesses in each specific domain, the point at which subject "becomes analogical" varies by content.

To re-examine the claims set forth by the relational shift hypothesis (e.g., decreased levels of responding based on object similarity with age; increased relational responding with age) Rattermann and Gentner (1998a) presented 4 to 5 year-old human children with simple word analogies. All choice alternatives were specifically created to analyze object- and relation-based responding. In all analogy problems, choices were either (1) correct – both object and relation, (2) wrong object/correct relation (3) correct object/wrong relation, (4) mere appearance

only / wrong object, but similar on at least one dimension. As predicted by the relational-shift hypothesis, the proportion of correct responses indeed increased with age and choice of mere appearance decreased with age. The proportion of incorrect choices by wrong object/correct relation remained relatively constant although rates of this choice were low for children at both ages. Finally, and consistent with their hypothesis, Rattermann and Gentner (1998a) observed a decline in correct object/wrong relation responses, although this was still the most common incorrect choice for children of both ages. Object-based selections overall declined with age presumably due to an emergence of preferential attention to relations.

Whereas the relational-shift helps to elucidate the development of skills in analogical reasoning, it may not fully explain the mechanisms of responding (e.g., nature of representations or symbols/language) for adults. In the structure-mapping model of analogy originally proposed by Gentner (1983), the mapping of knowledge from one domain to another is central to the assumption that there exists a relation held constant from one domain to the other. Thus, a focus on relational commonalities apart from the objects involved in them is required. Whereas this theory assumes the formation of mental representations (a contention in studies of animal cognition) of base and target relations, it is the mapping of these mental representations (in whatever form they may take) from base to target pair that is the critical process in analogical reasoning. Because the structure-mapping model relies heavily on the concrete formation of mental representations, it is not perhaps the best *representation* of analogy for nonhuman animals.

An important consideration of analogy by structure-mapping in nonhuman animals is this notion of representation that Penn et al. (2008) believed to be limited in principle alone to humans. Their view is that only humans can possess the representational capacities necessary to

reinterpret first-order perceptual relations as is apparently required for reasoning by analogy (the relational reinterpretation (RR) hypothesis). However, as Thompson and Flemming (2008) pointed out, not only is there an abundance of compelling evidence for representational capability by chimpanzees (e.g., Premack, 1976; 1983; Savage-Rumbaugh, Rumbaugh, Smith & Lawson, 1980) but there is also recent suggestive evidence for proto-symbolic treatment of relational information by monkeys wherein bidirectional associations between cues and paired relational stimuli are formed.

Because the nature of mental representation by nonhuman animals is contested (and believed by some not to be essential to reasoning by analogy), a new theory for analogy as relational priming (Leech, Mareschal & Cooper, 2008) is being embraced by comparative psychologists. Stating that analogy is driven largely by priming and transformations, Leech et al. (2008) propose that exposure to a situation primes relational knowledge of that situation that can then be applied to new instances via a transformation of the same type. Knowledge of relational information within a base (sample) acts to prime the employment of that same relational knowledge between base and target (choice/s). Leech et al.'s (2008) theory suggests that analogical abilities may in fact emerge from basic functions of a memory system provided concurrent increases in domain knowledge. In their view, the notion that analogy is a special cognitive faculty is denied. Instead, the seemingly complex reasoning skills arise from relatively more simple mechanisms. This employment of simpler mechanisms is especially appealing to comparative psychologists searching for analogical precursors in nonhuman animals within the constraints of parsimony.

Analogical-like behavior in birds and monkeys. Köhler's (1938) pioneering discovery of what he called transposition learning speaks to the application of relational knowledge that is

integral to so-called higher level reasoning by analogy. Köhler trained chickens to peck at boards of various shades of the same color, in effect instructing a relation for the “lighter” of two shades of a color. For example, chickens were required to peck a gray board when paired with a black board, then at a white board when paired with a gray board. He reasoned that they were able to see the relationship between the stimuli, instead of simply learning a single task or simply learning a specific stimulus-response-outcome association (Köhler, 1938).

Investigations of analogical reasoning via simple cognitive mechanisms in birds and non-ape primate species often lead researchers to a common conclusion that the behavior of their animals is in the very least a precursor to formal analogical reasoning. Wasserman and colleagues (Cook & Wasserman, 2007; Fagot et al., 2001) presented multiple icon arrays in a relational matching-to-sample paradigm to pigeons, baboons and humans. Using the same 16-icon identical/nonidentical stimulus arrays (i.e., Wasserman et al., 2002) for both sample and choices, Cook and Wasserman (2007) demonstrated successful matching of *same* and *different* arrays. With a reduction in entropy of stimulus arrays in RMTS, as in discrimination tasks, chance performance was observed in pigeons. Much like their discriminative behavior with the relational concepts, pigeons relied on contrasts of perceptual variability for the matching of these arrays (Cook & Wasserman, 2007) suggesting more limited abstract conceptual abilities in birds.

Fagot et al. (2001) presented the identical task to baboons with findings suggestive of a strategy somewhat less dependent on perceptual variability. Two baboons completed the RMTS task successfully with both samples and choices composed of 16, 12, and 8 items, providing evidence that entropy detection guided their choices. In another variation, these baboons also successfully matched two-item arrays (choices) with 16-item arrays (sample), suggesting that whereas detections of variability within a display are certainly important, conceptual thinking is

perhaps primed by an entropy-laden sample, encouraging sufficient conceptual extraction from a two-item choice array. According to the authors, the number of icons in the sample likely “exerts its effect on relational matching-to-sample performance quite independently” of the choices (Fagot et al., 2001, p. 327). For baboons, the recognition of and further application of relational concepts cannot be accomplished without detection of perceptual variability to at least prime further conceptual thinking (i.e., mental representations).

Analogy proper in monkeys. Fagot and Parron (2010) presented results that seem to indicate that variability is not a necessary component in relational matching for baboons. Using adjacent stimulus elements made of color patches, Fagot and Parron (2010) demonstrated the first evidence for two by two item RMTS. Six baboons were trained in an RMTS task involving compound stimuli made of two identical or nonidentical color blocks. During initial training, these compound stimuli were adjoined in what could be considered one stimulus sample (rather than a pair of images) and two choice stimuli (rather than two pairs of images), making it striking similar to an identity MTS task. In subsequent experimental phases, gaps between stimulus elements were introduced in incrementally larger sizes, effectively creating a true two by two item RMTS. The performance of baboons, which initially exceeded levels of chance, collapsed with increases in gap size between the stimulus elements, eventually falling to chance accuracy with a gap of just 30 pixels. This effect, which disappeared after 4,000 training trials, provided suggestive evidence for relational mapping of these identity/nonidentity pairs. Gaps of 60 pixels or larger between stimulus elements resulted in chance performance throughout the study, however, which is concerning because the acquisition of this supposed analogical rule lacks critical generalizability.

Fagot and Parron (2010) believed that this ability to match relations by monkeys had been previously masked due to local processing of stimuli that hindered monkeys' ability to perceive the stimuli as pairs rather than independent objects. Given these findings, it is possible that previous failures by monkeys on RMTS tasks in spite of clear understanding of relational the S/D concept is due to the way in which monkeys perceive the task. Evidence from studies of local versus global visual processing by monkeys (Fagot & Deruelle, 1997; Spinozzi, De Lillo & Truppa, 2003) strongly indicates that grouping of elements separated by gaps into a structure of a higher order is extremely taxing and sometimes impossible. Thus, solving the two- by two-item RMTS task requires that six stimuli be grouped into three distinct pairs. For monkeys, a local mode of processing, rather than a global one, dominates in this task. Because the RMTS task is very highly demanding of attention for monkeys, it may be the case that demonstrations of failure of this task are due to attentional deficits rather than a lack of ability to reason by analogy.

One such task that provides evidence for an “analogical monkey” in contrast to results often garnered from identity/nonidentity RMTS seems not to require such high levels of attentional demand. Spinozzi et al. (2004) presented capuchin monkeys with a very similar RMTS task, but not one involving the S/D concept at all, but rather inference of *above* and *below*. Concepts of *above* and *below* are relational, but pose no confound for within and between set comparison like *same* and *different* (e.g., sample = *different*, choose the pair exemplifying the same relation, choice = *different*). Stimuli presented to capuchin monkeys were composed of horizontal lines and dots positioned either above or below the line, beginning with configurations identical distances from the bar, transitioning in subsequent transfer trials to spatial configurations that varied widely from sample to choices. Transfer tests with novel images (stars and triangles positioned above and below lines of varying lengths) revealed a significant level of

correct responses in this RMTS task. These results would seem in contrast to the general agreement (see Thompson & Oden, 2000) of a lack of ability to reason analogically. Spatial relations, on the other hand, may simply be more easily processed by monkeys than relations of identity and nonidentity. Depy, Fagot and Vauclair (1999) suggested that, because of a specialized processing of categorical spatial relations, abstraction of these relations is perhaps less dependent on labeling than other relational concepts.

Kennedy and Frigaszy (2008) investigated the ability of capuchin monkeys to match relations in a 3-dimensional search task involving hidden food under plastic cups of different sizes. This procedure is often used with children in developmental applications. A food reward was first baited under two sets of cups out of sight of the subject and then revealed by an experimenter in one set of cups. The other set of cups of different absolute sizes was available for the capuchin monkey to search under. Capuchins searched directly under one cup by lifting it to reveal either the presence or absence of reward, contingent upon matching relative size between subject and experimenter sets. One of four capuchin monkeys performed at levels above chance not only on a basic two-item task, but also on a series of transfer tasks with three novel stimuli and distracters. The authors hypothesized that the extensive problem-solving experience of this subject may have provided the scaffolding on which this newly emerging analogical reasoning was built.

A three-dimensional search task has several advantages over RMTS. First, like studies by Spinozzi et al. (2004) and Fagot and Parron (2010) it does not allow for the employment of a strategy based on contrast in perceptual variability, strengthening the argument that success on this is exemplary of reasoning by analogy proper. Second, the concepts of *sameness* and *difference* within sets do not confound the search for sameness between sets. Finally, a three-

dimensional search task is both interesting and advantageous in certain ways over an RMTS task when studying analogies because it adds a level of application and ecological validity for reasoning. Rather than matching pre-determined concepts (i.e., *same* and *different*) subjects in this task are free to attempt any number of strategies, only one of which ultimately provides reward. Subjects may make selections based on absolute size by searching under the cup that is most physically similar to the absolute size of the sample. Alternatively, one may choose based on the same relative spatial position as the sample. Although not rewarded, this choice behavior is also analogical. Finally, and consistent with the reward contingencies of the task, subjects may (and should) choose based on relative size of the sample to the alternate cups in the set. It is noteworthy that even attempts at the former strategies provide support for analogy.

This species disparity is further supported by evidence from rhesus monkeys trained to choose geometric shapes associated with relational identity/nonidentity pairs (and the reverse) but subsequently failing to match relations (Washburn, Thompson & Oden, 1997). Unfortunately, the failure by these monkeys does not implicate symbol-training per se, but rather a more general qualitative difference in conceptual employment of monkeys and apes.

Analogical reasoning in humans. Studies of relational similarity and analogical reasoning are rarely free from consideration of language as a driving mechanism by which analogy is enabled. One such study, however, parallels the methodology used with pigeons and baboons (Young & Wasserman, 2001). If the relational matching strategies employed by humans are entirely disparate from those used by birds and monkeys, no decrement in performance would be observed with a reduction in the number of items in a *same* or *different* stimulus array as observed in both pigeons and baboons, implicating entropy (contrast in perceptual variability) as a controlling factor. Without every mentioning the words *same* and *different* in task

instruction, Young and Wasserman (2001) trained undergraduate students first to discriminate *same* from *different* 16-icon displays. Although never failing to complete any version of the task successfully, human responses were not entirely immune to effects of entropy: small decrements in performance and increases in reaction time were observed with each successively lower entropy contrast. Although it is usually believed that language plays an integral role in the mapping of one relation to another for humans (REF needed), other mechanisms in common with birds and baboons may also drive analogy for humans.

Developmental studies with human children often reveal not only the importance of linguistic labeling for employment of analogy, but also the role of explicit instruction to seek out relational information. Relational mapping is often observed in typically developing children between the ages of 3 and 4 years old, during a period of rapid language development. Rattermann and Gentner (1998b) argued for the importance of labels in the alignment of relational concepts for human children have. Rattermann and colleagues presented children with a three-dimensional relational-size analogical search paradigm in which stickers were hidden under analogous sets of plastic boxes of different sizes. In this “family size relations” task, each object was labeled as the “daddy,” “mommy” or “baby” object to provide the child with a familiar relational structure. For children instructed with family labels, successful mapping increased to levels significantly above chance, implicating the necessity of linguistic labels for the employment of an analogical strategy.

When surface similarities exist between old and new problems (e.g., using the same elements) analogical reasoning is more quickly applied to the new problem. However, if the similarities between previous experiences and novel problems are only structural (e.g., content) in nature, application of analogical reasoning skills is far less obvious and therefore not as salient

a strategy. In experiments with both children and adult humans, surface similarities seem to be integral in whether participants recognize analogical similarity in order to solve a problem when not explicitly told to do so (Catrambone, 2002; Gentner, Rattermann, & Forbes, 1993; Ross, 1987).

Gentner and Rattermann (1991) used an identical task to Rattermann and Gentner (1998b), but they included four distinct groups of objects to examine potential errors based on object similarity. Flower pots, houses, mugs and cars were arranged in decreasing size from left to right on a table top for both the child and experimenter. These sets often included distracter objects such as identical objects of the incorrect relative size to the sample (which were not the correct “relative size” choices) in order to determine whether the children relied on a strategy of object or relational similarity. For instance, if the experimenter’s set included a large car, medium house and small mug (S+), the set from which the child was required to select the smallest object might include a large mug, medium car and small house. At the onset of the trial, the experimenter demonstrated with her set of objects where a sticker was hidden. Half of the children were instructed to “use this information” to find a sticker hidden somewhere under his or her set. She then allowed the child to search his or her set to find the sticker. The correct choice was always to search under the object of the same relative size as the one lifted by the experimenter, a choice that was markedly difficult for 3-year-olds, but seemed to emerge gradually for 4-year-olds with this explicit instruction. Children that received no instruction often failed the task entirely. That 4-year-old children did not use analogy unless explicitly told to do so via focusing attention to the relational structure present further implicates the importance of attention and problem representation in analogical reasoning. Dunbar (2001) and Ripoll, Brude, and Coulon (2003) reported results from studies in which even adult human subjects failed to

solve a problem involving the analogical transfer of problem structure from one reading passage to another. As is the case with most investigations of analogical reasoning in human adults and children, these studies heavily rely on the use of language and thus present the intriguing idea that language and stimulus meaningfulness might play a critical role in the emergence of analogical reasoning (for comprehensive review of analogical reasoning in humans, see Gentner, 2003; Murphy, 2002; Vosniadou & Ortony, 1989).

Analogy-proper in apes. Once considered a hallmark of human intelligence, most studies in analogical reasoning in chimpanzees were inspired by the idea that language played an integral role in the mapping of relations. Symbol or so-called “language-trained” chimpanzees presented a unique opportunity to investigate the role that this special cognitive faculty might play for analogy. In contrast to results from pigeons and monkeys, evidence from chimpanzees is highly suggestive of an “analogical ape.”

One chimpanzee has provided perhaps the most extensive evidence for analogical behavior in a nonhuman (Gillian et al., 1981). After extensive training with plastic tokens for the words “same” and “different,” Sarah the chimpanzee was capable of completing and creating both standard item and functional analogies. In one study, she was provided with three terms of an analogy: two identical or nonidentical geometric chips to the left of her symbol for same, and one geometric chip positioned to the right of the same symbol. Sarah was then required to find the correct right-side companion chip to complete the analogy. If the chips on the left were identical, she would find the chip from a set of alternatives that was identical to the single chip in the right-side position. Likewise, if the left-side chips were nonidentical, she chose the nonidentically related companion for the right-side chip, matching the relation instantiated in the left-side pair.

Thompson and Oden (1996) also reported Sarah's abilities to arrange four geometric chips from a randomized group and one of her tokens for *same* or *different* on an empty board in an analogical fashion. Thus, she not only completed analogical transformation, but she also was capable of constructing them with no predetermined samples provided.

Not all of Sarah's reasoning abilities were limited to the identity/nonidentity concept. Functional analogies provided further insight into her application of relational matching, indicating more generalized understanding of analogy. Gillian et al. (1981) presented Sarah with pairs of objects that were related only in that they could function together. For example, when presented with a padlock and key as a sample pair, and a closed paint bucket as one choice, Sarah chose a can opener rather than a paintbrush, matching the "*A is opened by B*" relationship conveyed in the sample, rather than mere associative account due to probably proximity of the objects in space.

This symbolic language-like training was thought to be responsible for all of Sarah's success. Premack (1976; 1989), Gillian et al. (1981) and Thompson and Oden (1996) have all suggested that the critical role of her symbols for *same* and *different* was to provide her with a concrete means of encoding conceptual-relational information that was otherwise abstract. The task of matching then became one of covert symbol matching – mapping one mental representation to the other. At least in the case of abstract relations, acquisition of conceptual knowledge necessary for analogical reasoning is dependent upon these specific language-related skills.

Other than this token-trained chimpanzee, evidence of analogical abilities by chimpanzees without prior training with symbols for *same* and *different* is sparse. Thompson et al. (1997) found evidence of relational matching from language-naïve chimpanzees, implicating

generalized token training as important to analogy. The chimpanzees in this study had a history of conditional discrimination training using tokens and multiple pairs of objects. For example, they viewed identically or nonidentically related pairs of stimuli and were rewarded for choosing one of two arbitrary tokens. The opposite (required for symbolic training) had not been tested. That is, they could choose the correct token in the presence of a relational pair, but it is not known whether they could choose the same relational pair in the presence of a specific token. Four of five chimpanzees spontaneously judged the conceptual equivalence of relations-between-relations. The fifth chimpanzee differed in his learning history; he was naïve with respect to numeric problem solving and symbolic token training in addition to language training. Therefore, it seems that these tokens may have a functional role in the acquisition of abstract concepts.

Inspired by Gentner's (1989) notion of a developmental relational shift for children, Flemming et al. (2008) further examined the role of stimulus meaning in the analogical reasoning abilities of three different primate species. Humans, lexigram-trained chimpanzees, and Arabic-numeral-trained rhesus monkeys completed parallel relational matching-to-sample (RMTS) tasks with both meaningful and nonmeaningful stimuli. As Gentner (1989) suggested, the level of expertise for the objects involved mediates a relational shift in attention from physical traits to relational characteristics. Thus, it was potentially the case that the meaningfulness to participants of individual stimuli could allow for the expression of relational understanding and further application in analogy. Subjects were presented with a typical two- by two-item same/different RMTS task in which stimulus pairs were composed of either meaningful (humans – 3-7 letter words; chimpanzees – mastered lexigrams; rhesus monkeys – numerals 1-9) or nonmeaningful stimuli (humans – 3-7 letter nonword strings; chimpanzees – never-before-seen lexigrams; rhesus monkeys – Latin alphabet letters). Meaningfulness facilitated the

acquisition of analogical matching for human participants, whereas individual differences among the chimpanzees indicated that meaning could either enable or hinder their ability to complete analogies, much like errors in surface similarities described by Gentner and Rattermann (1991). Rhesus monkeys did not succeed in the RMTS task regardless of stimulus meaning, suggesting that their ability to reason analogically, if present at all, may be dependent upon a dimension other than the representational value of stimuli, or that the stimuli used were not of equal meaningfulness to those used with chimpanzees and humans. For a full account of the methodology and findings of this study, see Appendix.

It is important to note that evidence to vouch for the “analogical ape” is taken from the performance of less than ten individuals, most with specialized training. Recent evidence from Haun and Call (2009) provides less convincing evidence for the strong propensity of apes to reason by analogy. Chimpanzees, bonobos (*Pan paniscus*), gorillas (*Gorilla gorilla gorilla*) and orangutans (*Pongo pygmaeus*) were presented with a series of tasks involving a search for reward under sets of three cups in which a relational strategy resulted in success, in a fashion similar to Kennedy and Frigaszy (2008). In the first two conditions, correct choices of cups were physically connected to each other with plastic tubes or lines painted on the surface of the platform. In a final condition, no tubes or lines were present to connect correct choices, leaving a task in which correct choices are attributable to relational matching.

Gorillas and orangutans showed little success in matching on the basis of relation when objects were connected only by lines and were farthest in proximity to samples. In the final phase of the experiment where objects were not connected, only chimpanzees performed above chance, albeit undetermined statistical significance. One may argue that with physical connections between sample and choice objects, subjects in this series of experiments need not

employ a relational strategy at all to succeed. Rather, physical connectedness and proximity seem a more parsimonious explanation. That chimpanzees had markedly more difficulty with the task when objects were not physically connected leaves uncertain their ability to use relational similarity to reason analogically.

Whereas Premack (1976; 1986) emphasized the facilitative effect of formal language on analogical reasoning, several more recent studies with language-naïve apes and monkeys provide evidence to the contrary. Thompson and Oden (1993) propose a modified theory that even a more generalized training history involving the association between an arbitrary cue and abstract relation is sufficient for chimpanzees to successfully judge relations-between-relations. Why then is it the case that the same does not hold true for monkeys? Whereas monkeys can be trained to associate discriminative cues with *same/different* relations, their subsequent failure to match these same relations is likely a failure of another kind, implicating mechanisms simpler than symbol systems in analogy. Even with symbol training of this type (i.e., Flemming et al., 2008; Washburn et al., 1997) cues themselves did not take on the same representational qualities; the cues could not acquire the referential meaning for the relations of same and different that Thompson and Oden (2000) consider crucial to the further judgment of second-order relations. Is it the case then that this referential quality of symbols is in fact unique to humans and chimpanzees?

Closing the gap: An overview of this dissertation

Considering comparative data from human children and symbol-trained monkeys and apes, it would seem that several factors could mediate the ability to reason by analogy. The mapping of relations is not one that operates via a singular cognitive mechanism, but rather multimodally, and such mapping may be hindered by deficits in areas other than language. The

oft-observed perceptual to conceptual “disconnect” between apes and monkeys perhaps can be closed by a variety of methodological scaffoldings, making a strong distinction between analogical and non-analogical primates unnecessary.

Goldstone and Barsalou (1998) suggested that narrowing the gap between perception and concept use is easy given the mechanistic commonalities between perceptual and conceptual processes and a deep-rooted dependence on perception for abstract conceptualization. Both object similarity and higher order concepts have their cognitive foundations in perception; both rely on the same basic perceptual mechanisms for their implementation. Although abstract relations may seem far-removed from perception because of their generality and universal applicability outside of specific domains (unlike object similarity) Goldstone and Barsalou (1998) argued for implicit conceptual biases that likely emerge from learned perceptual similarities, explaining the continuity between the two processes.

Learned perceptual similarities (i.e., object similarity and relational concepts) may be difficult to train, but once constructed may become automatic and difficult to break, explaining to the difficulty animals experience with relational matching. Flexibly moving from a similarity rule involving only two objects “A=A” (within pairs) to one involving an equivalence calculation between pairs “AA=BB” requires transformation of the rule (Goldstone & Barsalou, 1998). These early similarity judgments serve to promote the transformation, but may require a shift in the focus of attention from perceptual to relational similarity as a jumping off point.

Consider an analogy of analogy proposed by Goldstone and Barsalou (1998): jaw bones are to perceptually-based concepts as ear bones are to abstractions.

... mammalian ear bones probably evolved from jaw bones. The sound-transmitting function of the jaw/ear bones was only selected for one the biting function of the jaw had already established the jaw bone’s basic shape. Likewise, the starting shape of our concepts may be perceptually-specific initially, but can be transformed in quite different

directions once developed. Later structures (ear bones and abstractions) depend on and grow out of earlier structures (jaw bones and perceptually-based concepts) for their very existence even as they acquire radically different functions. (p. 245)

The evolution of concepts from perception produces sometimes drastically different functions, just as in biological evolution. Throughout the chapters of this manuscript, studies designed to systematically clarify the cognitive factors involved in closing the gap between perceptual and abstract conceptual processes for nonhuman primates will be presented.

In Chapter 2, in which I examine the role of entropy and symbols for rhesus monkeys, the distinction seems wide between knowledge for relational concepts and their subsequent application in analogy. After repeatedly failing to perceive relations between pairs of stimuli in a two-choice discrimination paradigm, monkeys rapidly learned to discriminate between 8-element arrays, owing success to the perceptual variability of stimuli. Subsequent tests with smaller arrays indicated that although initially important for acquisition of the concept, entropy is not a variable on which monkeys based their subsequent discriminative choices. Not only did monkeys choose a corresponding relational pair in the presence of a cue, but they also chose the cue itself in the presence of the relational pair--in essence, labeling those relations. Subsequent failure on the RMTS task suggested a disparity between the ability to perceive and form mental representations of relations and the ability to use those mental representations instrumentally.

Chapter 3 continues the study of entropy measures for rhesus monkeys and introduces new investigation of the S/D concept in a new world primate, the capuchin monkey. Utilizing a method of *increasing* entropy, rather than conventional procedures of decreasing entropy, the data demonstrate unique evidence that capuchin monkeys are capable of making 2-item relational S/D conditional discriminations, in contrast to suggestions that S/D discriminations are markedly more difficult and likely involve detections of higher entropy contrast for monkeys. In

another experiment, the supposed level of difficulty in making S/D discriminations is examined in rhesus monkeys. With sustained accurate performance of 2-item S/D discriminations, both experienced and task-naïve rhesus monkeys appeared quite ‘comfortable’ in their conceptual knowledge of *same* and *different*. Learning of the *same/different* relational concepts may be less “entropy-important” than originally hypothesized for nonhuman primates.

In a return to the discussion of how these relational concepts are applied to problems of analogy, the study in Chapter 4 demonstrates unique success by rhesus monkeys to judge relations-between-relations due to a cognitive incentive. Rhesus monkeys completed a categorical (identity & nonidentity) relational matching-to-sample (RMTS) task with differential reward (pellet ratio) and/or punishment (timeout ratio) outcomes for correct and incorrect choices. Monkeys in either differential reward-only or punishment-only conditions performed at chance levels. However, the RMTS performance of monkeys experiencing *both* differential reward and punishment conditions was significantly better than chance. Subsequently, when all animals experienced nondifferential outcomes tests, their RMTS performance levels were uniformly at chance again. The results of this study indicate that combining differential reward and punishment contingencies provide an effective, albeit transitory, scaffolding for monkeys explicitly to judge analogical relations-between-relations, potentially mediated by a re-focusing of attention.

Chapter 5 presents a series of experiments with chimpanzees to further examine the employment of an analogical rule free from confounds of entropy or the relational concepts of same and different. Analogical strategies in three chimpanzees were examined using a 3-dimensional search task modeled on the study by Kennedy and Fragaszy (2008). Food items were hidden under one of two or three plastic cups of varying sizes for the subsequent search by

the subject under the cup of the same *relative size* in their own set of cups – reasoning by analogy. Two chimpanzees initially appeared to fail the first relational phase of the task. Upon further inspection, it appeared that they were instead using a secondary strategy not rewarded by the contingencies of the task – choosing based on the same *relative position* in the sample. Although this was not the intended strategy of the task, it was nonetheless analogical. In subsequent phases of the task, chimpanzees eventually learned to shift their analogical reasoning strategy in some ways like Gentner’s (1983) relational shift to match the reward contingencies of the task and successfully choose based on *relative size*). This evidence not only provides support for the “analogical ape” hypothesis (Thompson & Oden, 2000), but also exemplifies how foundational conceptually-mediated analogical behavior may be for the chimpanzee.

Through this series of comparative studies, the distinction between analogical and non-analogical beings is assessed, and the results will be interpreted from the position of a multimodal approach to the study of analogical reasoning. As discussed earlier, a multimodal approach for the employment of analogy allows for consideration of a variety of mechanisms by which the relational matching can be accomplished, rather than being resigned to a special faculty once thought unique to humans. I will argue in the discussion, on the basis of the evidence from the studies next presented, that the view of control for analogy by language alone is antiquated, counterproductive from a comparative perspective, and should be replaced with a more liberal view of other mediating factors through which a variety of species can accomplish the application of previously learned information in ways that afford analogical reasoning.

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Chapter 2: Disconnect in concept learning by rhesus monkeys: Judgment of relations and relations-between-relations²

Abstract

We investigated the role that entropy measures, discriminative cues, and symbolic knowledge play for rhesus monkeys in the acquisition of the concepts of *same* and *different* for use in a computerized relational matching-to-sample (RMTS) task. After repeatedly failing to perceive relations between pairs of stimuli in a two-choice discrimination paradigm, monkeys rapidly learned to discriminate between 8-element arrays. Subsequent tests with smaller arrays, however, suggest that, although important for the initial acquisition of the concept, entropy is not a variable on which monkeys are dependent. Not only do monkeys choose a corresponding relational pair in the presence of a cue, but they also choose the cue itself in the presence of the relational pair--in essence, labeling those relations. Subsequent failure in the judgment of relations-between-relations, however, suggests that perhaps a qualitatively different cognitive component exists that prevents monkeys from behaving analogically.

Keywords: CONCEPT LEARNING, SAME/DIFFERENT, ANALOGICAL REASONING, MONKEYS, *MACACA MULATTA*

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Not all concepts are equal. In his learning-intelligence hierarchy, Thomas (1980) placed conceptual abilities in the final three levels of an increasingly complex eight-level ordinal scale. At the bottom of the conceptual part of the continuum lies the ability to make class distinctions based on physical similarities, a skill present in many nonhuman animals. At the other end of this spectrum lies the capability to act on class distinctions based *not* on physical or functional similarities, but on relations-between-relations that form the necessary foundation for analogical reasoning.

Today, there is little debate over whether nonhuman animals exhibit at least basic conceptual abilities. But, how far are animals able to abstract these conceptual abilities in order to apply them to novel situations? This range of potential conceptual abilities has been extensively investigated for several species of the animal kingdom (Herrnstein, 1990), with mixed results. Many animals transfer learned discriminative performances to novel stimuli in tasks assessing identity matching and sameness/difference, which is the focus of the present article (e.g. Blaisdell & Cook, 2005; Burdyn & Thomas, 1984; Cook, Katz, & Cavoto, 1997; Cook, Wright, & Kendrick, 1990; Herman, Hovancik, Gory, & Bradshaw, 1989; Herrnstein, 1990; Pepperberg, 1987; Wasserman, Frank, & Young, 2002; Wasserman, Young, & Fagot, 2001; Wright, 1991, 1997; Wright & Katz, 2006; Wright, Rivera, & Katz, 2003; Zentall, Edwards, Moore, & Hogan, 1981). However, there is one conceptual task for which some researchers propose a major difference in the abilities of some animals and those of others. Premack (1983) argued that chimpanzees were unique in their ability to reason analogically, the highest degree of abstract conceptualization (and the highest level of Thomas's (1980) learning-intelligence hierarchy). In an analogy, a relationship must be established between the first two

elements in a series. Then, and only then, can one observe the second set of elements and seek the same relation between them. By discriminating between two abstract relations, one is able to acquire the knowledge needed to complete and construct analogies, much like the chimpanzee Sarah did (Gilliam, Premack, & Woodruff, 1981). Sarah was given a variety of analogical reasoning problems using arrays of meaningful plastic chips of different colors and shapes. Two tangible plastic objects that varied on one dimension (color, shape, or size) were placed to the left of a center chip that signified *same*. To the right of the *same* symbol was placed only one object. The task thus required the chimpanzee to perceive the relationship between the shapes on the left and recreate its analog to the right of the center chip.

Oden, Thompson, and Premack (2001) revisited analogical reasoning tests with Sarah in which she had to complete partial analogies from up to three alternatives and also construct analogical relations by placing geometric forms from a randomized group of up to five alternatives onto an initially empty canvas. Sarah showed evidence for the acquisition of analogical reasoning skills, and she proved capable of seeking out unspecified relations, followed by judging their analogical equivalence.

One task that mimics the use of analogies is the relational matching-to-sample paradigm in which subjects judge the relation between the items in a sample pair (either *same* or *different*) and select the choice pair in which the items are related in the same way. An example is a situation in which one learns “if AA, choose BB, not CD; if AB, choose CD, not EE.” Successful performance on a relational matching-to-sample task provides the necessary evidence that an animal has the most heightened degree of abstract conceptualization. Evidence from a select few chimpanzees with specialized token and/or symbol training suggests that abstract

conceptualization may not be a unique hallmark of human intelligence (Thompson, Oden, & Boysen, 1997).

Fagot, Wasserman, and Young (2001) investigated whether baboons could discriminate *same* from *different* by judging relations-between-relations in a delayed relational matching-to-sample task (RMTS). One 16-item array appeared on the computer screen as the sample, followed by a short delay and the presentation of two choice arrays, with only one of the choice arrays being of the same relational type as the sample. Two baboons successfully learned to perform the task by picking the choice display that involved the same relation among the icons (*same* or *different*) as in the sample display. However, performance deteriorated as the number of items in the arrays was decreased. The performance decrement that occurred when the number of items in the arrays was reduced was asymmetrical, with performance on "same" trials remaining high regardless of icon number, whereas performance on "different" trials decreased with decreasing numbers of icons. Importantly, the task was still entropy-dependent, meaning that while matching the relation-between-relations, the judgments were based more on a perceptual sense of the arrays, rather than a cognitive concept *same* versus *different*. In other words, baboons perceived the amount of perceptual variance to be greater in *different* arrays than in *same* arrays.

To date, no monkey species has been able to judge the relation between relations of pairs of stimuli at a level comparable to that of chimpanzees. It is often hypothesized that monkeys' abilities lie lower on the conceptual continuum (Thompson & Oden, 1996; Thompson & Oden, 2000; Thompson, 1995; Premack, 1983; Premack & Premack, 2003), and evidence pertaining to their relational matching abilities is limited. As proposed by Thompson and Oden (2000), the monkey is best described as "paleological" meaning that it accepts identity based only upon

physical attributes, whereas the chimpanzee is “analogical” referring to its abilities to judge relations-between-relations.

Thompson et al. (1997) hypothesized that the judgment of relations-between-relations is made possible by an animal’s representational capacity to re-encode abstract relations into iconically equivalent symbols. It should follow then, that symbol training produces a system for universal computation. Thus, the critical role of the tokens used with some symbol competent animals is to provide the animals with a concrete icon for encoding a propositional representation that is otherwise abstract. In the context of abstract relational matching-to-sample, the token may “objectify” a relationship or have the retrieval function of a word (Thompson et al., 1997). Thompson et al. (1997) also suggested that conceptual-relational matching is akin to covert symbol matching.

To examine further the role of symbolic representation in conceptual reasoning, Thompson et al. (1997) presented language-naïve chimpanzees with a conceptual matching-to-sample task. After being familiarized with a physical matching-to-sample task, five adult chimpanzees viewed pairs of random three-dimensional objects as samples to be matched to two-dimensional choice stimuli presented on a touchscreen monitor. The goal was to indicate the choice pair that conveyed the same relation between the objects as the sample pair. Four of five chimpanzees spontaneously judged the conceptual equivalence of relations-between-relations. The fifth chimpanzee differed in his learning history; he was naïve with respect to numerical problem solving tasks and had no symbolic token training. Therefore, it seems that these tokens may have had a functional role in the acquisition of abstract concepts.

To summarize, a disconnect in concept learning exists between the analogical chimpanzee and the paleological monkey. Although Fagot et al. (2001) reported relational

matching, stimulus sets had large numbers of elements, suggesting that entropy played a role in such performance. We know that monkeys can respond to the sameness or difference of pairs of elements. They do so when taught to pick an element that is the same as or different from a sample (e.g., Washburn, Rumbaugh, & Richardson, 1992), to make a response indicating sameness or difference in a pair of elements (e.g., Bhatt & Wright, 1992), or in response to a cue to choose sameness or difference (e.g., Burdyn & Thomas, 1984). They do not, however, look at a pair of stimuli and note the relation between those stimuli as the relevant cue for which response to make to two other pairs of stimuli (one having identical elements and the other different elements). This inability of monkeys to perform relational matching compared to the success reported for chimpanzees is a striking cognitive discontinuity given the general finding of shared cognitive capacities between apes and monkeys (albeit with apes sometimes performing quantitatively better than monkeys on specific tasks; Thompson et al. 1997).

In an attempt to examine the nature of the relation-between-relations paradigm further, and to build on the successes of other research programs that have incorporated various features into conceptual tasks (e.g., entropy measures, discriminative cues), we presented rhesus monkeys (*Macaca mulatta*) with a series of same-different tasks. We sought ultimately to answer the question of why monkeys fail in a relational matching paradigm. Might there be task-related hurdles to overcome? Might monkeys first attempt a more procedural strategy that must in some way be circumvented methodologically? Might their concepts be more entropy-dependent? Might they require a discriminative cue or symbol-based training? Through a progressive series of computerized tasks, we tested many of the above possibilities in an attempt to outline the meaningful failures that ultimately lead to failure by rhesus monkeys in the relational matching-to-sample paradigm.

Experiment 1

Before participating in Experiment 1, all monkeys were presented with a series of preliminary training tasks. It was their failure on these that led to the design of Experiment 1. Those tasks are outlined briefly. Monkeys first failed to learn a computerized relational matching-to-sample (RMTS) task using trial-unique stimuli. This was not unexpected given the lack of evidence to date for such skills in monkeys. Next, we provided the monkeys with an easier task using a two-choice discrimination paradigm (removing any and all analogical components) in which pairs of identical and non-identical images were displayed. The rewarded relation between the two stimuli (same or different) was designated at the beginning of a testing session, and animals needed to repeatedly choose that relation. However, the monkeys still failed on this task. This suggested that perhaps they may have had difficulty perceiving and processing the pairs as consisting of two distinct elements. That is, they may have seen the pairs as one conglomerate of information, rather than two distinct images (whether physically the same or different) joined together to form a pair. Displays of eight clipart images then replaced the two-element pairs we had previously used.

The monkeys successfully completed this 2-choice discrimination task with arrays of 8 images each: indeed within the *first* testing session of 500 trials, all animals achieved the 80% criterion that we had established. However, something interesting occurred after this initial successful session. Although all monkeys succeeded in meeting criterion for the initial rewarded relation (no matter whether that relation was *same* or *different*) they then perseverated and never exceeded chance levels after the rewarded relation was reversed. For example, if the computer

program randomly assigned *same* as the first S+, monkeys learned this discrimination by consistently choosing the stimulus set that included 8 identical items. However, after reaching criterion, *different* was rewarded, but the monkeys never learned to make that response. Instead, they continued to choose *same* for hundreds of trials after the reversal. Therefore, the entropy manipulation was successful in establishing initial same/different relational judgments, but we still were faced with finding a way to indicate on a block-by-block (or more ideally, a trial-by-trial) basis which of the two relations was the S+.

To aid in S+ reversal learning, discriminative cues are often used in similar paradigms to indicate which rule must be followed (Riopelle & Copelan, 1954; Burdyn & Thomas, 1984). In Experiment 1, we gave the monkeys a cue to indicate whether they needed to “*choose same*” or “*choose different*.” In order to convey this information, background colors were assigned to each relation type. These cues provided the relevant information the monkeys needed in order to discriminate the S+. When the monkeys succeeded with arrays of 8 elements using these discriminative cues, we reduced the number of elements to investigate further the role of entropy (e.g. Young & Wasserman, 1997) in this performance.

Method

Subjects. In all experiments, five male rhesus monkeys (*Macaca mulatta*) individually housed at Georgia State University’s Language Research Center in Atlanta, GA served as subjects. The animals were Murph (age 10 years), Lou (age 10 years), Willie (age 18 years), Gale (age 20 years) and Hank (age 20 years). These animals had extensive testing histories in which they responded via joystick movement to computer-generated stimuli presented on a monitor (Richardson, Washburn, Hopkins, Savage-Rumbaugh, & Rumbaugh, 1990). All monkeys were familiar with, and proficient at completing, computerized matching-to-sample

(MTS) and delayed matching-to-sample (DMTS) tasks in which choice stimuli were exact replicas of sample stimuli (e.g., Washburn et al., 1992).

The monkeys were not food or water deprived during the course of the study, and they had continuous access to the computerized programs for blocks of time ranging from 4 hours to 24 hours. Therefore, they produced varying numbers of trials across sessions dependent on how long they were presented with the task. During this time, the computer program controlled reward delivery and trial presentation.

Apparatus. The Language Research Center's Computerized Test System (LRC-CTS) consists of an IBM-compatible desktop personal computer (described in Richardson et al., 1990, and Washburn et al., 1992). Each animal had access to its own testing station. During tasks, monkeys controlled a cursor on a 17-inch SVGA monitor via a vertically mounted joystick. The monitor was positioned approximately 24 cm from their home cage behind a transparent Lexan plate. Speakers provided sound feedback for all tasks, including a low buzzing sound for incorrect responses and an increasing crescendo sound for correct responses. These sounds have been paired with these outcomes on many previous tasks. For the current tasks, the increasing crescendo sound was always accompanied by the dispensing of a single 94-mg banana-flavored pellet. This same apparatus was used throughout all experiments.

Design and Procedure. Each monkey was tested while individually housed in its home cage. On each trial, two sets of 8 clipart images (3 cm x 3 cm) were displayed: one set of physically identical objects and one pair in which each object was physically distinct. These images were commercially available clipart images. Arrays were located on the top and bottom of the computer screen, with the location of *same* and *different* pairs being randomly determined on each trial (see Figure 2.1).

Discriminative cues indicated to the monkeys which of the two relations (*same* or *different*) was the correct choice on a given trial. These cues took the form of screen background colors. If the background was colored pink, the correct response was to select the set with all identical elements. If the background was colored black, the correct response was to select the set with all different elements. Monkeys were required to move a cursor (via their joysticks) into contact with one of the arrays by touching any area in that section of the monitor (i.e., the top or the bottom). If the contacted array was correct (S+), a banana-flavored pellet was dispensed, followed by an increasing crescendo sound. If the contacted array was incorrect, no pellet was dispensed, and a low buzzing sound was played. Inter-trial intervals of 2 seconds (correct choices) and 15 seconds (incorrect choices) were imposed. This same reward/nonreward system remained consistent throughout all phases of this experiment.

During Phase 1, the background color (and the rewarded relation) remained the same until the monkeys met a criterion of 80% correct for the most recent 50 trials. A new rewarded relation then was randomly selected, and the background color changed accordingly. This meant that sometimes the rewarded relation was reversed after criterion was met (e.g., from *same* to *different*) and other times it remained the same (e.g., remaining as *same*).

Because all monkeys rapidly achieved criterion, *and shifted their responses with shifts in the rewarded relation from the outset unlike in the pilot tests*, we removed the consistency of the rewarded relation in Phase 2. During Phase 2, the computer program randomly chose a rewarded relation on each trial, with an attendant shift in the background color to match the rewarded relation. This meant that each trial offered a new cue as to the correct response, as well as new stimuli drawn randomly from the set of 500 items. It is important to note that there was no way for any one stimulus to consistently appear as a member of *same* pairs or *different* pairs. This

ensured that the animals could not learn anything about particular stimuli and how to respond to those stimuli (i.e., item-specific learning was controlled).

During Phase 3, we gradually reduced the numbers of elements in each set. First, the set was reduced to 6 elements, then to 4 elements, and finally to 2 elements. Each reduction occurred after a monkey met a criterion of 80% correct over the last 200 trials. During this phase, the rewarded relation was randomly determined on each trial as in Phase 2.

Results

As noted, all monkeys rapidly learned to select the correct relation in Phase 1. All monkeys completed approximately 500 trials, with an average accuracy of 78.8% (Murph $z = 14.93$, Lou $z = 13.24$, Willie $z = 9.84$, Gale $z = 13.68$, Hank $z = 12.70$, $ps < .01$). In Phase 2, the monkeys continued to perform at high levels (see Figure 2.2). In Phase 2, each monkey (Murph, Lou, Willie, Gale, and Hank) selected the rewarded relation significantly more often than expected by chance on its first 1,000 trials ($z = 19.22$, $z = 16.94$, $z = 22.89$, $z = 18.72$, $z = 19.73$, $ps < .01$, respectively). Within the first 500 trials of Phase 3, each monkey selected the rewarded relation with 6-item sets at levels reliably higher than the 50% value expected by chance ($z = 16.19$, $z = 14.31$, $z = 18.33$, $z = 14.58$, $z = 16.99$, $ps < .01$, respectively). After the transition to 4-item arrays, selection of the rewarded relation again exceeded chance levels for all monkeys ($z = 14.04$, $z = 12.16$, $z = 13.41$, $z = 12.70$, $z = 14.22$, $ps < .01$, respectively). When sets were reduced to 2 element pairs, 1,000 trials were required by each animal in order to reach criterion. Nonetheless, all five monkeys produced accuracy scores that differed significantly from the 50% expected by chance ($z = 19.66$, $z = 21.69$, $z = 17.20$, $z = 20.42$, $z = 18.28$, $ps < .01$, respectively).

To further ensure that the monkeys had not learned equivalence classes based on the identity of the stimuli themselves, we conducted transfer tests with novel stimuli for Phase 4 of

Experiment 1 (as well as Experiment 2). These transfer tests, conducted almost one year after the original studies were completed, were encouraging as evidence that the concepts of same and different were learned and that we did not need to consider item-specific learning as an explanation of the monkeys' behavior.

In transfer tests, a set of 1000 completely novel clipart images replaced the previous pool. All methods were identical to those in Experiment 1, with one adaptation. Stimuli were drawn randomly to compose pairs for each trial, as in Experiment 1. However, rather than remaining available for random selection in subsequent trials, the image file was discarded after being used once in one trial. Therefore, after an image was used in a stimulus display, it was never seen again in any subsequent trials, including those in transfer tests for Experiment 2.

In transfer tests, two monkeys were tested with novel sets of stimuli and performed at levels reliably higher than the 50% value expected by chance within the first 225 trials. Murph completed 91.1% of 225 trials correctly ($z = 12.33, p < .01$). Gale performed 88.9% of 225 transfer trials correctly ($z = 11.67, p < .01$).

Addressing the possibility of asymmetric performance on *same* versus *different* trials, we conducted a post-hoc analysis examining levels of performance for all *same* trials and for all *different* trials. For Phase 1, performance did not differ between *same* trials and *different* trials, Murph $\chi^2(1, 1000) = 1.35, p > .05$). Likewise, in phases 2-4, symmetrical performance was observed on same versus different trials (6 items, $\chi^2(1, 500) = 1.29, p > .05$; 4 items, $\chi^2(1, 500) = 0.66, p > .05$; 2 items, $\chi^2(1, 1000) = 0.39, p > .05$). For all other monkeys, asymmetric performance was not observed in any phase, $p > .05$.

Discussion

Discriminative cues produced a substantial improvement in relational conceptual responding in these monkeys. When given cues as to which relation would be rewarded, monkeys learned to transfer from choosing *same* sets to *different* sets, and the perseverative errors from the pilot studies disappeared. Additionally, these cues provided scaffolding for the eventual reduction of the number of elements in the sets back to a level where the monkey now could respond on a trial-by-trial basis to either sameness or difference between 2-item arrays. Their performance was high, and they clearly now discerned the relation between only two elements on the screen. Unlike the performance of baboons (Fagot et al., 2001), these rhesus monkeys were not constrained by entropy in their final performance in discrimination of sets of elements on the basis of the relation of those elements to each other. However, entropy may have facilitated learning the task rules.

Rather than concluding that the monkeys in our study show evidence of an abstract concept of relational sameness (or difference), we should consider another approach to solving the task. Thompson and Oden (2000) suggested that a monkey could solve this task purely by applying a single physical matching operation. Given that one cue is present, the correct response would be to choose the set in which one item physically matches the other (A is A). Likewise, in the presence of another cue, the correct response would be to choose the other set (implying no conceptual knowledge of difference). This type of strategy would allow monkeys to succeed on the task without knowledge of conceptual relations between stimuli. Thompson and Oden (2000) suggested that an organism that understands conceptual relations must also be able to abstractly recode those relations so that they can be applied in different experimental paradigms. For example, if the monkeys in the present study understand sameness and difference, they

should also be able to examine a single pair of stimuli, encode the relation between those stimuli, and label that relation in some way. Given that we had integrated discriminative cues into the paradigm, we believed that those cues might come to operate as the necessary labels that would allow the monkeys to report the relation between pairs of stimuli. If those color cues did come to operate at some level as indicators of the abstract concepts of sameness and difference, then perhaps the cues could operate in a bi-directional manner akin to that reported for chimpanzees in symbol acquisition projects (e.g., Savage-Rumbaugh, 1986). This bi-directionality might approach the level of symbolic representation argued to be so important in providing animals with a concrete icon for encoding a propositional representation that is otherwise abstract (Gillan et al., 1981). In Experiment 2, we assessed whether these color cues would operate in a bi-directional manner as labels for relation concepts.

Experiment 2

The aim of Experiment 2 was to investigate further the nature of the discriminative cues assigned to the concepts of *same* and *different*. Given that the colors served as discriminative cues to choose either the pair exemplifying the concept of same or the concept of different for the monkeys, we asked whether the monkeys would choose the correct color in the presence of either a relation of sameness or difference. If they would, this would indicate that the cues operated as labels or perhaps at a level similar to that of the symbols and tokens that have been learned by chimpanzees (e.g. Gillian et al., 1981; Savage-Rumbaugh, 1986).

Method

Participants and Apparatus. The same five monkeys participated, using the same computerized apparatus.

Design and Procedure. In this variation of the task, two clipart stimuli were presented at the top of the screen. They were either identical or non-identical, and this relation was randomly determined on each trial. The monkeys first had to contact that pair of stimuli with the cursor. Next, two colored squares appeared in the bottom corners of the monitor. One square was pink, and the other was black, and their positions (left or right) were randomly determined on each trial. If the stimuli at the top of the screen were identical, the correct response was the pink square. If the stimuli at the top of the screen were non-identical, the correct response was the black square (see Figure 2.3 for examples of each trial type). At a functional level, monkeys were presented with trials produced by the following if-then statements: “if same, then pink is correct” and “if different, then black is correct.”

As in previous experiments, moving the cursor into contact with the correct colored square corresponding to the sample relation resulted in the automatic delivery of a 94-mg banana-flavored pellet, an increasing-crescendo sound, and a 2 s ITI. Choosing the incorrect color block, however, resulted in no pellet reward, a low buzzing sound, and a 7 s penalty ITI.

Results

In the first block of 100 trials, two monkeys (Murph and Gale) were 81% and 78% correct ($z = 6.2, z = 5.6, ps < .01$). The remaining three monkeys (Lou, Willie, and Hank) performed at chance (50%) levels for over 1,000 trials ($z = 1.65, p = .10; z = 1.20, p = .23; z = -.25, p = .80$, respectively). Although more than 1,000 trials might have led to the monkeys learning the association, this would not be indicative that the cues functioned as symbols but that they were relearned as part of the procedural rules of the present task, so the task was discontinued.

To discount the possibility of item-specific associative learning, transfer tests of Experiment 2 were carried out with novel stimuli. Like the replications for Experiment 1, we used a set of 1000 completely novel clipart images that were discarded after use in one stimulus display. On the first 100 trials (completed directly following the transfer tests conducted a year after Experiment 1) the two monkeys tested performed at levels significantly above the 50% expected by chance. Murph completed 94% ($z = 8.80$, $p < .01$) of the first 100 trials correctly; Gale completed 89% ($z = 7.80$, $p < .01$) of the first 100 trials correctly. See Figure 2.4.

Discussion

Two monkeys matched the color cues to abstract relations between stimuli, in essence labeling those relations. One could argue that the color cues may also function as symbols, at least in a limited sense. Not only did monkeys correctly choose the relational pair in the presence of the color, but they also correctly chose the color itself in the presence of the relational pair.

Symmetrical treatment of a relational pair and a discriminative cue would indicate that an individual has recoded the relational properties of the stimuli (Thompson & Oden, 2000). Successive presentations of the abstract relations should then evoke representations of these symbols. These evoked representations, then, should permit an individual to explicitly judge what would otherwise be only perceptually implicit (Thompson et al., 1997). That is, recoded relational knowledge should allow an individual to complete a relational matching task. To see whether this might now be true in this group of animals, we returned the animals to the RMTS task.

Experiment 3

Although Experiments 1 and 2 demonstrated various aspects of same/different knowledge in rhesus monkeys, we had not shown that they passed the “relations-between-relations”

paradigm set forth in the relational matching-to-sample (RMTS) task. We speculated that after having the opportunity to learn the concepts of *same* and *different* through the use of entropy and acquiring a symbol-like system for the concepts themselves, monkeys now may be successful on such a task. Given that monkeys clearly judged *sameness* and *difference* in a way congruous to humans with pairs of items (Experiment 1), relational matching with pairs of objects should be within the realm of possibility for these animals.

Method

Participants and Apparatus. The same five monkeys participated, using the same computerized apparatus.

Design and Procedure. In this task, the monkeys moved the cursor into contact with the sample in the top center of the screen. This sample consisted of either two identical clipart stimuli or two different clipart stimuli, AA or CD. When the sample was contacted, two additional pairs of choice stimuli appeared on the left and right sides of the monitor. One pair contained two identical stimuli and the other contained two different stimuli, EE or FG (both comparison stimulus pairs contained stimuli different from those in the sample pair). The two pairs were randomly assigned to the left and right positions on each trial. Selection of the choice pair matching the relation of the sample (*same* or *different*) led to food reward whereas selection of the choice pair that did not match the sample led to no food and a timeout period as in the previous experiments.

Results and Discussion

None of the five monkeys (Murph, Lou, Willie, Gale, and Hank) completed the task at levels significantly better than chance (50%) after more than 10,000 trials. In addition, no changes in performance over time were observed. The accuracy scores for the final 1,000 trials

did not differ significantly from the value predicted by chance ($z = 1.39, p = .16$; $z = .44, p = .65$; $z = -.14, p = .16$; $z = -1.34, p = .14$; $z = .70, p = .49$, respectively).

General Discussion

After several demonstrations of conceptual knowledge, monkeys still seem to lack the analogical reasoning skills necessary to complete the RMTS task successfully. Monkeys are able to perceive the relational concepts of same and different within pairs of items. Furthermore, 2 monkeys successfully labeled the identically- or nonidentically-related pairs, suggesting that they mentally represented the concepts symbolically. With the ability to recode the concepts, we might expect the animals to pass the relation-between-relations paradigm (Thompson & Oden, 2000). They did not, however, leaving us with the same disconnect between the analogical reasoning skills of chimpanzees (Premack, 1983; Thompson et al., 1997) and the apparent lack of such skills in monkeys when such reasoning is applied in judgments of pairs of stimuli.

This disconnect is not unique to nonhuman animals. Gentner (2003) presented an explicit analogical reasoning task to 3- and 5-year-old children. Three-year-olds, thought to lack the capacity to referentially label real world objects, failed the reasoning task. Five-year-olds, who demonstrated understanding and use of labels, completed the task with no difficulty. However, when aided by the presence of labels, 3-year-olds successfully completed the analogical reasoning task. Immediately, their performance increased to a level comparable to that of the 5-year-olds, suggesting that labels play a critical role in relational matching. This pattern is similar to that observed in symbolically and non-symbolically trained chimpanzees (Thompson et al., 1997) as well as in other developmental studies with children (e.g., Ratterman & Gentner, 1998).

The RMTS task presented to our rhesus monkeys has a number of methodological components that may cause failure. The first of these is a constantly changing rule from one trial

to the next. In the RMTS paradigm, relational knowledge must be gleaned at the onset of every trial and applied only to the immediately presented trial. In essence, the rule may change on every trial unlike a standard matching-to-sample paradigm where the rule remains constant across all trials within a testing session even as the stimuli change. Macaques may be more procedurally rule-bound than chimpanzees (Thompson & Oden, 2000), making the task more difficult when rules change so frequently. In our study, keeping the rule constant led to improved (although still restricted) conceptual responding during the early experiments, and yet the monkeys were successful with discriminative cues and pairs of stimuli when the rule changed on a trial-by-trial basis.

Because the monkeys initially demonstrated a difficulty in extracting relational knowledge from a pair of same or differently related clipart images, we presented the monkeys with larger arrays to include an entropy component that may play a role in the discrimination of same from different (e.g., Wasserman et al., 2001). Relations became instantly perceptible with the introduction of 8-object arrays. Initially, these results led us to believe that rhesus monkeys, much like baboons or pigeons, relied heavily on the amount of variety within a display in order to determine *same* from *different*. However, our monkeys showed perseverative errors even with this entropy component, suggesting that more information was needed beyond just greater variability in the arrays. In Experiment 1, with the advent of a discriminative cue presented to facilitate rule-switching, monkeys began to respond to the relations between arrays even with trial-by-trial shifts in the rewarded relation and a decrease in the number of elements back down to the critical 2-element pairs. Unlike with baboons and pigeons, decreasing the number of icons in the displays did not affect rhesus monkeys' ability to judge same from different. We believe that, rather than relying on the variety of a display as a means on which to base same/different

judgments, rhesus monkeys need only to use entropy in order to initially perceive same and different. Perhaps monkeys extract no relational information from pairs until being prompted by entropy-infused displays, at which time, the discrimination rule becomes generalizable to displays of any size. Given that success in Experiment 1 was dependent upon first experiencing the task with 8-item arrays, conceptual knowledge may better be described as a “uniformity versus chaos” distinction which quickly generalizes to a “same versus different” distinction in the way that we more broadly conceive it, although other researchers have found conceptual same/different distinctions with pigeons and great apes beginning with pairs of items, while skipping the entropy-infused phases (Blaisdell & Cook, 2005; Edwards et al., 1974, Katz & Wright, 2006; Vonk, 2003).

Experiment 1 also indicated the facilitative role of discriminative cues. As in Burdyn and Thomas’ (1984) study, monkeys in our study utilized such cues to control responding on the basis of the relation between stimuli. Further, in Experiment 2, we observed the bi-directional nature of this cue in two of five monkeys by requiring the monkeys to label presented relations with stimuli that shared perceptual features with the discriminative cues. Those two monkeys immediately used the colored squares in an appropriate, and symbol-like, manner. With this symmetrical-like function, the cues now may operate similarly to the tokens used by some chimpanzees. Supporting this contention that these stimuli can act as symbols, two monkeys performed at high levels right from the outset of the transfer tests, despite the delay of almost a year during which time they were not exposed to the tasks. And, the monkeys performed well both in using those colored stimuli as cues to the rewarded relation as well as labels for presented relations. This suggests a symbolic aspect emerged from the integration of these cues into the series of tasks, with the symbols operating as representations of the concepts same and different.

If those stimuli do function as symbols, one should expect them to provide the necessary mental representations that manifest in successful judgments of relations between relations in chimpanzees (Premack & Premack, 2003; Thompson & Oden, 2000), yet clearly those judgments do not occur. Therefore, although bidirectionality was present in these two monkeys, elevating these cues to the level of symbols may be premature.

A distinction in the conceptual abilities of chimpanzees and monkeys has been imposed on the basis of their ability to label relations (Thompson & Oden, 2000). Previously, little evidence supported labeling by monkeys. Our monkeys could label abstract relations of sameness and difference, but they still failed to match those relations. If success on the RMTS task is not contingent on labeling related pairs of stimuli with symbols or tokens (Thompson & Oden, 2000), what is it contingent upon? Likely, success on the RMTS task is not solely contingent upon being able to label related pairs of stimuli with symbols or tokens.

Some capuchin monkeys have been shown to succeed on a spatial RMTS task (Spinozzi, et al., 2004). In spatial RMTS, capuchins matched the relations *above* and *below*. Importantly, these relations were not contingent upon the *physical* identity/nonidentity concept, but rather the spatial organization of one item in relation to another. Moreover, stimuli components were physically the same in samples and both matches (e.g. if a star appeared above a horizontal line in the sample, choice relations consisted of differently positioned stars above and below horizontal lines).

The sample in the RMTS task consists of two elements that *could* be recoded on the basis of their relation to each other. However, something prevents monkeys from recoding these elements in such a way that the representation is useful when having to find a pair of visually different but relationally identical elements. Perhaps there exists a qualitatively larger difference

between perceptual and conceptual strategies for rhesus monkeys than for humans and perhaps chimpanzees. That is, in a matching-to-sample format, perceptual processes may dominate conceptual judgments, preventing monkeys from using the relevant information in a stimulus pair. As we observed in the pilot studies and in Experiment 1, conceptual strategies can emerge through the use of discriminative cues and entropy-infused displays that overcome the dominance of perceptual based responding. In a matching-to-sample format, however, attending to configural patterns and physical elements may be dominant to use of concepts for rhesus monkeys as is observed in pigeons (Wright, 1997).

In sum, the present study provides evidence that monkeys do possess conceptual knowledge of the identity/nonidentity relations that is not entirely dependent on entropy-infused displays and that these relations can be symbolically recoded. However, even with this experience, monkeys still failed the RMTS task, lending support to the hypothesis that monkeys are not conceptually driven to the same extent as humans and chimpanzees. Data have yet to reveal why it is that such relational matching fails to emerge for monkeys as it evidently does for other species. We expect that continued methodological variations and differential experiences with concept formation tasks will shed some light on this disconnect, perhaps toward the end of finally demonstrating relational matching by monkeys.

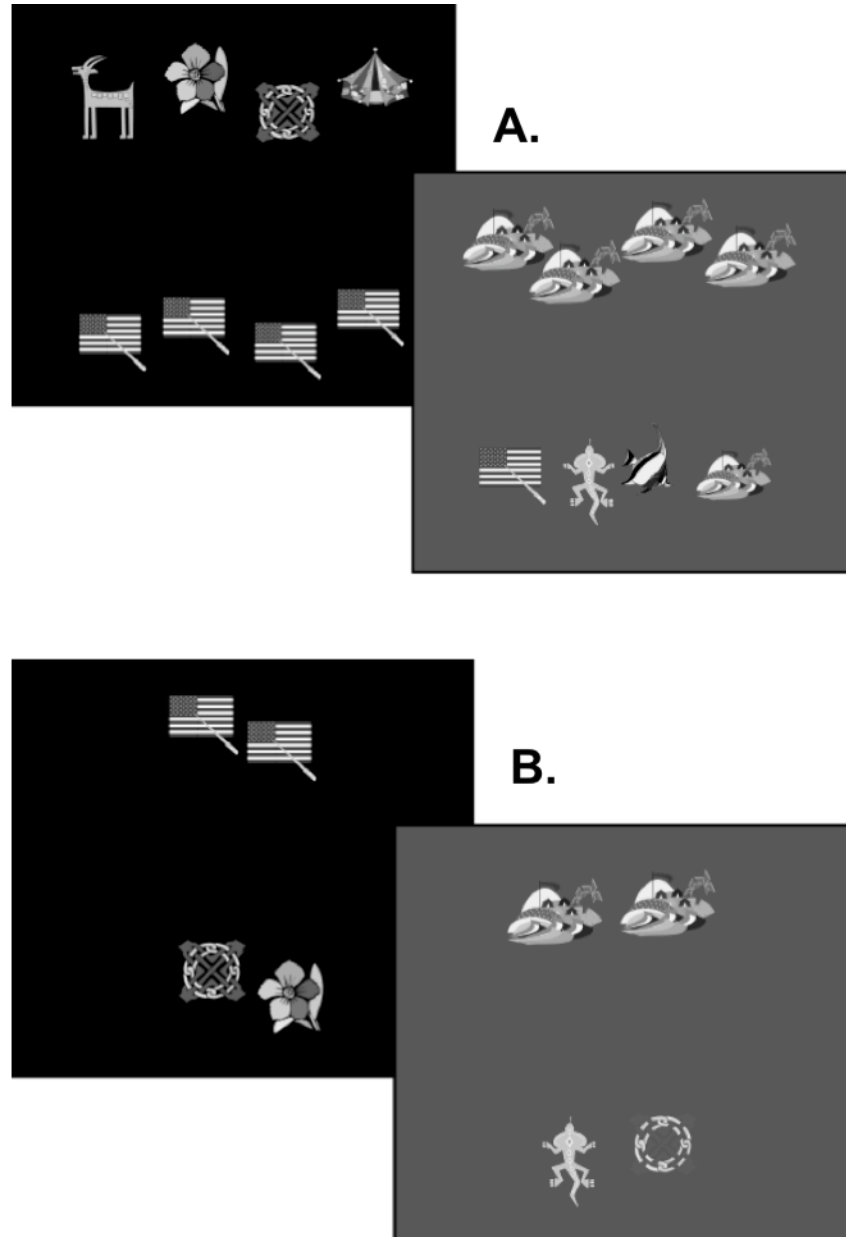


Figure 2.1. Trials from the two-choice paradigm completed by monkeys in Experiment 1. Trials exemplified are those in which monkeys discriminated between rows of four or two clipart images. Background colors served as discriminative cues (i.e. black background = *different* S+; pink (lighter grey in this reproduction) = *same* S+).

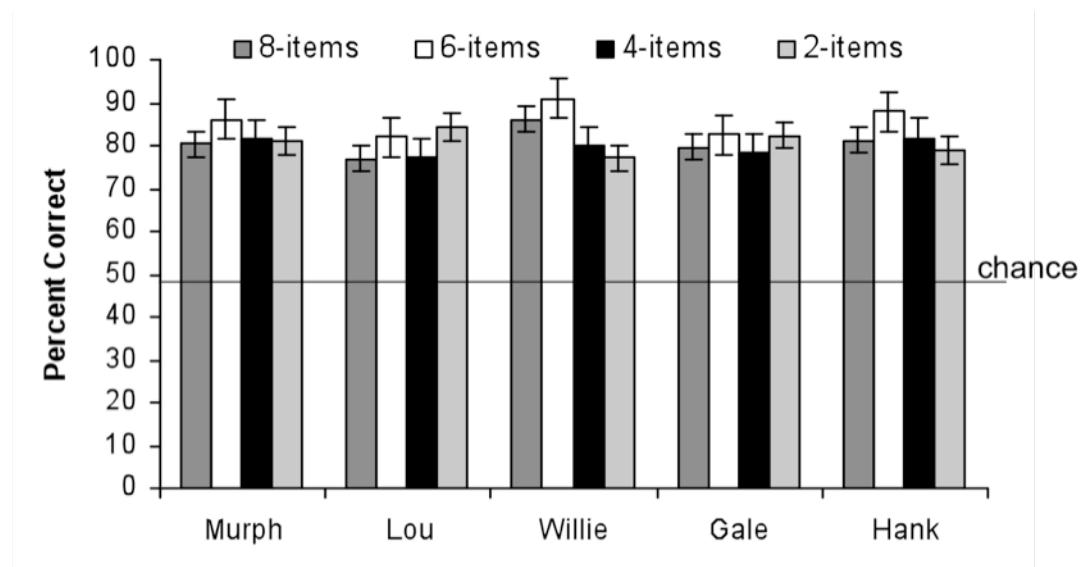


Figure 2.2. Percentage of trials correct for all trial types (arrays composed of 8, 6, 4, and 2 images) presented in Phases 2 and 3 of Experiment 1. Horizontal line represents chance performance.

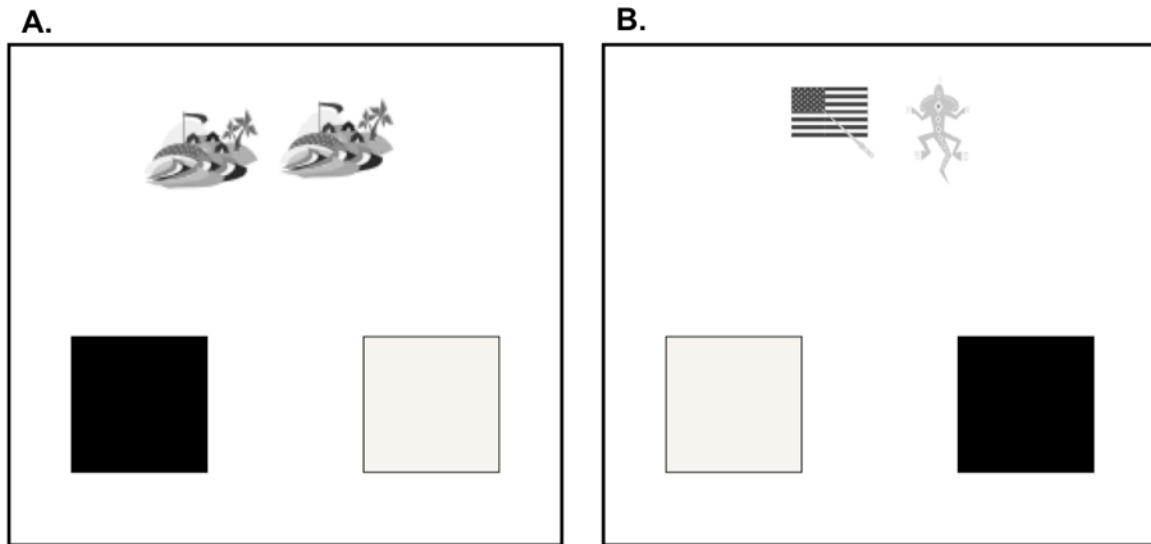


Figure 2.3. Exemplary trials from Experiment 2. In this matching-to-sample (MTS) paradigm, choices consisted of color blocks used as discriminative cues in Experiment 1. In the presence of the *same* sample pair (A), correct response = pink (lighter grey in this reproduction). In the presence of a *different* sample pair (B), correct response = black.

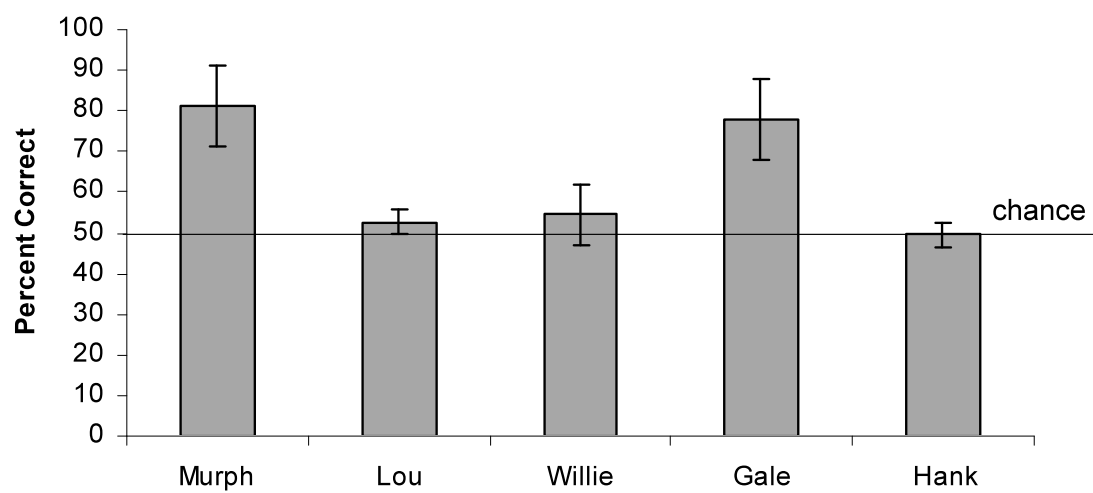


Figure 2.4. Percentage of trials correct on discriminative cue transfer testing presented in Experiment 2. Horizontal line represents chance performance.

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Chapter 3: Conceptual thresholds for *same* and *different* in old-(*Macaca mulatta*) and new-world (*Cebus apella*) monkeys³

Abstract

Learning of the relational same/different (S/D) concept has been demonstrated to be largely dependent upon stimulus sets containing more than two items for pigeons and old-world monkeys. In the present study, we investigate the threshold at which a new world primate, the capuchin (*Cebus apella*) may be able to make such a discrimination. Utilizing a method of *increasing* entropy, rather than conventional procedures of decreasing entropy, we demonstrate unique evidence that capuchin monkeys are capable of making 2-item relational S/D conditional discriminations. In another experiment, we examine the supposed level of difficulty in making S/D discriminations by rhesus monkeys (*Macaca mulatta*). Whereas pigeons and baboons have shown marked difficulty discriminating same from different arrays at all when composed of less than 8 items each, rhesus monkeys seem to understand that pairs of stimuli connote sameness and difference just the same (Flemming et al., 2007). With sustained accurate performance of 2-item S/D discriminations, both experienced and task-naïve rhesus monkeys appear quite ‘comfortable’ in their conceptual knowledge of *same* and *different*. We conclude that learning of the same/different relational concept may be less “entropy-important” than originally hypothesized for nonhuman primates.

Keywords: abstract concept; *Cebus apella*; concept learning; *Macaca mulatta*; monkey; same/different

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The judgment of relational concepts of identity and nonidentity (*same* vs. *different*) has proven difficult for several nonhuman animal species from pigeons to chimpanzees (e.g., Fagot, Wasserman & Young, 2001; Flemming, Beran & Washburn, 2007; Thompson & Oden, 1996; Vonk, 2003; Wasserman, Frank & Young, 2002; Wright & Katz, 2006; Young & Wasserman, 1997). Classification of items as the same or different from one another requires a level of abstraction (and perhaps abstract representation) beyond that which one might need for other types of concept formation.

Relational concepts, such as *same/different* and *above/below* involve a comparison of the relationship between (or among) two or more objects. These concepts thus do not depend on any absolute perceptual properties of stimuli (Zentall, Wasserman, Lazareva, Thompson & Rattermann, 2008), but rather are entirely based on the instantiation of the relation between or amongst them. Unlike most natural concepts, relational concepts are abstract in that classification based upon shared physical features of stimuli is impossible (Katz & Wright, 2006).

Judgments of identity and nonidentity are not entirely disparate from matching or non-matching to sample paradigm, but involve an additional level of assessment and computation. In a matching-to-sample (MTS) paradigm, subjects make one such equivalence computation (Thompson & Oden, 1996). In a same/different (S/D) discrimination task (make responses to identity but not nonidentity), one can use a similar singular equivalence computation. Finally, in a conditional S/D discrimination task wherein the subject makes responses to both identity and nonidentity based on specific discriminative cues present, two separate cognitive computations (one for identity and one for nonidentity) are required (Burdyn & Thomas, 1984). These computations, however, are no more complex individually as those utilized for matching to sample.

While the matching of specific stimulus features in common is not a viable strategy in abstract concept learning, perception has been shown to play an integral role. In one of the first demonstrations of the necessity of multiple icon arrays for the learning of the S/D concept, (and subsequent transfer to novel stimulus sets) Wasserman, Hugart and Kirkpatrick-Steger (1995) presented 16-icons arrays (*same* = 16 identical images; *different* = 16 nonidentical images) to pigeons (*Columbus livius*). There was observed relatively more rapid acquisition and stronger transfer of the S/D concept with these larger displays. Young & Wasserman (1997) continued this investigation by decreasing the number of items in each stimulus array to discover incremental depreciating effects on the pigeons' performance. In addition, pigeons demonstrated marked difficulty in discriminating at all displays of less than 8 icons each. *Entropy*, they report, accounted for this variation in performance at each successively lower level.

While humans (Young & Wasserman, 2001) and great apes (Vonk, 2003) appear less sensitive to and certainly not dependent upon entropy of stimulus displays for the extraction of conceptual information for identity and oddity, pigeons, baboons and rhesus monkeys are all species for which entropy plays a role. Entropy, the amount of variation within a display, is a measure of diversity in these relational concepts. For stimulus-stimulus comparison purposes, it is calculated by the number of pieces of information necessary to predict the categorical nature of that relational concept (Young & Wasserman, 1997). Thus, all displays of identical images, no matter the number have entropy equal to zero. Displays of all nonidentical images have entropy that increases on a logarithmic scale as the number of items contained within them increases (i.e. 2 nonidentical, entropy = 1.0; 4 nonidentical, entropy = 2.0; 6 nonidentical, entropy = 2.5). Discrimination tasks involving comparisons of entropy-infused S/D displays often receive criticism as subjects may well perceptually detect general orderliness or disorderliness of the

display rather than extracting relational-conceptual information, making a two-item S/D discrimination (entropy = 0, same vs. entropy = 1, different) the most plausible truly “conceptual” strategy.

Investigations of the role of entropy in nonhuman animal relational S/D concept acquisition traditionally involve methods of reduction in the number of stimulus array items to discern the point of entropy at which subjects can no longer successfully extract relational information. Pigeons appear to be especially sensitive to changes in entropy in the acquisition of the S/D concept (e.g. Wasserman & Young, 1997). That pigeons have marked difficulty discriminating same from different with low levels of entropy contrast suggests a predisposition to attend to perceptual stimulus features over the conceptual. Rather than discriminating displays on the basis of their relational identity/nonidentity, pigeons default to a more item-specific strategy attending to (and perhaps memorizing large sets of) individual stimulus features (Wasserman, Frank & Young, 2002). In addition, pigeons show strong asymmetric preferences for learning *same* displays over *different* displays (Young & Wasserman, 2002) suggesting only partial learning of these concepts. Can it be said that one truly knows *same* from *different* if one only understands the concept of identity, but not nonidentity?

Baboons (*Papio papio*) have also been shown to exhibit sensitivity to entropy in the discrimination of *same* from *different* visual displays (Wasserman, Young & Fagot, 2001). In a pattern much like pigeons, baboons are detrimentally impacted by a reduction in the number of icons from 16 in S/D stimulus arrays. One considerable difference in the behavior of baboons was that they did not exhibit asymmetric discriminative abilities. Baboons were equally as accurate on both *same* and *different* trials, indicating that their knowledge of the S/D concept was complete, albeit its strong perceptual dependency.

Capable of completing 2-item simultaneously presented S/D discriminations, rhesus monkeys (*Macaca mulatta*) utilize entropy quite differently (Flemming et al., 2007). Monkeys originally failed a 2-item (paired) S/D discrimination task for more than 10,000 trials. Within the first 500 trials of an 8-item S/D discrimination (entropy = 0, same; entropy = 3.0, different), rhesus monkeys completed the task successfully, achieving (sometimes greater than) 85% accuracy. Fleming et al. (2007) observed no decrement in performance of the rhesus monkeys with a reduction in the number of icons from 8 to 2 in the stimulus arrays; that is, immediate, spontaneous transfer was observed. In addition, like baboons, rhesus monkeys did not exhibit any propensity toward uniformity; their treatment of *same* and *different* was symmetric. Although monkeys were not initially able to extract conceptual-relational information from identical/nonidentical pairs, entropy would seem responsible for their ultimate ability to do so. Fleming et al. (2007) concluded that while entropy was certainly vital for early relational S/D concept learning, rhesus monkeys unlike both pigeons and baboons were not dependent upon entropy in the further employment of the relational rule.

Recent evidence examining relational concept acquisition in new-world primate species provides support for knowledge of *same* and *different* on par with old-world species (e.g. Spinozzi, Lubrano & Truppa, 2004; Wright & Katz, 2006; Wright, Rivera, Katz & Bachevalier, 2003). In an attempt to further investigate the conceptual boundaries of their relational concept knowledge as well as the nature of entropy in *same* and *different* for capuchin monkeys (*Cebus apella*), the present study utilizes a new methodology of increasing entropy whereby the minimum entropy necessary for S/D discriminations can be evaluated. In addition, conceptual thresholds, levels of difficulty with which subjects experience discriminations at successively

lower levels of entropy, are investigated in the rhesus monkey using a fluid method of entropy titration across trials for simultaneous S/D discriminations.

1.0 Experiment 1

The aim of Experiment 1 was to further address the role of entropy for capuchins (*Cebus apella*) in which knowledge of same and different are concurrently necessary in a conditional discrimination task that flexibly requires comparison of *same* vs. *different* relational information on a per-trial basis. A two-choice cued discrimination paradigm similar to the methodology of Flemming et al. (2007) previously presented to rhesus monkeys was utilized. One important difference here was that all capuchins were given the opportunity to complete a two-item (pair) discrimination before presenting displays of increased entropy. This experiment is unique in its design to *increase* entropy, rather than in a fashion of *decreasing* entropy.

1.1 Method

1.1.1 Subjects and Apparatus

Six socially-housed brown tufted capuchin monkeys (*Cebus apella*) age 2 to 18 (3 female) housed at Georgia State University's Language Research Center in Atlanta, GA, served as subjects in Experiment 1. For isolated testing, each monkey entered a small box through a door attached to the enclosure with access to a vertically-mounted joystick and visual access to a computer monitor. All monkeys had very recently completed computer joystick training (Evans, Beran, Chan, Klein & Menzel, 2008). The only training experience that monkeys completed relevant to the present task was a standard 1 to 1 item physical matching-to-sample task.

The monkeys were not food or water deprived during the course of the study, and they had continuous access to the computerized programs for blocks of time ranging from 2 to 4 hours. Therefore, they produced varying numbers of trials (averaging 200) across sessions

dependent on how long they were presented with the task. During this time, the computer program controlled reward (45-mg banana-flavored pellet) delivery and trial presentation. Speakers provided auditory feedback for all tasks, including a low buzzing sound for incorrect responses and an increasing crescendo sound for correct responses. These sounds had been paired with these contingencies on several previous tasks.

1.1.2 Design and Procedure

Capuchin monkeys completed either one or both of two testing phases in this experiment, each including transfer tests, based on their success in the phase 1. Beginning with the smallest stimulus relation set (2-item), monkeys completed a second phase beginning with a larger, entropy-infused stimulus array (4-item) if failure to achieve criterion in phase 1 was observed.

On each trial, two sets of clipart images (3 cm x 3 cm) were displayed: one set of physically identical objects and one pair in which each object was physically distinct. These images were commercially available clipart images. All stimulus sets were composed of trial-unique clipart images; no image was ever duplicated throughout the entire duration of the experiment. Arrays were located along the top and bottom edges of the computer screen, with the location of *same* and *different* pairs being randomly determined on each trial.

Discriminative cues (background color) indicated to the monkeys which of the two relations (*same* or *different*) was the correct choice on a given trial allowing for random assignment of S+ on every trial. This meant that each trial offered a new cue as to the correct response, as well as trial-unique stimuli. This flexible employment of alternating S+ in addition to the comparison between same and different choices concurrently on every given trial is a unique methodological innovation for this paradigm adapted from Flemming et al. (2007).

In both phases, if the background was colored pink, the correct response was to select the set with all identical elements. Likewise, if the background was colored black, the correct response was to select the set with all nonidentical elements. Monkeys were required to move a cursor (via their joysticks) into contact with one of the arrays by touching any area in that section of the monitor (i.e., the top or the bottom). If the contacted array was correct (S+), a banana-flavored pellet was dispensed, followed by an increasing crescendo sound. If the contacted array was incorrect, no pellet was dispensed, and a low buzzing sound was played. Inter-trial intervals of 5 seconds (correct choices) and 15 seconds (incorrect choices) were imposed. This same reward/nonreward system remained consistent throughout all phases of this experiment.

1.1.3 Phase 1

Monkeys were first presented with the two-item (pairs of stimuli) two-choice (identical versus nonidentical) cued discrimination task. This phase was considered complete when an approximate 80% criterion was achieved within a testing session (200 trials). Monkeys then completed a transfer test session of 100 trials, again with trial-unique stimuli, to verify accuracy in performance. If subjects did not achieve 80% accuracy after 1000 trials in Phase 1, testing ended and Phase 2 began.

1.1.4 Phase 2

If failure to discriminate *same* from *different* 2-item displays occurred in Phase 1, monkeys were presented with 4-item [higher entropy, *different*] displays. All procedures of this phase were the same as Phase 1, only the composition of stimulus arrays differed. Monkeys began this phase with 4-item stimulus arrays. The training portion of this phase was considered complete if an 80% criterion was achieved within a testing session (approximately 200 trials). Once criterion was achieved, subjects completed two subsequent transfer tests. The first transfer

test was a 100-trial redundant 4-item array discrimination, again with trial-unique stimuli. A final 100-trial 2-item transfer test identical to Phase 1 was completed on the next testing day.

1.2 Results and Discussion

Two capuchins spontaneously (within 200 trials) made judgments of *same* and *different* in the two-item (pair) phase of the task (entropy 0 [*same*] vs. entropy 1 [*different*]). See Figure 3.1.

All four remaining capuchins failed to make successful discriminative judgments with pairs of items, but succeeded in the 4-item phase within 200 trials. After successful completion and transfer to the 2-item phase, all four capuchins met an approximate 80% criterion within the first 100-trial block. See Table 3.1 for accuracy levels for each animal.

That 2 capuchins succeeded in making 2-item conceptual-relational discriminations of same and different spontaneously (without entropy-infused training as in Flemming et al. (2007) with macaques) suggests a less integral dependence on perceptual driving mechanisms in concept learning for these capuchins. Although we cannot conclude that entropy plays no role for these new world monkeys, 4 additional monkeys required only a maximum of 4-item displays, compared to 8-12 items for old-world monkeys (rhesus - Flemming et al., 2007; olive baboons - Fagot et al., 2001). While it was previously concluded that relational-conceptual knowledge of *same* and *different* was largely entropy-important, but not entropy-dependent, we find that this may be true to an even lesser extent for some new world monkeys.

2.0 Experiment 2

It is typically assumed that judgments of *same* and *different* are more difficult the fewer items a relational array contains. The aim of Experiment 2 was to determine the level of difficulty associated with varying levels of entropy for rhesus macaques in a conceptual-

relational two-choice discrimination task. Magnitude of reward decreased for each successive level of increasing entropy (larger displays) and allowed movement freely across entropy-level boundaries based on success in meeting or failure to meet criterion.

2.1 Method

2.1.1 Subjects and Apparatus

Six male rhesus macaques (*Macaca mulatta*) housed at Georgia State University's Language Research Center, age 5 to 26 completed Experiment 2. Two macaques (Hank and Gale, both age 26) had prior experience on a very similar battery of S/D tasks from Flemming et al., 2007. In these assessments, Hank and Gale successfully learned the 2-item S/D discrimination task in a paradigm of decreasing entropy beginning with 8-item sets. Although the tests were completed 4 years before the current experiment, it is worthy of mention with the current comparison to other macaques completely naïve to S/D procedures also included in the present experiment. Four macaques (Obi, age 5; Han, age 6; Luke, age 11; Chewie, age 11) naïve to S/D testing completed the same procedures in this experiment. The only training experience that these naïve macaques completed relevant to the present task was a standard 1 to 1 item physical matching-to-sample task.

Subjects were not food or water deprived during the course of the study. All rhesus macaques had continuous access to the computerized programs for blocks of time ranging from 4 hours to 24 hours. During this time, the computer program controlled reward delivery (94-mg banana flavored pellet) and trial presentation. The Language Research Center's Computerized Test System (LRC-CTS) consists of an IBM-compatible desktop personal computer (Washburn, Rumbaugh & Richardson, 1992). Each animal had access to its own testing station. During tasks, macaques controlled a cursor on a 17-inch SVGA monitor via a vertically mounted

joystick. Speakers provided auditory feedback for all tasks, including a low buzzing sound for incorrect responses and an increasing crescendo sound for correct responses. These sounds have been paired with these outcomes on many previous tasks.

2.1.2 Design and Procedure

Testing sessions for all rhesus macaques began with cued 2-item S/D discriminations visually identical to presentation in Experiment 1 with capuchin monkeys. Macaques were able to move fluidly throughout the levels in 50 trial increments, moving up or down or remaining at the most difficult level based on their degree of success at the current level. Under the assumption that macaques prefer a higher reward, it was expected that they always maintain or move up to the most difficult (highest payoff) level if they are capable of doing so. See Figure 3.2 for a depiction of sample trial types.

For these 2-item (pairs) discriminations considered most difficult, rhesus macaques received 4 pellets as reward. Thus, the incentive to complete these trials was relatively (4:1) high. To remain at the current level, macaques had to meet a criterion of 40 out of the last 50 consecutive trials correct. If they performed at levels of chance (20 out of the last 50 consecutive trials incorrect) the computer would initiate a sequence of “easier” 4-item array discrimination trials. In this level of increased entropy, reward magnitude was decreased, such that reward contrast from the previous level was 2:1. If macaques met a criterion of 40 out of the last 50 consecutive trials correct (80%), the computer would immediately initiate a sequence of 2-item discrimination trials with a higher reward payoff. Alternatively, if the macaques again performed near levels of chance (20 out of the last 50 consecutive trials incorrect) the computer would initiate a sequence of the “easiest” 6-item array discrimination trials. In this level of increased entropy, reward magnitude was again decreased, such that reward contrast from the previous

level was 2:1 (1 vs. 2 pellets). The same contingencies for moving up a level (decreased entropy, higher pellet magnitude) remained in place.

All macaques completed one 500-trial block within which they moved back and forth throughout the varied entropy levels. Because this task is highly susceptible to learning and asymptotic leveling with prolonged training, the macaques' spontaneous performance was of primary interest. To assess possible sustained performance and verify accuracy of results, one 100-trial transfer test was completed 2-3 days after the initial 500-trial testing block.

2.2 Results and Discussion

All but one monkey (Luke –naïve) completed trials at the Level 3 (2-item) difficulty for more than half of the 500-trial session. All monkeys initially failed the two-item discrimination and dropped to the 4-item set, but only 2 monkeys (1 experienced, 1 naïve) failed the 4-item set trials to drop into the 6-item set discrimination. A main effect for entropy level (number of items) was observed using a one-way ANOVA $F(2,15) = 32.90, p < .01$ across all monkeys (both naïve and experienced). Tukey's post-hoc analyses revealed that while the number of trials completed in Level 3, 2-item and Level 2, 4-item were distributed more evenly ($p=.057$), a significantly greater proportion of trials in the 500-trial session were completed in Level 3, 2-item than Level 1, 6-item ($p=.002$) and in Level 2, 4-item than Level 1, 6-item ($p=.006$).

Most notably, no significant effect of experience was observed at any entropy level ($p = .737$; $p = .389$; $p = .759$, respectively). In addition, no position or relation biases (asymmetry) were observed. See Table 3.2 for a summary of level transitions, number of trials performed at each level and symmetric performance verifications. See Figure 3.3 for performance distribution.

In a subsequent 100-trial transfer session under the same methodological conditions, all monkeys remained at the most difficult level and never dropped into a level of higher entropy

distinction. Percent accuracies ranged from 75%-93%, all significantly above chance. Accuracies for each monkey are displayed in Table 3.2.

That macaques were able to retain successful performance for both 2- and 4-item S/D discriminations when given the option to perform perceptually easier trials suggests that nonhuman primates are less dependent on entropy than originally hypothesized (Flemming et al., 2007; Fagot et al., 2001). More importantly, 4 macaques naïve to any S/D task completed trials with levels of success equal to (or better than in some instances) macaques with prior experience on the task. Whereas macaques in our previous study (Flemming et al., 2007) completed the task beginning with sets of 8-items, monkeys here garnered success with very minimal exposure (150-250 trials) to displays containing as few as 4 items, rendering 6- and 8- item training redundant and unnecessary. Thus, rhesus macaques are capable of learning the relational-conceptual S/D discrimination task with entropy distinctions of only 2 (4-item *different*, entropy = 2; 4-item *same*, entropy = 0). Spending relatively fewer trials in contingencies of lower reinforcement and higher entropy (“easier”), these distinctions thus seem less “entropy important” than originally hypothesized. In addition, displays of lower entropy seem no more difficult for macaques to discriminate with success. Rather, the macaques appear quite comfortable in their knowledge of *same* and *different* without elevated levels of entropy.

3.0 General Discussion

Learning about *same* and *different* relational concepts may be less “entropy-important” than originally hypothesized. The general pattern of relational concept acquisition observed was, if not immediate for 2-item S/D discriminations, one of immediate transfer after performing trials correctly at a level of increased entropy distinction, even for animals completely naïve to S/D tasks. This study provides unique evidence that both rhesus and capuchin monkeys are capable

of making simultaneous same/different relational discriminations with arrays of as few as 2-4 items [entropy contrast of 0:1-2]. The novel technique of gradually increasing entropy contrast rather than decreasing stimulus array number introduced in this study perhaps more accurately estimates the threshold at which nonhuman primates are capable of extracting true conceptual information about the relations of *same* and *different*.

Because of findings in the pigeon (e.g. Young & Wasserman, 1997), baboon (Fagot et al., 2001) and rhesus monkey (e.g. Flemming et al., 2007) literatures, it is often assumed that discriminations of lower entropy distinction are more difficult for the animal. With an assumed predisposition to attend to physical properties of stimuli (Flemming, Thompson, Beran & Washburn, *in review*; Thompson & Oden, 2000), it would stand to reason that judgments of conceptual relatedness would fall under increased cognitive control for many nonhuman animals. Perhaps it is the case that gaining this level of cognitive control is not as difficult a task for the monkeys in the present study.

Wright and Katz (2006) also report an understanding of abstract sameness and difference for rhesus monkeys, capuchin monkeys, and pigeons without the use of entropy-infused stimulus arrays. Both primate and avian species used matching and nonmatching rules to judge relational sameness or difference and generalized these rules to novel stimulus sets with varying rates of acquisition, dependent on measures such as training set size, test stimuli and contingencies. While this study sheds light on the employment of abstract match/nonmatch rules independent of one another, the current study addresses conceptually relational knowledge of same versus different by requiring the *simultaneous* discrimination of identical *from* nonidentical pairs of stimuli within a trial.

Also in contrast to other S/D discrimination studies with pigeons (e.g. Wasserman et al., 2001), Blaisdell and Cook (2005) provide evidence for simultaneous 2-item S/D discrimination in pigeons. This recent discrepancy from aforementioned studies, but corroboration with present findings from capuchin and rhesus monkeys, might be attributed to the use of rather simple geometric stimuli that encouraged a focus on the relational information present, rather than a focus on specific stimulus features as might occur with more intricate clipart icons used in previous investigations. Blaisdell and Cook (2005) utilized only 6 different geometric shapes of 6 different highly-discriminable colors. By creating 12,960 unique dimensional displays, pigeons were never given the opportunity to memorize specific stimulus combinations. By simplifying the task and removing many perceptually-based discrimination strategies, it is perhaps the case that relational information was simply more salient and thus conceptual strategies begin to emerge. Like the utilization of trial-unique stimuli in the present study, methodology encouraging a shift in attention away from perceptual features of stimuli allows for the emergence of more conceptually-guided behavior.

Worthy of mention to future investigations of the application of these relations to analogical reasoning, that monkeys still are not successful on relational matching-to-sample paradigms suggests a qualitative difference in the types of cognitive computations necessary for the employment of relational concepts in analogy from the understanding of identity and nonidentity on a discriminative level. This further implicates a difference in kind for a mechanism for analogical reasoning (Thompson & Oden 1996). It should stand to reason that if monkeys are capable of making judgments of identity vs. nonidentity in paradigms such those in the present task, they could make those same evaluations between relations if they were qualitatively of the same type. Not only are animals making fewer cognitive computations of

identity and nonidentity in the present conditional discrimination tasks compared to tests of relational matching, but they also may not be employing the same mechanisms when computing relational identity/nonidentity between relations (as in RMTS). For instance, computing identity between two like images requires one type of evaluation. It may be the case that an identity evaluation between two pairs of similarly related images not only requires an additional evaluation, but one that is fundamentally different in mechanism. If these computations required the same type of underlying mechanism, we may expect those animals/species displaying a propensity for 2-item S/D discrimination to also match relations-between-relations, which is not the case.

Are 2-item S/D discriminations markedly more “difficult” for a nonhuman primate as previously implicated? Given the ability of *Macaca* to sustain completion of these trial types when motivated to do so with increased reward contingency, it would seem not. Taken together with the results of Flemming et al. (2007) wherein no decrement in performance was observed with decreases in entropy contrast for S/D discriminations, it is likely that rhesus monkeys are equally capable of extracting relational-conceptual information from a 2-item pair as they are from a larger stimulus array. This pattern of performance seems to support the case that the conceptual-perceptual “divide” is often misrepresented. Goldstone and Barsalou (1998) argue that many of the same underlying cognitive mechanisms may drive both perception and conception or in the very least work in parallel. The conceptual processes used by monkeys in the current study may be the emergent result of their perceptual processes simply becoming less bound to the perceptual features of the stimuli.

In conclusion, it is certainly the case that entropy plays a slight facilitatory role for some *Cebus* individuals and *Macaca* in the acquisition of the relational concepts of both *same* and

different. However, contrary to previous findings, both the amount of perceptual contrast and duration of training need not be as substantial as suggested for these and other nonhuman animal species. With some new-world individuals (*Cebus apella*) discriminating pairs of S/D stimuli relatively spontaneously, it is likely that the employment of relational-conceptual knowledge is at the forefront of their cognitive reasoning skills. Are new-world monkeys less perceptually-predisposed than previously hypothesized with old-world monkeys? If so, future studies with capuchin and other new-world primates may help to elucidate the supposed disconnect in perceptual-conceptual reasoning, even as it is applied in analogical reasoning.

Table 3.1

Performance summaries for *Cebus* on S/D relational discrimination task

<u>Phase 1</u> <u>2 items</u>	<u># Trials</u>	<u># correct (% acc)</u>		<u>Z</u>		
Logan	200	163	(81.5%)	8.84*		
Liam	200	155	(77.5%)	7.71*		
Nala	500	266	(53.2%)	1.39		
Wren	500	271	(54.2%)	1.83		
Lily	500	244	(48.8%)	-0.49		
Gabe	500	259	(51.8%)	0.76		
<u>Phase 2</u> <u>4 items</u>	<u># Trials</u>	<u># correct (% acc)</u>		<u>Z</u>		
Nala	200	166	(83.0%)	9.26*		
Wren	200	171	(85.5%)	9.97*		
Lily	200	160	(80.0%)	8.41*		
Gabe	200	157	(78.5%)	7.99*		
<u>Transfer</u> <u>100 trials</u>	<u>4 items</u> <u>(% acc)</u>	<u>Z</u>	<u>2 items</u> <u>(% acc)</u>	<u>Z</u>	<u>Top/Bottom</u> <u>Symmetry</u>	<u>S/D</u> <u>Symmetry</u>
Logan	-	-	85.0	6.9*	-1.5	1.3
Liam	-	-	81.0	6.1*	-0.9	-0.3
Nala	78.0	5.5*	86.0	7.1*	1.1	1.7
Wren	84.0	6.7*	78.0	5.5*	-1.3	1.5
Lily	84.0	6.7*	83.0	6.5*	1.3	-0.5
Gabe	81.0	6.1*	77.0	5.3*	-0.7	-0.1

*p<.01

Note: 4-item training sessions not completed for Logan and Liam due to success with 2-item training session. Only 200-trial training sessions and 100-trial transfer tests were completed by Logan and Liam.

Table 3.2.

Performance summaries for *Macaca* on titrating S/D relational discrimination task

<u>Phase 1</u> <u>500 trials</u>	<u>↑Entropy</u> <u>2 to 4</u>	<u>↓Entropy</u> <u>4 to 2</u>	<u>↑Entropy</u> <u>4 to 6</u>	<u>↓Entropy</u> <u>6 to 4</u>	<u>Remain</u> <u>in 2</u>	<u>Remain</u> <u>in 4</u>	<u>Remain</u> <u>in 6</u>
Han	2	2	0	0	260	240	0
Obi	3	4	0	0	316	184	0
Luke	4	3	1	1	138	270	92
Chewie	1	1	0	0	328	172	0
§ Hank	3	2	1	1	275	152	73
§ Gale	2	2	0	0	293	207	0

<u>Phase 2</u> <u>100-trial Transfer</u>	<u>Remain</u> <u>in 2</u>	<u>% Correct</u>	<u>Z</u>	<u>Top/Bottom</u> <u>Symmetry</u>	<u>S/D</u> <u>Symmetry</u>
Han	100	82.0	6.3*	0.7	1.3
Obi	100	78.0	5.5*	-0.3	-0.5
Luke	100	75.0	4.9*	1.1	0.5
Chewie	100	93.0	8.5*	0.9	0.1
§ Hank	100	79.0	5.7*	0.7	-1.1
§ Gale	100	86.0	7.1*	1.3	0.5

* $p < .05$; § indicates a monkey with substantial experience on S/D relational discrimination tasks (Flemming et al., 2007)

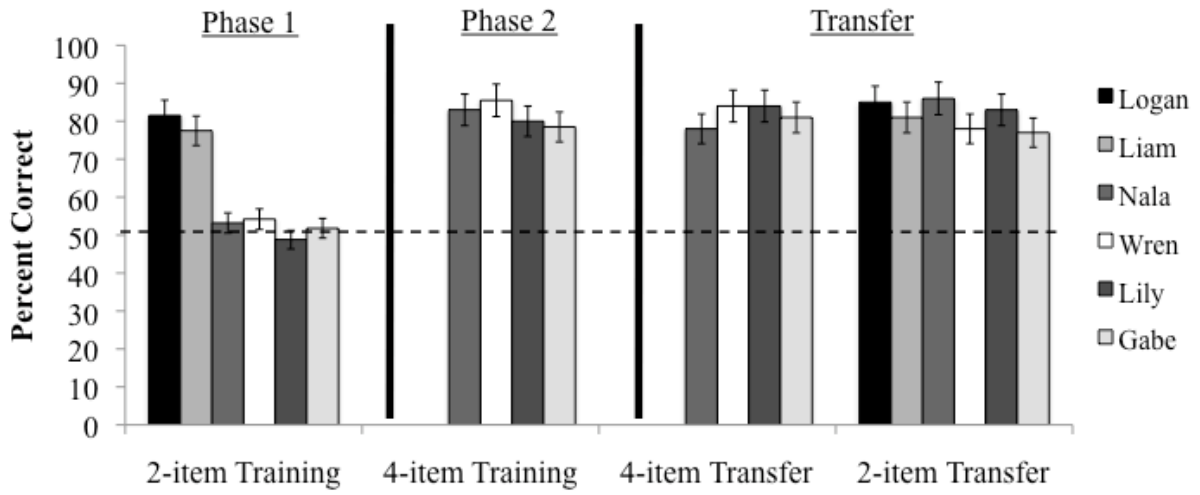


Figure 3.1. Performance summaries for *Cebus* across phases. Dashed line represents chance performance. If criterion (80%) was met in phase 1 (Logan and Liam) phase 2 was not completed, only 2-item transfer tests were presented subsequently.

* $p < .01$

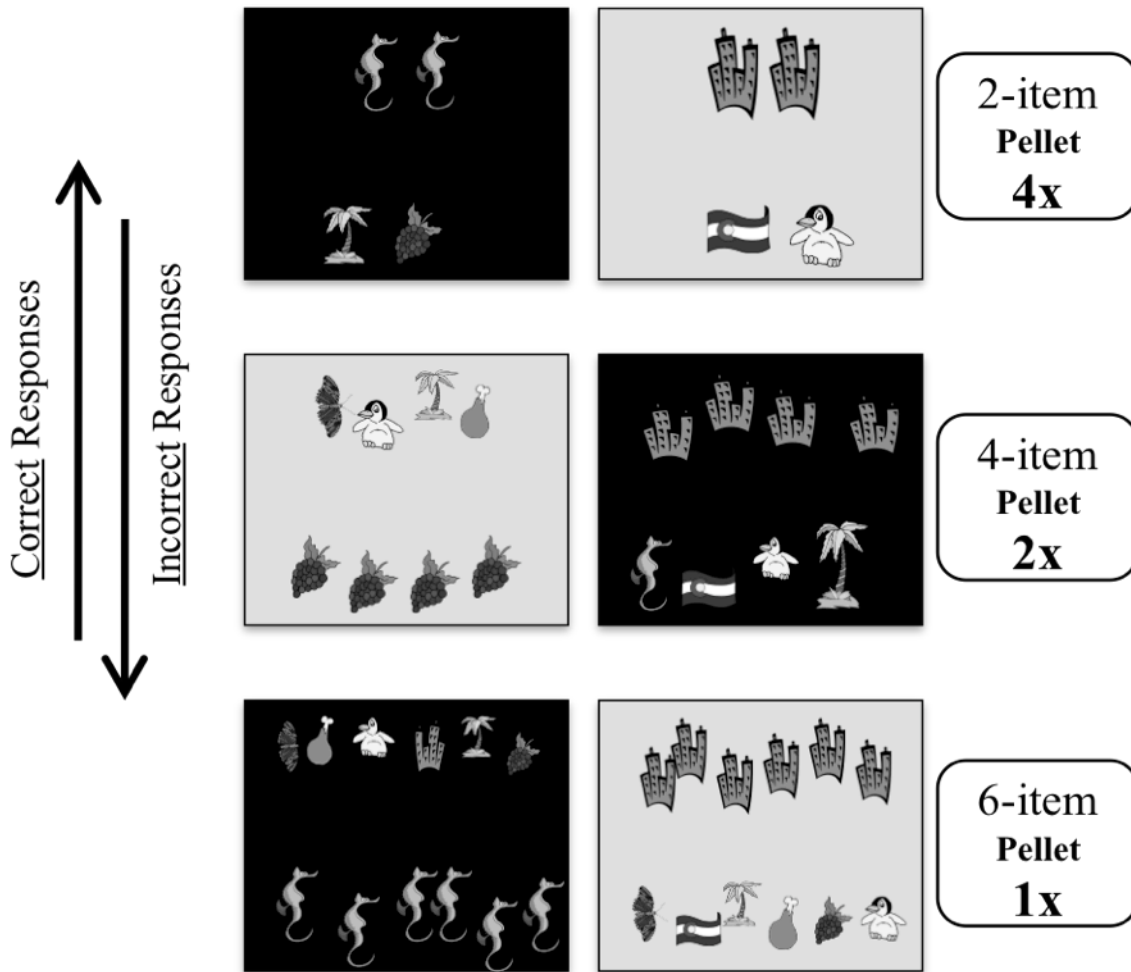


Figure 3.2. Depiction of titrating S/D discrimination task presented to *Macaca*. All macaques began the experiment with 2-item discrimination trials. Based on accuracy, trials from the next level of increased entropy were presented. Subjects could be moved to the next level of increased entropy for performance consistent with chance or back to a level of decreased entropy for performance significantly better than chance. Absolute reward magnitude (number of pellets) is presented with each corresponding level of entropy.

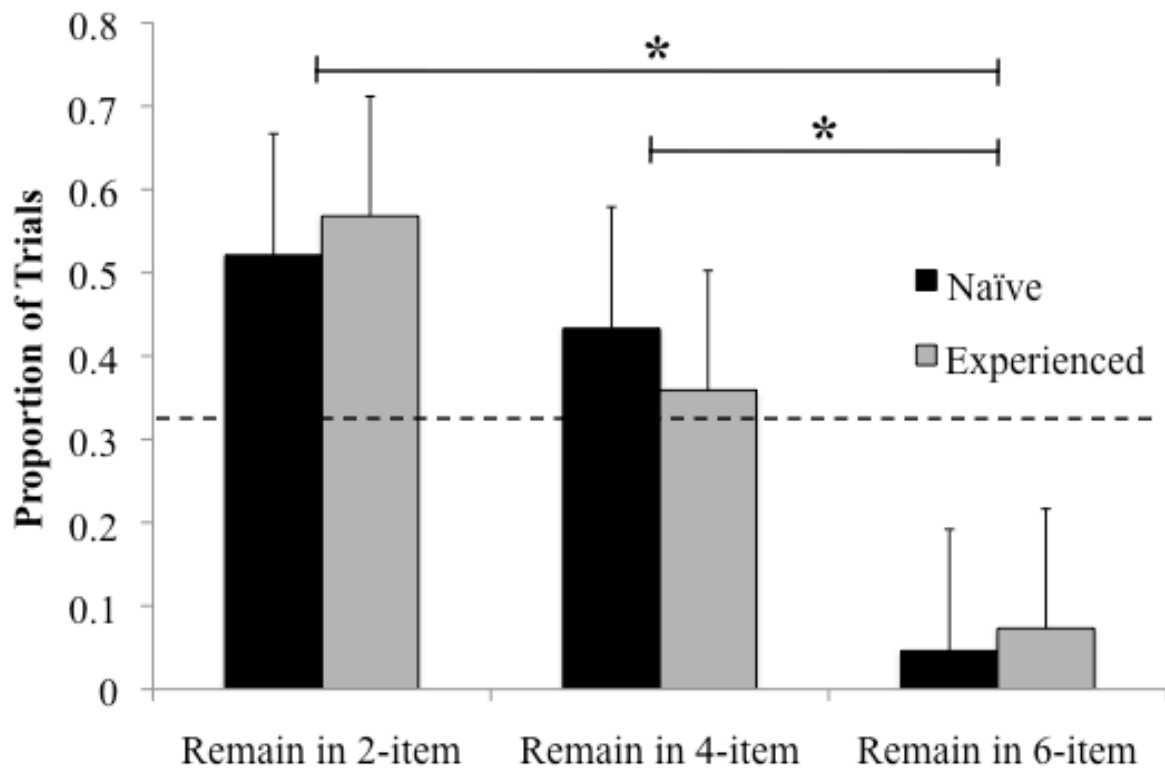


Figure 3.3. Proportion of 500-trial session performed in each entropy level by *Macaca* on a titrating S/D relational discrimination task. Dashed line represents chance distribution.

* $p < .01$

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Chapter 4: Analogical reasoning and the differential outcome effect: Transitory bridging of the conceptual gap for rhesus monkeys (*Macaca mulatta*)⁴

Abstract

Monkeys unlike chimpanzees and humans have a marked difficulty acquiring relational matching-to-sample (RMTS) tasks that likely reflect the cognitive foundation upon which analogical reasoning rests. In the present study, rhesus monkeys (*Macaca mulatta*) completed a categorical (identity & nonidentity) relational matching-to-sample (RMTS) task with differential reward (pellet ratio) and/or punishment (timeout ratio) outcomes for correct and incorrect choices. Monkeys in either differential reward-only or punishment-only conditions performed at chance levels. However, the RMTS performance of monkeys experiencing *both* differential reward and punishment conditions was significantly better than chance. Subsequently when all animals experienced nondifferential outcomes tests, their RMTS performance levels were uniformly at chance. These results indicate that combining differential reward and punishment contingencies provide an effective, albeit transitory, scaffolding for monkeys explicitly to judge analogical relations-between-relations.

Keywords: ANALOGICAL REASONING, DIFFERENTIAL OUTCOME EFFECT, RHESUS MONKEYS, RELATIONAL MATCHING, SAME/DIFFERENT, VISUAL PROCESSING OF CONCEPTS

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Thompson and Oden (1996, 2000) pace Premack, (1983) argued that there is a ‘profound disparity’ between chimpanzees (*Pan troglodytes*) and monkeys in their capacity for analogical reasoning which is often referred to as a hallmark of human reasoning (e.g., Gentner, 2003). Thompson & Oden (2000) based their strong conclusion on the respective success and failure of apes and monkeys in categorical relational matching-to-sample tasks (RMTS) that require animals to judge abstract relations (e.g., relational identity and nonidentity) in comparison stimulus pairs as being relationally the ‘same’ as or ‘different’ from that represented in the sample.

In a typical categorical RMTS task two items that are either identical (e.g., AA) or nonidentical (e.g., BC) are presented simultaneously as the relational sample against which another two pairs of relational stimuli (e.g., DD & EF) are to be compared. The animal is rewarded for choosing the comparison stimulus pair that is relationally identical to the sample. Hence, if the sample consists of an identical pair (AA) then the animal is rewarded for choosing the (DD) comparison stimulus pair that is relationally the same as the sample. Conversely, if the sample consists of a nonidentical pair (BC) then it is rewarded for choosing the (EF) pair which instantiates the same relation as the sample.

Importantly, as in the above example, no single stimulus element within a pair (sample and the two comparisons) is present in either of the other two pairs. Hence, successful matching performance with sets of novel stimulus pairs is taken as evidence that the animal is making explicit relational judgments. That is, the animal judges the relation of ‘identity’ or ‘nonidentity’ in the comparison pairs to be the ‘same’ or ‘different’ relation as that instantiated by the sample. In short, the animal is judging relations-between-relations to be the same or different, and this

ability is arguably the cognitive foundation for analogical reasoning (Gillian, Premack & Woodruff, 1981; Thompson & Oden, 1993, 2000).

Interestingly, despite their failure on RMTS tasks, macaque monkeys like baboons perform above chance and generalize to novel stimulus sets on a relational matching task when the samples and comparison stimuli representing identity or nonidentity are comprised of not two but multiple icon arrays (Fagot, Wasserman & Young, 2001; Wasserman, Young & Fagot, 2001). Nevertheless, the monkeys' performances decrease as the number of icons within each array is systematically decreased from an initial 16 icons and is at chance levels with only two icons within each array. The pattern of results displayed by the baboons (Fagot et al., 2001) and interestingly 20 percent of human subjects (Young & Wasserman, 2002) reflects their learning to discriminate identity and nonidentity in the RMTS task along the perceptual dimension of relative entropy (i.e., variability vs. uniformity) rather than on a categorical basis.

Alternatively, some rhesus monkeys (Flemming, Beran & Washburn, 2007) and pigeons (Blaisdell & Cook, 2005) have proven successful in two-item *same/different* discrimination tasks, leaving ambiguous the mechanism by which these choices are made: perceptually or conceptual/categorically. Without abstract representation, nonhuman animals may rely on entropy measures in order to discriminate relations between relations. Fagot et al. (2001) presented baboons with arrays of 16 icons in a relational match-to-sample paradigm. Baboons successfully learned to match arrays of identically and nonidentically related icons. By varying the number of icons composing the displays, Fagot et al. (2001) provided evidence that entropy plays a key role in the conceptual behavior of monkeys and some of the first evidence that animals other than humans and chimpanzees can discriminate relations-between-relations. One striking difference between the behavior of baboons and that of human participants completing

the same task is the cutoff point in entropy of the displays; baboons require a significantly greater amount of perceptual difference and sameness within displays in order to make analogical judgments. We may therefore infer that analogical thinking for a nonhuman species is more closely tied to and dependent on perception than abstract conceptualization. In fact, these entropy-dependent behaviors often regarded as “analogical” are likely perceptually grounded.

One might well wonder why monkeys have consistently failed to acquire the categorical two-item RMTS task given their success on simultaneous same/different discriminations and performance levels more or less equivalent to that of chimpanzees in conditional same/different tasks (cf., Blaisdell & Cook, 2005; Flemming, et al., 2007; Flemming, Beran, Thompson, Kleider & Washburn, 2008; Katz & Wright, 2010; Thompson, Oden & Boysen, 1997; Wright & Katz, 2006). Flemming et al. (2007) hypothesized that the monkeys’ failure to acquire RMTS is due to a cognitive “disconnect” between their perceptual and categorical conceptual abilities to process relational information, wherein abstract conceptualization of relations is hampered by a natural predisposition of the animals to attend to the perceptual qualities of the stimuli. This hypothesis is supported by the evidence from preferential handling and gaze studies that abstract relational properties are implicitly more salient for chimpanzee and child even at an early age than is the case for monkeys for whom physical elemental properties are more salient (Oden, Thompson, & Premack, 1990; Tyrrell, Stauffer & Snowman, 1991; Vauclair & Fagot, 1996). Thompson & Oden (2000) concluded from these results that monkeys are *paleologists*; their conceptual categories are based on shared predicates – absolute and relational features bound by perceptual and/or associative similarity, whereas symbol-trained apes are *analogical* in the sense that they perceive abstract propositional similarities spontaneously.

Apart from these differences in attentional focus on either physical or conceptual stimulus properties, Thompson & Oden (1996) further suggested that a major contributing factor to the difficulty of the RMTS task is that it is cognitively more demanding than either conditional or simultaneous relational same/different discriminations with respect to the number of matching/nonmatching operations and number of encoded abstract relations to be retained for successful completion of a trial. In the RMTS task, the animal must first compare the physical properties of each item within the sample to identify the categorically abstract relation they represent. It must then retain the encoded outcome of that operation while performing the same comparative operation on each comparison stimulus pair and encoding those outcomes. Finally, the animal must compare the encoded abstract representations resulting from all of the former operations and judge them to be the same or different before executing its decision response.

Hence, in order to make explicit same/different judgments of abstract relations as in analogical judgments, one must represent the abstract concepts in some way. Little is known of the modality of such representations for nonhuman animals but one possibility is that the provision of physical symbols affords chimpanzees and children, if not monkeys, the opportunity to encode abstract same-different relations as iconic representations thereby functionally reducing the RMTS task to a covert physical matching problem (Thompson & Oden, 1996, 2000; Thompson, Oden & Boysen, 1997). Symbol systems appear to provide apes and humans the representational scaffolding for manipulation and expression of propositional knowledge in relational matching-to-sample (RMTS) and related nonverbal analogy tasks (Gillan, Premack & Woodruff, 1981; Oden, Thompson & Premack, 2001) there is no evidence as yet that physical conditional cues associated with specific conceptual relations similarly acquire symbolic meaning for monkeys (Flemming et al., 2008).

In the present study we examined the possibility that differential expectancies of reward and punishment associated with specific relational matching choices might provide a functional alternative ‘scaffolding’ effect for attention to and representation of abstract relations analogous to that of conceptual symbols for ape and child. Our choice of the differential outcomes procedure was prompted by evidence for differential outcome effects (DOE) in which rates of acquisition and terminal accuracy are increased when response outcomes are inequitable across different stimulus types (e.g., Meyer, 1951; Trapold, 1970). Evidence for the strength of the DOE in conditional learning procedures has been provided for rats (Ludvigson & Gay, 1967), pigeons (Kelley & Grant, 2001) and for young children in classroom settings (Maki-Kahn, Overmier, Delos & Gutmann, 1995; Estevez et al., 2001). However, this effect is not ubiquitous, with some reports of mixed results for pigeons in several studies (Brodigan & Peterson, 1976; Williams, Butler & Overmier, 1982).

Thorndike (1911), in his early learning theory, proposed that the sole purpose of reinforcement was to “stamp in” an association between the stimulus and response. In instrumental learning conditions, however, stimuli preceding reinforcement can evoke the expectation of that reinforcement (Spence, 1956). These expectancies likely influence the strength of the SR association and in turn the rate of or latency in responding. Thus, subjects learn stimulus-type specific representations or expectancies of the reinforcing/punishing event (i.e. Spence’s, 1956, incentive motivation mechanism). Although associated with the instrumental response, this expectancy is acquired independently of the response itself but retains partial control over the behavior due to the interaction that exists with the SR association (Trapold, 1970). The mechanism that drives the increased speed and accuracy in differential

reward contingencies (DRC) is posited to be the hedonic value of the reward (Astley, Peissig & Wasserman, 2001).

In another study illustrating the DOE, Trapold (1970) rewarded rats differentially with a food pellet or sucrose solution for bar presses across several schedules of reinforcement. Subjects were required to choose one of two bars (right bar always designated correct) and commit to 10 responses on that bar in order to end a trial after the initiation of a tone. Rats consistently made more correct responses when a different reinforcer was used for the two separate stimulus-response components than when the same reinforcer was used for each. Trapold concluded that the rats had developed different expectancies for food and for sucrose which in turn produced distinctive stimulus properties allowing for a similar function as any other stimuli.

Although the expectation generated by a differential outcome procedure has traditionally proven effective as a cue for choice behavior, the nature of this anticipation has not been extensively explored. Recent evidence suggests that the DOE is not dependent on differences in hedonic value, but rather that different stimulus representations can serve as a cue to guide comparison choice behavior. Miller, Friedrich, Narkavic, and Zentall (2009) presented pigeons with a matching-to-sample task in which the differential outcomes effect was created using hedonically *nondifferential* outcomes. Using differently colored houselights following correct responses rather than hedonically-weighted rewards, Miller et al. (2009) found facilitated retention for correct choices.

Astley, Peissig and Wasserman (2001) provided evidence that hedonic reward expectancies associated with hedonic values drive these differences in performance. Pigeons were trained with different keys yielding differential amounts of reinforcement (1 or 5 pellets) and different delays of reinforcement (1 or 15 s). For test trials, these keys were used both as

samples or comparison stimuli in a conditional discrimination. Pigeons tended to match those keys associated with similar hedonic outcomes: 1 pellet key matched with 15 s key, 5 pellet key matched with 1 s key. This study not only provided evidence that hedonic value may drive differential responding, but also that there may exist a vague representation of said hedonic value which is stored and can later be used when matching associated stimuli.

Several studies have concluded that functional-equivalence class formation can be accomplished via association with unique outcomes for humans and animals (Dube, McIlvane, Mackay & Stoddard, 1987; Edwards, Jagielo, Zentall & Hogan, 1982). Further, assigning different hedonic values has been shown to effectively create equivalence classes of perceptually dissimilar stimuli (Astley & Wasserman, 1999). Through the employment of differential outcomes for each equivalence class, Astley and Wasserman (1999) provided unique feedback for pigeons substantial enough to allow for the formation of superordinate categories. In a go/no-go paradigm, pigeons pecked images from 4 large sets of perceptually complex multidimensionally related stimuli, receiving 1 s or 15 s delay to reinforcement after pecking correct images from within their category. All 8 pigeons pecked at levels significantly above chance to within-category perceptually-distinct novel images because of associations established with a common delay of reinforcement during training phases, giving credence to the use of differential outcomes as a successful learning tool beyond more basic S-R associations (Astley & Wasserman, 1999).

Beyond single stimuli, human judgments of relations have been shown to be enhanced by differential outcome procedures (Estevez, et al., 2007). Participants viewed mathematical “greater than” and “less than” relational statements (e.g. $5.88 > 5.31$) and were asked to indicate whether the statement was true or false. Upon their choice, participants were given one of two

different outcomes: a melodic tone or the word “great.” Response times were shorter for those participants in the differential outcomes condition. Further, with increased task difficulty (the inclusion of two negative numbers) participants in the differential outcomes condition not only showed improved response times, but also performed at rates of higher accuracy.

Given this evidence of differential outcome effects with single and categorical physical stimuli we hypothesized that a similar effect might be obtained also with abstract relational stimuli in the RMTS task to instantiate a novel rule: analogical-relational matching. We attempted to emphasize the conceptual relational nature of the stimulus pairs over the physical properties of physical elements within pairs by consistently associating different hedonic values with each exemplar of a given relation following correct matching responses. We further attempted to bias attention to the conceptual content of the stimuli by differentially punishing incorrect response choices that reflected attention to nonconceptual stimulus properties.

Specifically, we presented rhesus monkeys with a relational matching-to-sample (RMTS) task with pairs of identical/non-identical images serving as the sample and match stimuli. A given monkey was tested in one of 3 conditions: Differential reward (DR), differential punishment (DP), and differences in both reward and punishment (DB). With the inclusion of the “both” condition, we were able to assess the relative magnitude in differential strength required to observe the DOE. After completing trials under differential outcome conditions, monkeys then completed sessions with non-differential outcomes to determine the retention or permanence of these learned choices. Finally, monkeys returned to their original DR/DP/DB condition to investigate a possible rebound effect for choice behavior and/or dependence on these conditions to guide behavior.

Method

Subjects

Six male rhesus monkeys (*Macaca mulatta*) aged 5 to 20 years and housed at Georgia State University's Language Research Center in Atlanta, GA, served as subjects for all phases of this experiment. All monkeys had extensive testing histories responding via joystick-guided cursor movement to computer-generated stimuli presented on a monitor (Washburn, Rumbaugh & Richardson, 1992). All monkeys also successfully passed tests of matching- and delayed matching-to-sample in which correct choices were identical matches to computer-generated sample stimuli (e.g., Washburn et al., 1992).

Further, three of the monkeys previously participated in relational matching-to-sample tasks (e.g., Flemming et al., 2008). The remaining three monkeys were naïve to relational tasks. Monkeys were pseudo-randomly assigned to one of three differential outcome testing conditions: differential reward only (DR), differential punishment only (DP), and both differential reward and punishment (DB) assigned. Monkeys that had previously participated in the Flemming et al. (2007, 2008) tasks were each assigned to one of the outcome conditions as was one other monkey in that same condition from the naïve group. Monkeys were each then randomly assigned one relation (identity vs. nonidentity) to be “emphasized” for the entire duration of the differential outcome sessions as described below.

Each monkey was tested while individually housed in his home enclosure. They had continuous access to the computerized program for blocks of time ranging from 4 to 8 hours, completing 1 of 4 500-trial blocks per session (total of 4 sessions per condition per phase per animal). During testing, the computer program controlled all stimulus presentations and reward

delivery. No animals were food or water deprived for any portion of testing; all procedures were approved by the Institutional Animal Care and Use Committee of Georgia State University.

Design and Procedure

Monkeys first completed 2,000 trials in their pseudo-randomly assigned DO condition, then two sets of test sessions (2,000 trials each) with equalized outcomes, and subsequently another 2,000 trials in their originally assigned DO condition.

Within each trial, monkeys first saw a sample pair instantiating either the identical or nonidentical relation (AA or BC). Bringing a joystick-guided cursor in contact with that pair revealed two choice pairs: a novel identical pair (DD) and novel nonidentical pair (EF). Monkeys then selected a choice by contacting the pair with the cursor. Stimuli consisted of trial-unique clipart images so that after inclusion in one pair, either the sample pair or the choice pairs, it was discarded and not used in any other relational pair throughout all phases of the experiment.

Outcome schedules. In the first phase (A1), monkeys completed RMTS trials in 1 of 3 DO conditions. Two monkeys (Willie and Luke) were assigned to differential reward-only (DR), two monkeys (Hank and Han) to differential punishment-only (DP), and two monkeys (Gale and Obi) to both differential outcomes (DB). Each monkey was also randomly assigned to either identity or nonidentity as their relation of “better” hedonic value. For example, if assigned to identity, the better (i.e. great number of pellets) payoff followed correct choices only if the sample was identical and choice pair selected was identical.

Rewards differed in magnitude of pellets delivered for correct responses. In the differential reward only (DR) condition, correct choices of the assigned higher hedonic relation resulted in the delivery of 4 pellets whereas correct choices of the other relation resulted in the

delivery of only 1 pellet. Any incorrect match resulted in a 5s inter-trial interval (ITI) for both relations.

Punishments (penalties) differed in the duration of ITI following incorrect choices. In the differential punishment only (DP) condition, correct responses resulted in the delivery of just 1 pellet regardless of relation type. If monkeys chose incorrectly on a trial of the more heavily punished relation (e.g., choosing a nonidentical pair in the presence of an identical sample pair) they experienced a 45 s ITI as compared to a 10 s ITI following the incorrect selection of the less heavily punished relation.

In the *both* (DB) condition, correct responses to the emphasized relation led to delivery of 4 food pellets whereas incorrect responses to the other relation resulted in only 1 pellet. Additionally, incorrect responses to the emphasized relation were followed by a 45 s ITI and incorrect responses to the other relation were followed by a 10 s ITI. See Figure 4.1 for an example depiction of the DB trial type for Gale (*same* emphasized).

In the next phase (B1), monkeys completed all trials with equalized outcome (EO). A condition with equalized outcome following a potential DOE for all six animals was conducted to examine possible carry-over effects from Phase A1 including the possibility that perhaps any observed DOE effect from Phase 1 might facilitate continued relational matching in the absence of differential outcome procedures. It is perhaps the case that the DOE results in a lasting learned rule for the RMTS. In this phase, all correct choices resulted in delivery of 1 pellet while incorrect choices resulted in a 10 s ITI.

Following Phase B1, all six monkeys completed an additional phase of equalized outcome (Phase B2) where correct choices resulted in the delivery of 4 pellets (EO 4) in contrast

to only a single pellet to determine if any observed effects in Phase 1 may be attributed to the sheer magnitude of the larger reward *per se* as opposed to a true differential outcome effect.

In the final phase (A2), monkeys completed a second set of 2,000 trials in their originally assigned DO condition from A1. This phase was conducted to examine possible rebound effects from potential loss of the DOE in phases B1 and B2.

Results

Experimental Phase A1 – Differential Outcome. In DR and DP conditions, no effects due to differential outcome were observed. Luke, Han and Hank completed the final 500 trials of their sessions with an average accuracy of 50.8% (chance = 50%; see Table 4.1). One monkey performed significantly better than chance in the DR condition (73.4%). However, this was due to an asymmetrical selection⁵ of the emphasized relation only (Willie, $z = 10.42$, $p < .01$). This monkey chose the correct relation significantly above chance levels only when the sample was of the assigned emphasized relation. Of the trials that were completed correctly, 85.2% were matches of *same* to *same* relation, rather than distributing his responses evenly, $\chi^2(1, N=1424) = 400.73$, $p < .01$. Performance for all other monkeys was symmetric in the DR and DP conditions (see Table 4.1).

In the DB condition (Phase A1), in which both reward magnitude and punishment duration differed across relations, both Gale and Obi performed significantly above chance with accuracies of 84.1% and 86.3% respectively (Gale, $z = 15.25$; Obi, $z = 16.23$, $ps < .01$). This

⁵ Assessing the possibility of asymmetric performance on *same* versus *different* trials, we conducted post hoc analyses examining performance for all same and different trials that were completed correctly. Achieving levels of significance (above chance) was possible by garnering higher success rates of one trial type over another. One could potentially succeed on a very high percent of only one trial type and perform at below chance levels on the other, still providing overall levels of performance significantly above chance.

marks the first success in an RMTS task by rhesus monkeys.⁶ Symmetrical performance was also observed for both monkeys, indicating that performance on *same* and *different* trial types was equally high (see Table 1).

Experimental Phases B1 & B2 – Equalized Outcome. In both equalized outcome (EO 1 and EO 4) phases, regardless of pellet magnitude, performance did not differ significantly from chance (50%) for any monkey. Symmetrical performance was observed for every monkey. See Table 1 for a summary of results.

Experimental Phase A2 – Differential Outcome. In Phase A2, a pattern of results similar to A1 was observed. In DR and DP conditions, no effects due to differential outcome were observed. Willie, Han and Hank completed the final 500 trials of their sessions with an average accuracy of 51.8% (chance = 50%; see Table 1). While one monkey in the DR condition performed at a level significantly chance, 75.1% (Luke, $z = 11.23$, $p < .01$), his performance was not symmetrical and therefore an artificial reflection of successful relational matching $\chi^2(1, N=1424) = 327.53$, $p < .01$. Performance for all other monkeys was symmetric in the DR and DP conditions (see Table 1).

In the DB condition (A2), in which both reward magnitude and punishment duration differed, both Gale and Obi performed significantly above chance with accuracies of 87.5% and 89.2% respectively (Gale, $z = 16.68$; Obi, $z = 17.49$, $ps < .01$). Symmetrical performance was also observed for both monkeys (see Figure 4.2 for performance summaries).

⁶ Monkeys who have previously performed similar RMTS tasks with equalized outcome in Flemming et al. (2007, 2008) were Willie, Gale, and Hank. All other monkeys were completely naïve to RMTS tasks. Important to note is the fact that of the experienced monkeys, although none had prior success on similar tasks, 1 monkey now performed at levels above chance. Additionally, 1 naïve monkey performed at levels above chance in the current task, negating the possibility that prior performance on similar tasks had any effect on current task performance.

Discussion

Results from the present experiment provide the first evidence that macaque monkeys (*Macaca mulatta*) are capable of making explicit categorical-conceptual two-item (2x2) judgments of analogical relations (*same* or *different*) between relations (*identity* or *nonidentity*) with trial unique stimulus pairs. Interestingly, however, the monkeys did so only under conditions of differential outcomes of both reward and punishment in the relational matching-to-sample task (RMTS). With differential scaffolding provided, rhesus monkeys seem to have at least in a transitory manner “bridged the conceptual gap” oft ascribed in their representational abilities (Flemming et al., 2007; Premack, 2010; Thompson & Oden, 1993, 2000). Importantly, these results extend the evidence for differential outcome effects (DOE) beyond conditional discriminations involving perceptual physical and relational stimuli to those involving categorical relations-between-relations (cf., Brodigan & Peterson, 1976; Friedrich & Zentall, 2010; Schmidtke, Katz & Wright, 2010; Trapold, 1970).

As hypothesized, differential outcomes allowed for the expression of the requisite trial-unique abstract conceptual skills forming a cognitive foundation for analogical reasoning. However, contrary to our expectation, these skills depended upon sustained differential outcomes and did not transfer under conditions of nondifferential reinforcement and punishment. No monkey successfully completed RMTS trials at levels above chance with equalized outcome (EO) receiving 1 pellet. Hence we conclude that differential outcomes were likely the cause of success in the *both* (DB) condition of phase A1. Moreover, given the lack of the animals’ success on trials in which they received 4 pellets, we can rule out the possibility that heightened performance in Phase A1 (DB) is attributable to simple magnitude effects resulting in a preference for one type of trial configuration.

Not unlike 3 to 5 year-old children or chimpanzees given referential labels for relations (Premack, 1983; Rattermann & Gentner, 1998a) explicit judgments of analogical relationships by the rhesus monkeys were significantly facilitated by the conceptual scaffolding provided by differential outcomes. However, the transitory nature of the DOE effect observed in the present experiment notably differs from the sustained facilitative and priming effects of symbol training and linguistic labeling on RMTS and related analogical task performances of, respectively, chimpanzee and child even in the subsequent absence of those cues. We suspect it is unlikely that possible outcome expectancies associated with the identity and nonidentity relations function as proto-symbols analogously to the hypothesized representational role of physical tokens/symbols or verbal labels. (Oden et al., 1990; Premack, 1983; Thompson & Oden, 1993; Thompson, Oden & Rattermann, 2001).

The issue of the transitory or sustained nature of rule-learning facilitated by a differential outcomes procedure is seldom explicitly noted in the literature. Cook, Cavoto and Cavoto (1995) instituted a system of differential outcome to promote learning of same-different texture discrimination when pigeons appeared not to show success. On subsequent transfer tests with equalized outcomes, Cook et al. (1995) observed no change in their birds' performances. Schmidtke et al. (2010), found that the differential outcomes procedure did not affect rate of acquisition of *same* and *different* concepts for pigeons, but rather enhanced rate of transfer to novel 32-item sets (but not smaller set sizes). Their pigeons' transfer, albeit marginal, to an equalized outcome procedure is consistent with the results reported by Cook et al. (1995).

Alternatively, Uricuioli & DeMarse (1994) found that while a differential outcomes procedure facilitated acquisition of matching-to-sample by pigeons, the observed transfer observed was "neither perfect nor as strong as" what might be observed in other studies. The

authors argued that the reason for such low transfer is that the differential outcomes *control*, rather than simply *facilitate* choice behavior. Uriciolo & DeMarse (1994) did not speculate as to how the differential outcomes control behavior but results from other studies suggest that the relative differential hedonic value of the outcomes alone may be sufficient to facilitate comparison choice (Astley et al., 2001; Astley & Wasserman, 1999).

Other recent reports provide evidence for differential outcome-facilitated *same/different* concept learning in pigeons (Friedrich & Zentall, 2010; Schmidtke, Katz & Wright, 2010). Friedrich & Zentall (2010) trained pigeons on a conditional discrimination task which involved either differential probability of reinforcement or differential responding (via key pecks) to comparison stimuli. Differential outcomes in two conditional discriminations effectively formed two stimulus classes. With the institution of a differential outcome system of equalized hedonic value, the authors state that arbitrary differential properties of outcomes can effectively serve as choice comparison cues. While this study illustrated an enhancement in speed of acquisition of same/different concepts, it did not address the learning of a novel rule via differential outcome procedures.

At this point, one might ask exactly *how* differential outcomes allow for the attainment of a seemingly novel analogical rule for our rhesus monkeys. Although additional studies will be required to elaborate on the specific mechanisms involved, one explanation for our observed ‘analogical emergence’ via differential outcomes draws on Spence’s (1956) theory of reward expectancy as a guiding mechanism for choice behavior. As previously reported (Fagot et al. 2001; Flemming et al. 2008) relational matching is not only difficult for monkeys to attain, but also perceptually grounded. Thus, it stands to reason that a conceptual shift in attention (not unlike the relational shift children experience from perceptual to relational properties, e.g.

Rattermann & Gentner, 1998b) may be difficult as well.

We assume that the monkeys' default attentional focus under nondifferential reinforcement and punishment is on the perceptual properties (predicates) of individual stimuli instantiating the experimental stimulus pairs (i.e. Thompson & Oden, 2000). There is good independent evidence that monkeys focus on the local properties of stimuli grouped together and, more so than chimpanzees (Fagot & Tomanaga, 1999), find it difficult to focus on the more global structures they instantiate (De Lillo et al., 2005; Dereulle & Fagot, 1998; Fagot & Dereulle, 1997; Spinozzi et al., 2003). We further assume that monkey subjects learn stimulus-type specific representations or expectancies of the differential reinforcing/punishing events. Berridge and Robinson (2003) discuss these reward expectations as a form of "cognitive incentive" wherein hedonic expectations serve as a basis for motivation. Brain substrates for cognitive incentives, however, are different from and operate independently of typical motivational components that may account for mere associative responses. Cognitive incentives, rather, allow for the emergence of more goal-directed strategies (Berridge & Robinson, 2003). Perhaps the contrast in reward only, punishment-only, and both conditions is driving the facilitative effect by a selective attention mechanism that operates to assist in analogical reasoning abilities. This cognitive incentive-motivation system guiding choice behavior may operate to shift and maintain the animals' attentional focus from the local features of the individual stimuli within pairs to the more global relational properties of the stimulus pairs in a manner analogous to the way in which the decision criteria of marine mammals are systematically made more conservative or liberal as measured in ROC curves by differential contingencies of reward and punishment (Schusterman, Barrett & Moore, 1975).

With attention to the conceptual pair and hedonic state instantiated, a search between two alternate choice pairs (also hedonically enhanced) and animals' choice behavior is guided much in the same way as a traditional one-item matching-to-sample task. Differential outcome procedures such as those instantiated in the current study may then provide the means necessary for multiple representations of relational-conceptual stimuli and the subsequent mapping of relations-between-relations. We suggest that the magnitude of reward and punishment in the *both* condition provides a sufficient and adequate 'cognitive incentive' to compensate for the increased cognitive cost/load of executing the series of computational steps requisite for identifying the correct choice in the RMTS task as suggested by Thompson & Oden (1996). That the monkeys in the current study could not retain the analogical rule learned with differential outcomes further suggests that the hedonic cognitive incentives in the absence of differential outcomes (reward & punishment) are no longer sufficient to maintain responding at the global conceptual relational level in the face of its cognitive costs (i.e., retention of sequential matches). Hence the monkeys revert to the cognitively less demanding default perceptually grounded level of attention to local/physical properties stimuli. The intermittent 50% reinforcement rate associated with such a strategy presumably is sufficient to maintain execution of responses to sample and comparison stimuli without regard to their abstract categorical/conceptual content.

Although there is no evidence that we have no evidence that differential outcomes serve as proto-symbolic cues oft-cited as integral to analogical reasoning (Oden et al., 1990; Premack, 1983; Thompson & Oden, 1993), it appears that differential outcomes can provide the animals with the requisite hedonic cognitive incentive 'magnets' to focus the animals attention from local features to more global relational properties and thereby 'bridge' the hitherto uncrossable 'conceptual gap' in analogical reasoning by monkeys.

Table 4.1

Performance Summaries by Experimental Phase

Phase Condition and subject	% correct	z	% emphasized of correct trials	χ^2
<u>A1 – Differential Outcome</u>				
<u>Reward Only (DR)</u>				
Willie (s)	73.4	10.42*	85.2	400.73*
Luke (d)	53.9	1.74	50.8	.12
<u>Punish Only (DP)</u>				
Han (s)	47.5	-1.03	52.2	.83
Hank (d)	51.1	.49	47.6	.58
<u>Both (DB)</u>				
Gale (s)	84.1	15.25*	52.4	1.09
Obi (d)	86.3	16.23*	53.0	2.78
<u>B1 – Equalized Outcome 1</u>				
Willie (s)	46.9	-1.39	50.7	.08
Luke (d)	51.1	.49	50.1	.01
Han (s)	52.5	1.12	47.6	1.05
Hank (d)	51.2	.49	51.7	.47
Gale (s)	52.7	1.21	49.5	.03
Obi (d)	54.2	1.83	46.4	2.64
<u>B2 – Equalized Outcome 4</u>				
Willie (s)	52.1	.94	49.2	.12
Luke (d)	48.1	-.76	48.3	.47
Han (s)	52.7	1.21	47.9	.76
Hank (d)	54.0	1.74	46.2	2.99
Gale (s)	50.3	.13	46.9	2.00
Obi (d)	46.2	-1.65	50.23	.01
<u>A2 – Differential Outcome</u>				
<u>Reward Only (DR)</u>				
Willie (s)	54.2	-1.83	53.5	2.62
Luke (d)	75.1	11.23*	81.7	327.53*
<u>Punish Only (DP)</u>				
Han (s)	53.0	1.3	50.7	.07
Hank (d)	48.3	-.67	48.6	.34

<u>Both (DB)</u>				
Gale (<i>s</i>)	87.5	16.68*	49.1	.26
Obi (<i>d</i>)	89.2	17.49*	52.4	1.89

Note. Emphasized relation is represented after subject name in parenthesis (*s* = *same*; *d* = *different*). Percent correct was calculated from the last 500 of 2000 total trials. These percentages reflect the same pattern of results as reported in Figure 1 for the entire block of 2000 trials. Within the last 500 trials, learning curves had reached a threshold and remained at levels approximate to the percent correct reported above. Binomial tests were run only on this last quartile of the data for representative statistical results that would not otherwise have been reflected with the full 2000 trials. Data for symmetry (% emphasized and corresponding χ^2) analyses were taken from all correct trials out of 2000.

* $p < .01$.

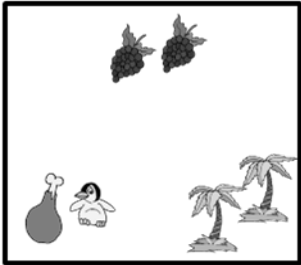





Condition: DB (both), same emphasized		
Sample	Choice	Outcome
 <p><i>Same</i></p>		4 pellets 5-sec ITI
		0 pellets 45-sec ITI
 <p><i>Different</i></p>		1 pellets 5-sec ITI
		0 pellets 10-sec ITI

Figure 4.1. Depiction of trial choices and outcomes from the DB (both) condition with “same” emphasized. Screen captures (left) represent stimulus-pair arrangement as the monkey would see; sample pair is centered along top edge and choice pairs are located in lower corners. Stimulus images depicted are simplified for publication purposes. Trial-unique multi-colored clipart images were used throughout all phases of this project.

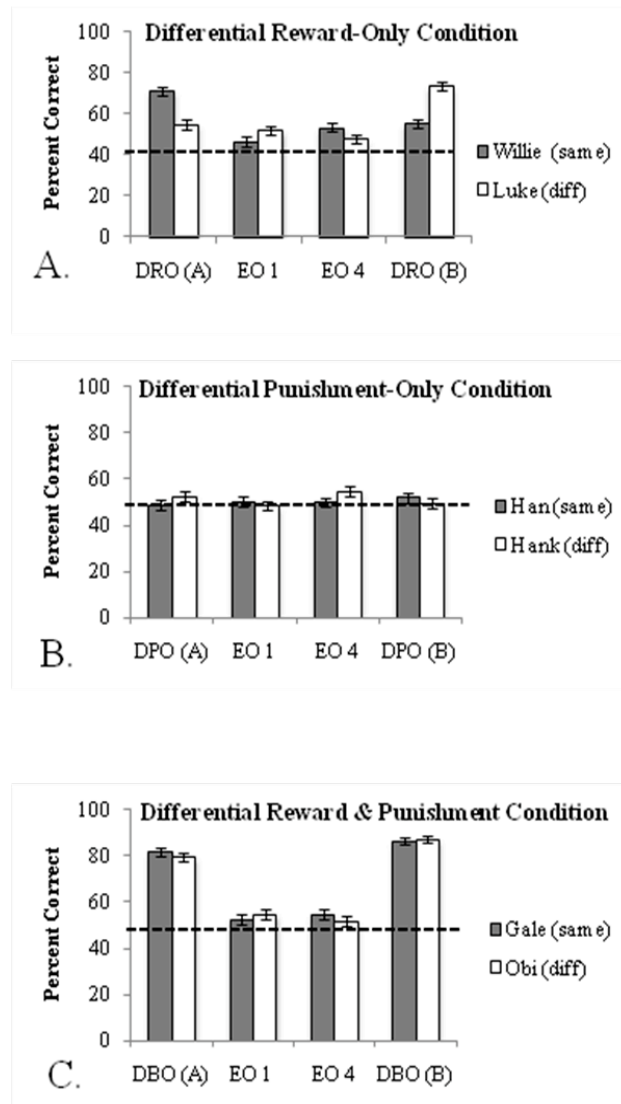


Figure 4.2. Performance summaries by condition. Percent correct was calculated for each individual out of the full set of 2000 trials in each of 4 experimental phases. Order of presentation of experimental phases was consistent for each animal and is represented left to right on the charts. Emphasized relation for each monkey appears in parentheses after their name. Horizontal dashed lines on each graph represent a level of responding consistent with chance (50%).

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Chapter 5: Chimpanzee relational matching: Playing by their own (analogical) rules⁷

Abstract

Chimpanzees have been known to exhibit rudimentary abilities in analogical reasoning (Gilliam, Premack & Woodruff, 1981; Flemming, Beran, Thompson, Kleider & Washburn, 2008; Haun & Call, 2009; Thompson, Oden & Boysen, 1997; Thompson & Oden, 2000). With a wide array of individual differences, little can be concluded about the species' capacity for analogies, much less their strategies employed for solving such problems. In the current study, we examine analogical strategies in three chimpanzees using a 3-dimensional search task (e.g., Kennedy & Frigaszy, 2008). Food items were hidden under one of two or three plastic cups of varying sizes. Subsequently, chimpanzees searched for food under the cup of the same *relative size* in their own set of cups – reasoning by analogy. Two chimpanzees initially appeared to fail the first relational phase of the task. Meta-analyses revealed, however, that they were instead using a secondary strategy not rewarded by the contingencies of the task – choosing based on the same *relative position* in the sample. Although this was not the intended strategy of the task, it was nonetheless analogical. In subsequent phases of the task, chimpanzees eventually learned to shift their analogical reasoning strategy to match the reward contingencies of the task and successfully choose based on *relative size*. This evidence not only provides support for the “analogical ape” hypothesis (Thompson & Oden, 2000), but also exemplifies how foundational conceptually-mediated analogical behavior may be for the chimpanzee.

Keywords: analogical reasoning, relational matching, chimpanzee

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For humans, analogies have stimulated critical thinking by helping to identify and construct relationships amongst items and ideas allowing for the generation of novel thought. It is this higher-level reasoning that traditionally was ascribed only to humans, but throughout the years has been observed with varying degrees of success in some apes (e.g. Premack, 1976; Thompson, Oden & Boysen, 1997) and arguably even in monkeys (e.g. Fagot, Wasserman & Young, 2001; Spinozzi, De Lillo & Truppa, 2005). Little is known of the emergence of analogical reasoning and its complexity of use within vertebrate evolution. In the present study, we examine the extent to which chimpanzees may use analogies, which combined with other recent research may help to outline the evolutionary underpinnings of our own propensity for analogical reasoning and its associated cognitive mechanisms.

By reasoning analogically, one determines the relationship amongst two or more items and searches for that same relationship amongst a novel problem or set of instances. Loosely defined, analogies involve a comparison of similarities between items that would otherwise not be considered alike. Thus, a conceptual-relational strategy is applied rather than an item-specific perceptually-driven strategy. Analogies are both functionally adaptive and cognitively efficient in that they allow us to apply previously-learned concepts, strategies, or rules to novel problems. Because of their application to critical thinking, inference, problem-solving, decision-making, and even memory, Hofstadter (2001) refers to analogies as the “core of cognition,” cementing their importance to human thought.

Due to our shared evolutionary ancestry, chimpanzees have several cognitive commonalities with humans. Analogical reasoning as one such potential commonality has been explored since the late 1970s. One chimpanzee (Sarah) has provided perhaps the most extensive evidence for analogical behavior in a nonhuman (Gillian, Premack & Woodruff, 1981). After

extensive training with plastic tokens for the words “same” and “different,” Sarah was capable of completing and creating both standard item and functional analogies. Importantly, it is this symbolic language-like training that was thought to be responsible for her success. Thompson and Oden (1996) suggest that the critical role of her symbols for “same” and “different” was to provide her with a concrete means of encoding conceptual-relational information that is otherwise abstract. The task of matching then becomes one of covert symbol matching. Premack concurs (1976, 1986) that at least in the case of abstract relations, acquisition of conceptual knowledge necessary for analogical reasoning is dependent upon these specific language skills.

Other than a token-trained chimpanzee, few nonhuman animals have completed a relational matching-to-sample task without prior training with symbols for *same* and *different* (Thompson, Oden & Boysen, 1997). These chimpanzees, however, had a history of conditional discrimination training using tokens and multiple pairs of objects. For example, they viewed identically or nonidentically related pairs of stimuli and were rewarded for choosing one of two arbitrary tokens. The opposite (required for symbolic training) had not been tested. That is, they could choose the correct token in the presence of a relational pair, but it is not known whether they might be able to choose the same relational pair in the presence of a specific token. When tested using a relational matching-to-sample paradigm, they successfully chose a novel same-relational pair of objects in the presence of an identical or nonidentically-related pair. Although met with minor criticism, this paradigm is widely used and accepted as a test for knowledge of analogical reasoning capabilities (Flemming, Beran & Washburn, 2007; Premack, 1986; Flemming, Beran, Thompson, Kleider & Washburn, 2008; Fagot, et al., 2001; Vonk, 2003).

Baboons naïve to any symbolic training whatsoever have shown tendencies for analogical-like behavior (Fagot et al., 2001). We classify their behavior as “analogical-like”

because of its dependence on elevated levels of entropy. Entropy, as Wasserman (2002) defines it, is a measure of randomness or disarray within a visual field. It is the detection of this entropy that is thought to underlie *same* and *different* conceptualization for pigeons and baboons. The degree to which an animal can detect lower levels of entropy predicts well the success in the utilization of the concepts for reasoning tasks such as analogies. Baboons were presented with displays of up to 16 identical or nonidentical icons in a relational matching-to-sample (RMTS) paradigm. Their acquisition of the relational matching rule was slow and gradual, taking as many as 7,000 trials until an 84% criterion was reached and subsequently transferred to new sets of exemplars. While success was high with these displays of 16 icons, failure to meet criterion even after thousands of trials began when the displays were composed of 8 icons or less. That success on the RMTS task could not be garnered with fewer than 8 icons within a display reveals a perceptually-grounded understanding of the *same* and *different* concepts (as in Flemming et al., 2007). Without a more rich interpretation of these concepts (i.e., symbolic encoding), one may argue that their rudimentary matching behavior was more or less implicit, driven by perceptual mechanisms.

Was this success by the baboons truly exemplary of analogical reasoning? We propose that the “perceptual feel” the baboons seem to receive for “same” and “different” utilizing display entropy makes matching displays in an RMTS format elementary. Thus, we do not believe that their success in this task is attributable to the same cognitive mechanisms that true reasoning by analogy requires. Even with two-item displays, then, one could argue that judgments utilizing entropy play a role in performance (match display of entropy=1 [2 different objects] to another of entropy=1; match display of entropy=0 [2 identical objects] to another of entropy=0).

In an effort to re-examine reasoning by analogy paradigms, Kennedy and Fragaszy (2008) investigated the ability of capuchin monkeys to use analogical reasoning in a 3-dimensional search task involving hidden food under 1 of 2 or 3 plastic cups of different sizes. Food was hidden under two sets of cups and then revealed by an experimenter in one set of cups. The other set of cups of different absolute sizes was available for the capuchin monkey to search under. Capuchins searched directly under one cup and lifted it to reveal either the presence or absence of reward, contingent upon matched relative size between subject and experimenter sets. One of four capuchin monkeys performed at levels above chance not only on a basic 2-item task, but also on a series of transfer tasks with 3 novel stimuli and distracters. This study along with results of Spinozzi et al. (2005) provides the first evidence of analogical reasoning in a capuchin monkey. The authors hypothesized that the intentional extensive problem-solving experience of this subject may have provided the scaffolding (*physical to relational* matching) on which this newly emerging analogical reasoning was built.

This design has several advantages over RMTS. First, it distances any connection to a dependency on entropy. Perceptual uniformity and chaos are no longer able to guide choice behavior, strengthening the argument that success on this task is exemplary of reasoning by analogy in the most stringent sense. Secondly, the concepts of *sameness* and *difference* are no longer fraught with the potential to confound with the search for sameness between sets. For analogy, it is trivial that the relationship within sets is the same relationship instantiated between sets. For example, in an analogy where the first two terms may be banana/grape, we are not likely to label them “same” but rather we would more specifically say that they are both “fruits.” If we were to label the pairing as “same” (“fruit” being implied) the search for the same relationship becomes more confounded.

Finally, a 3-dimensional search task is both interesting and advantageous over an RMTS task when studying analogies because it adds a level of application and ecological validity for reasoning. Rather than matching pre-determined concepts (i.e., *same* and *different*) subjects of this task are free to attempt any number of strategies, only one of which ultimately providing reward. For instance, the subject may choose based on absolute size searching under the cup that is most physically similar to, or an exact match for the absolute size of the sample. Alternatively, one may choose based on the same relative position as the sample. While not rewarded, this choice behavior is also analogical. Finally, and consistent with the reward contingencies of the task, subjects may (and should) choose based on relative size to the sample. Importantly, we should not ignore attempts using other strategies, particularly the second which is exemplary of analogical behavior despite reward contingencies.

From a comparative perspective, another advantage of using the three-dimensional analogical search paradigm is that this task is more similar to analogical tasks that have been presented to children. Kennedy and Fragaszy (2008) modeled their task on one presented to 3- to 4-year-old children by Gentner and Ratterman (1991). In this study, children searched for stickers hidden under analogous sets of flower-pots of different sizes. Flower pots were arranged in decreasing size from left to right on a table top for both the child and experimenter. Importantly, the sets often included distracter objects such as pots of the same absolute size (which were not the correct “relative size” choices) in order to determine whether the children relied on a strategy of object or relational similarity. To begin a trial, the experimenter demonstrated with her set the pots where a sticker was hidden and instructed the child to “use this information” to find a sticker hidden somewhere under his or her set. She then allowed the child to search his or her set to find the sticker. The correct choice was always to search under

the pot of the same relative size as the one lifted by the experimenter, a choice that was markedly difficult for 3-year-olds, but seemed to emerge gradually for 4-year-olds.

This development over time of the ability to reason analogically forms the basis for the relational shift hypothesis (Gentner, 1988). While children initially utilize physical similarity to respond to problems involving two or more objects, developmental psychologists have recognized a ‘relational shift’ whereby the ability to understand relational similarities emerges. This knowledge of relational sameness subsequently allows for an application to analogical reasoning abilities. Attentional resources based on the amount of contextual novelty are thought to drive this shift (Gentner, Rattermann & Forbes, 1993). For instance, if an analogy is proposed in a somewhat unfamiliar context, surface similarities override any attentional focus on structural (relational) similarities. In familiar contexts, though, analogies can be solved because attentional resources are no longer consumed by surface analyses, allowing for a structural analysis to commence.

Because of confounding results highly dependent on methodology, the visual MTS paradigm has recently been argued to be less certain in assessing “relational similarity proper” (Haun & Call, 2009). Because entropy could play a role in even small stimulus arrays, any outcome from a visual MTS test could rely heavily on exact physical features of individual stimuli. In an effort to examine truly conceptually-mediated analogical behavior in token-naïve animals, we chose to implement an adapted spatial relational similarity paradigm that has been used to investigate both human children (Gentner & Rattermann, 1991) and capuchin monkeys (Kennedy & Frigaszy, 2008). The current study examines not only the possible existence of analogical reasoning skills in chimpanzees with no prior training of *same/different* concepts, but also the emergence of such reasoning given multiple potential strategies by which to approach a

task. In a series of three-dimensional interactive search tasks, chimpanzees were given the opportunity to search for a food reward under a cup analogous to one from a demonstrated baiting by an experimenter. With the oft-cited argument for the “analogical ape,” (Thompson & Oden, 2000) we hypothesized that chimpanzees would successfully employ an analogical strategy in significantly fewer trials than a capuchin monkey (c.f., Kennedy & Fragaszy, 2008). In accordance with the relational shift hypothesis, we also expected to observe an initial focus on surface similarities with a later emergence of the focus on structural similarities for analogical reasoning.

Method

Subjects

Three adult chimpanzees (*Pan troglodytes*) age 23-38 years old participated in all phases of this study. The chimpanzees were housed at Georgia State University’s Language Research Center (LRC) and have been involved in research for more than 20 years. These animals participated in many studies as part of the LRC’s Language Project including symbol and concept acquisition tasks (see Rumbaugh & Washburn, 2003 for comprehensive review). While they are lexigram-trained chimpanzees, they had not acquired symbols for *same/different* or and size relations. All animals were symbol-naïve with respect to these analogical tasks. Two years prior to the current study, the chimpanzees completed 75-200 trials of a computerized relational matching-to-sample (RMTS) task examining the effects of meaningful stimuli on analogical reasoning with varying degrees of success (Flemming et al., 2008). We do not believe that this experience presented any confound for the current study due to the differences in computerized and interactive methodology as well as the duration between the tasks and minimal degrees of success in the previous tasks.

All chimpanzees were familiar with testing paradigms in which pointing through metal fencing resulted in the receipt of an object or the indication of an object for the subsequent delivery of reward. Chimpanzees remained in their home cages during testing and were not food or water deprived. All housing and testing procedures were approved by Georgia State University's animal care and use committees.

Materials

Two sets of eight plastic stacking cups served as the experimental stimuli under which food rewards (M&M candies) were hidden. All cups were painted black to ensure uniform appearance apart from size (diameter range 5 cm to 9 cm). For subsequent transfer tests, two new sets of yellow plastic stacking cubes (width range 4 cm to 7 cm) were presented in order to vary both shape and color. These same stimulus sets were previously used by Kennedy and Frigaszy (2008) with capuchin monkeys.

Testing stimuli were presented on a sliding wooden bench positioned slightly below eye level of the animal directly in front of the home enclosure. The 25cm x 15cm bench consisted of a stationary surface and a sliding surface 2.5 cm below the stationary top surface that could slide toward the home cage, much like a computer drawer on an office desk. To obstruct the subject's view of the cups during baiting with food reward, a 40cm x 40cm white plastic panel was positioned between the testing bench and the front of the enclosure.

Procedure

Test sessions took place approximately once per week over the course of 4-5 months for each animal. Sessions lasted no more than 30 minutes and/or 30 trials. Refusal to participate resulted in the termination of a session. All animals completed sessions from test phases in the following succession with the exception of one animal who skipped phase 2: 1- match-to-sample

training; 2- relational matching; 3- relational matching with distracter; 4- relational matching with novel transfer distracter; and 5- relational matching with dissimilar transfer distracter.

In all testing phases, one set of cups was linearly positioned on the upper level of the bench and served as the experimenter's demonstration set. Another set was simultaneously placed on the lower sliding shelf and served as the set to which the animal could indicate via pointing. Cups were randomly assigned to one of five positions on each surface level in all testing phases so that no spatial arrangement was consistent between or within trials. Therefore, the likelihood that an animal would make absolute position-based selections was low. After invisible baiting of cups, trials in all phases began with the experimenter lifting a cup to reveal the location of an M&M candy reward. The sliding shelf was then pushed toward the animal to request selection via pointing. All pointing resulted in the experimenter lifting the cup indicated to reveal the presence or absence of an M&M candy reward. In the event of a correct selection, the visible M&M candy reward was delivered by hand to the animal through the front of the enclosure.

Careful attention was given not to cue the subjects during trials. The experimenter indicated the location of the reward in the sample set and immediately looked away from all stimuli before sliding the subject's set forward. The experimenter only looked toward the stimuli once a choice was made by the subject to verify the location of the selection. See Figure 5.1 for a depiction of stimulus arrangements for all experimental phases.

Matching-to-Sample (MTS)

Out of view of the animal, the experimenter placed one or two cups upside-down on the higher platform (the experimenter's set) and two upside-down choice cups (subject's set) containing one identical match to the sample in randomly assigned locations on the lower sliding

shelf. Both the sample and correct choice were baited with one M&M candy reward. The experimenter then removed the obstructing panel revealing the entire apparatus and cups to the subject. To initiate a trial, the experimenter lifted his sample cup and pointed to the M&M. After two seconds, the cup was replaced, re-covering the reward. The experimenter then slid the lower shelf toward the front of the subject's enclosure. To find the hidden reward in their set, the subject had to choose via pointing to the cup that matched the absolute size of the sample. Once indicated, the experimenter lifted the cup and revealed either the absence (incorrect choice) or presence (correct choice) of reward and handed the subject the reward in the event of a correct choice.

Each subject continued testing until he/she reached a significant criterion of 9 correct trials out of 11 consecutive trials in 2 testing sessions. This criterion provides statistical significance under a binomial test with chance responding at 50%, $p < 0.05$. In a trial type involving sets of 2 cups (2 choices for the subject) chance responding was 50%. In phases of this experiment involving sets of 3 cups (3 choices for the subject) chance responding was 33%. However, in an effort to be more conservative, the alpha level remained at .05 for all analyses in all phases of the experiment.

Relational Matching

Subjects progressed to relational matching trials only after reaching criterion on the MTS phase. In relational matching trials, each of the four cups was of different size. Relational matching procedures were carried out in exactly the same manner as previous MTS trials, however, the hidden reward in the subject's set was always under the cup of the same relative size as the experimenter's. That is, if the experimenter revealed the location of the hidden food in his set under the larger of the two cups, the subject could only find their reward by indicating the

larger cup in their set, regardless of absolute size. Careful attention was given not to present correctly matching cups of the same absolute size. Rather, employing a strategy of searching under the cup of the same relative size was the only option that yielded reward. Each subject continued testing until he/she reached a significant criterion of 9 correct trials out of 11 consecutive trials in 2 sessions.

After reaching criterion on two-cup sets (with the exception of one animal), we introduced trials with sets of three cups. Sample and choice sets each included: largest, intermediate, and smallest size cups. Rewards were hidden under any one of the three cups in both the experimenter's and subject's sets. The correct strategy remained the same, requiring the animal to point to the cup in their set of the same relative size as indicated in the experimenter's set whether largest, intermediate, or smallest. Each subject continued testing until he/she reached a significant criterion of 9 correct trials out of 11 consecutive trials in 2 sessions.

Relational Matching with Distracter

All procedures in the first part of this phase were identical to those followed in relational matching, albeit the inclusion of a purposeful foil as one of the two choice cups in the four cup arrangement. In order to validate correct choices as the result of relational matching only and not one of absolute size, we utilized the cup of the same absolute size as the target sample as a distracter - the incorrect choice cup. For instance, if a reward were hidden under a size 6 cup in a sample set comprised of size 6 (larger) and size 1 (smaller), a size 6 cup would be included in the choice set as the smaller of the two; while it is identical to the sample cup under which the reward was hidden, it is not the same relative size and should be ignored.

In addition to two-cup trials, we also used three-cup sets in the second part of this phase. In three-item trials, the distracter cup was used as either of the two incorrect choices. Thus, if a

size 3 cup was the target and smallest of the experimenter's set, that size 3 cup would be included in the subject's set a either the intermediate or largest. All subjects continued testing until a criterion of 9 correct trials of 11 consecutive trials in 2 sessions was achieved.

Relational Matching with Distracter: Novel Transfer

All procedures for this phase were identical to those of relational matching with distracter except for the objects under which the rewards were hidden. Yellow stacking cubes replaced all black cups for this transfer test. Of special importance to the demonstration of analogical reasoning, generalization to novel stimuli can provide the necessary evidence for flexible use of the strategic rule rather than the possible employment of rote memorization.

Relational Matching with Distracter: Dissimilar Transfer

As a final transfer test, we utilized both sets of previously presented stimuli. Both black cups and yellow cubes served as sets for relational matching. Groups of three black cups could be presented as either the experimenter's or subject's set, while yellow cubes comprised the other set. For example, the experimenter hid the reward under the intermediate yellow cube in his set and the intermediate black cup of the subject's set. Employment of the correct strategy required using the relational size rule to match physically dissimilar objects from two completely different stimulus sets. All subjects continued testing until a criterion of 9 correct trials of 11 consecutive trials in 2 sessions was achieved.

Results

Matching-to-Sample

On the one-sample MTS task, all 3 chimpanzees met a criterion of 9 correct of 11 consecutive trials in 2 sessions within an average of 33 trials (Panzee – 21 trials; Sherman – 38 trials; Lana – 39 trials). No apparent side-biases or alternate strategies were observed.

On the physical match of a two-sample MTS task, all 3 chimpanzees met the same criterion in an average of 28 trials across 2 testing sessions. Again, no apparent side biases or alternate strategies were observed. See Figure 5.2 for a summary of trials to criterion.

Relational Matching

Two of three subjects met criterion on the relational matching task. Panzee met criterion after completing 54 trials. Sherman met criterion after only 42 trials, relatively consistent with his rate of acquisition on simple physical matching tasks. The third subject, Lana, completed more than 143 trials without meeting a criterion of 9 consecutive trials correct.

No side biases were observed. However, alternate strategies and consistent patterns of error were observed for two of three animals. Sherman's first strategy relied on relative position of the choice cups to the sample cups, rather than relative size. In 100% of the first 14 trials performed, Sherman chose the cup in his set that was in the same relative position as the sample cup. If the reward was revealed to be under the experimenter's right-side cup (from the subject's point of view), Sherman indicated for a search under the right-most cup in his set. Because of randomly assigned positioning of cups, this strategy cannot be attributed to proximity of choice cups to sample cups. In some trials, the leftmost sample cup was in closer proximity to the right choice cup (and vice versa). Within his 42 trials to criterion, 27 were chosen on the basis of a relative positioning within each set ($z = 1.7, p < .05$).

Panzee completed trials with chance accuracy in the first session of 33 trials ($z = 2.87, p > .05$). Like Sherman, Panzee significantly favored a relative position strategy ($z = 3.83, p < .05$); on 28 of 33 trials, she chose the cup in the same relative position as the correct sample, before switching to the intended relative size strategy.

The third subject, Lana, had no clear alternate strategies and performed at levels consistent with chance alone for 143 trials ($z = -.17, p > .05$). No other biases were observed.

Relational Matching with Distracter

Two subjects met criterion with two-item sets on the relational matching with distracter phase. Panzee completed 100% of the first 9 trials correctly. Sherman met the set criterion within 30 trials. Because Lana did not meet criterion in the previous phase, she was not tested on the same paradigm with distracters. No apparent biases or alternate strategies were observed.

In sessions including 3 cup sizes, all 3 subjects were tested and met criterion. Panzee and Sherman both met criterion within 46 and 53 trials respectively, a rate relatively consistent with acquisition in other phases. Panzee and Sherman both initially favored a relative position strategy. Panzee chose the cup of same relative position in 100% of the first 17 trials performed before switching to a consistent pattern of choice on relative size. Sherman perseverated on choice by relative position for 13 out of 13 trials before utilizing a relative size strategy.

Lana, who had not met criterion on any phase of the experiment involving sets of 2 cups, met criterion in only 26 trials in the 3-item relational matching with distracter.

Relational Matching with Distracter: Novel Transfer

All 3 subjects met criterion on this novel transfer test consisting of sets of yellow cubes. Panzee, Sherman, and Lana chose correctly on 9 of 11 consecutive trials in 2 sessions within totals of 32, 27, and 24 trials, respectively. No apparent side biases or alternate strategies were observed.

Relational Matching with Distracter: Dissimilar Transfer

All 3 subjects met criterion on the final transfer test with dissimilar sets of sample and choice stimuli. Panzee, Sherman, and Lana searched correctly on 9 of 11 consecutive trials in 2

sessions within totals of 29, 23, and 26 trials, respectively. No apparent side biases or alternate strategies were observed. See Figure 5.2 for a summary of trials-to-criterion data for all experimental phases.

Discussion

Three chimpanzees used conceptual size information about relations to successfully employ reasoning by analogy in a conceptually-mediated three-dimensional search task. Along with the results of one capuchin monkey (Kennedy & Fragaszy, 2008), this series of experiments with chimpanzees provides unique evidence of analogical reasoning in nonhuman primates without dependence on specialized token training. In addition, chimpanzees in the current study demonstrate a pattern of responding that, while not initially intended by the experimental contingencies, was nonetheless analogical in nature. Initial errors made in relational matching tests were almost entirely due to a search under cups that matched in relative position to the sample, rather than the intended cup of relative size. This predisposition for the utilization of an analogical strategy provides the first evidence that the so-called “analogical ape” (Thompson & Oden, 2000) is not merely capable of such reasoning with extensive specialized training, but perhaps reliant on relational or analogical rules in its daily behavioral repertoire.

In experiments with children and adult humans, researchers agree that surface similarities are the key to whether participants will employ analogy to solve a problem when not explicitly told to do so (Catrambone, 2002; Gentner, Rattermann, & Forbes, 1993). In addition, human participants are particularly distracted by surface similarities in analogous problems, even when they are unimportant (Ross, 1987). That chimpanzees avoided these purposely included distracters in the current study is worthy of further discussion. Since all stimuli presented were cups identical in every respect except for size, it is perhaps the case that surface properties were

quickly disregarded as a viable search dimension. Because structural similarities often present such confound in the employment of analogies, using less variable stimuli seems to present a distinct advantage for relational learning and provides insight for future studies.

Also sensitive to surface similarities and perceptual predisposition, Vonk (2003) demonstrated understanding by orangutans and a gorilla of second-order relations similar to requirements in the current study. Animals completed an identity vs. nonidentity relational matching-to-sample task akin to those that often present difficulty for non-apes. Importantly, all stimuli were drawn from a set of four simple geometric shapes filled with one of four colors. By controlling the number of dimensions on which the stimulus pairs and relations could vary, Vonk's (2003) task encouraged a strategy not reliant upon extensive perceptual processing. Like the current study, orangutans and a gorilla demonstrated rapid learning of the analogical rule perhaps due to a mediated shift in focus to more conceptual properties available in the test display.

The findings of the current study extend the results of Haun and Call (2009) investigating recognition training for relational similarity. Three groups of great apes (chimpanzees, bonobos, and orangutans) as well as 3- and 4-year old children were presented with a series of tasks involving a search for reward under sets of three cups in which a relational strategy resulted in success. Haun & Call (2009) presented the sets of cups on an inclined platform with one set at the top and another at the bottom for subjects to search amongst. In two conditions, correct choices of cups were physically connected to each other with plastic tubes or lines painted on the surface of the platform. In a final condition, no tubes or lines were present to connect correct choices, leaving a task highly analogous to the present study. While the first two conditions provide little evidence for true relational understanding and analogy completion, subjects

excelled in making correct choices, specifically in those trials in which correct choices were in the closest proximity to samples. Gorillas and orangutans showed less success in matching on the basis of relation when objects were connected only by lines and were farthest in proximity to samples. In the final phase of the experiment where objects were not connected, only chimpanzees performed above chance, albeit undetermined significance. Human children, bonobos, and gorillas were not presented with this variation of the task. One may argue that with physical connections between sample and choice objects, subjects in this series of experiments need not employ a relational strategy to succeed. Rather, physical connectedness and proximity seem a more parsimonious explanation. That chimpanzees had markedly more difficulty with the task when objects were not physically connected leaves uncertain their ability to use relational similarity to reason analogically. Thus, our current study is unique in providing such evidence.

In contrast to results from 3 of 4 capuchins from Kennedy and Fragaszy (2008), chimpanzees in our current study appeared to have no greater difficulty meeting criterion on relational tasks than physical matching-to-sample tasks (See Figure 5.3). Presenting physical matching tasks before those in which relational matches could have created an additional confound of the necessity to switch rules between tasks. That no deficits were observed when transitioning from physical matching to relational matching for both our chimpanzees and 1 of 4 capuchins (Kennedy & Fragaszy, 2008), it is likely that physical matching tasks (with which the chimpanzees in this study have extensive experience) facilitate parallel relational tasks.

While we observe less contrast between physical matching and relational matching in chimpanzees than Kennedy & Fragaszy (2008) found with capuchins, the most notable difference between ape and monkey performance is a reduction in the number of trials required to reach criterion for chimpanzees. One capuchin monkey reached criterion on tasks involving

relational similarity in an average of 150 trials (with more than 800 trials required for MTS training). With 54 trials, Panzee was the chimpanzee who required the most trials to reach criterion on any task requiring a relational match. Notably, this was also the first task requiring a shift from physical to relational matching. On average, the three chimpanzees in this series of experiments required approximately 34 trials to reach a criterion of 9 out of the last 11 consecutive trials correct in 2 consecutive testing sessions. Acquisition of the analogical rule in this case required roughly $\frac{1}{4}$ the number of trials on average for chimpanzees than a capuchin monkey.

A possible contributing factor for the success of the chimpanzees in the present study, as suggested by Thompson, Oden and Boysen (1997), is their generalized symbol-training history. Although these animals never received any symbolic training for referents relevant to the current tasks, we believe that symbols may provide a more generalized system by which animals can otherwise represent their world. With the use of symbols, external objects can be represented internally, allowing for the mapping of two iconically equivalent states in an analogy (Thompson et al., 1997; Premack, 1986). Future studies with completely symbol-naïve chimpanzees would provide the potential for comparison in possible rates of success.

Previous tasks suggest difficulty in identity/nonidentity RMTS tasks for several nonhuman primate species including monkeys and apes (Flemming et al., 2008; Thompson et al., 1997). The three-dimensional search task presented in the current study is perhaps more effective and applied for chimpanzees (and capuchins in Kennedy & Fragasy, 2008) given a higher degree of ecological salience. Consider a foraging scenario for a primate in which it must choose a site based on its size relative to the size of surrounding sites. It is likely that primates would learn the benefits of choosing the largest tree/site in its field of vision because it produces the highest gain.

In its next encounter with foraging sites, knowledge of relative size comparisons and the corresponding yield may be recalled. In the case of impending predators, one may also consider size relations in reverse preference: avoid the largest of visible predators. The rather spontaneous employment of analogies by chimpanzees in the current study may speak to application of the strategy in a more ecologically salient setting than in some previous studies.

Recognizing relations within a set appears almost trivial for both rhesus monkeys (e.g., Fagot et al., 2001; Flemming et al., 2007) and chimpanzees (see Thompson & Oden, 2000 for review), but the application of that relational knowledge between sets is hindered for some. Why? We suggest that in identity vs. nonidentity (same/different) tasks, there exists a confound between *within* and *between* set comparisons. For example, in traditional RMTS tasks, the question posed is “here is the *same* sample pair, now pick the *SAME* choice pair as the sample from either *same* or *different*.” In these tasks, subjects are required to apply the same concept in two conflicting ways. This added layer of difficulty in RMTS tasks may help to explain prevalent failures by non-ape species as well as the success of a capuchin monkey in the present size-relation three-dimensional search paradigm.

It is perhaps the case that the success demonstrated by chimpanzees in the current study along with the successful performance of other apes (for review, see Thompson & Oden, 2000; Vonk, 2003) and monkeys (Kennedy & Fragaszy, 2008; Spinozzi et al., 2003) in contrast to failure of some monkeys (Flemming et al., 2007) to succeed in the judgment of relations-between-relations may also be attributable to differences in experimental procedures. A paradigm shift for future studies toward less perceptually-dependent concepts may more fairly evaluate the analogical abilities of non-apes and allow for a more critical analysis of mechanisms involved from a comparative perspective based on what is truly required for analogy.

In conclusion, this study provides unique evidence for successful employment of reasoning by analogy by token-naïve chimpanzees on a task that is less grounded in perceptual features of stimuli (i.e. not based on identity/nonidentity relations). That chimpanzees so readily learn this analogical task and employ analogical strategies even when the reward contingencies of the task are not met suggests a predisposition for and deeper integration of analogical abilities with other areas of cognition and daily behavior than originally hypothesized.

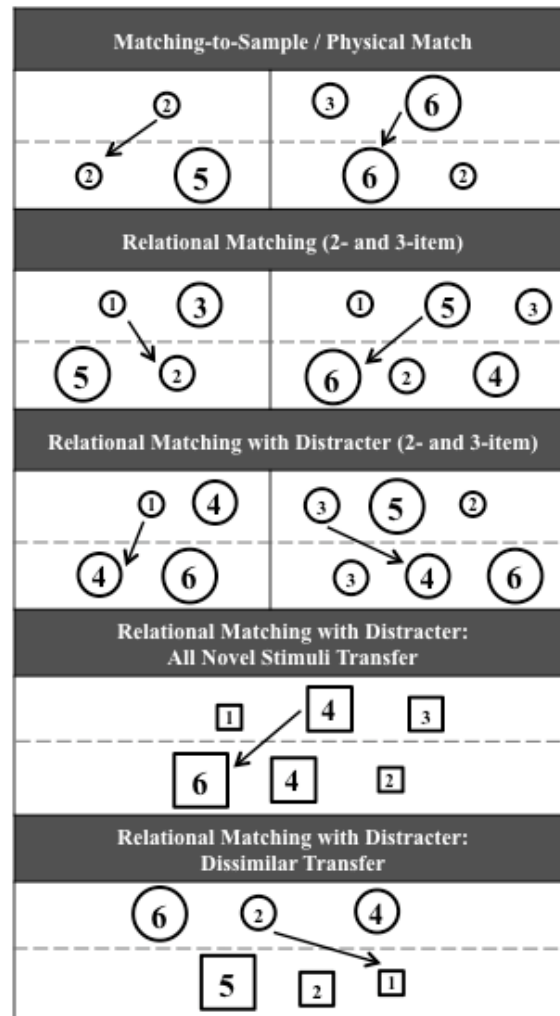


Figure 5.1. Rendering of trial types presented to chimpanzees. Numbered circles represent cups of an example absolute size. The top row in each phase represents the experimenter's set of cups; bottom row represents subject's choice set. Arrows connecting cups indicate correct matches. Squares represent cubes used for transfer tests. Not all images drawn to scale between phases.

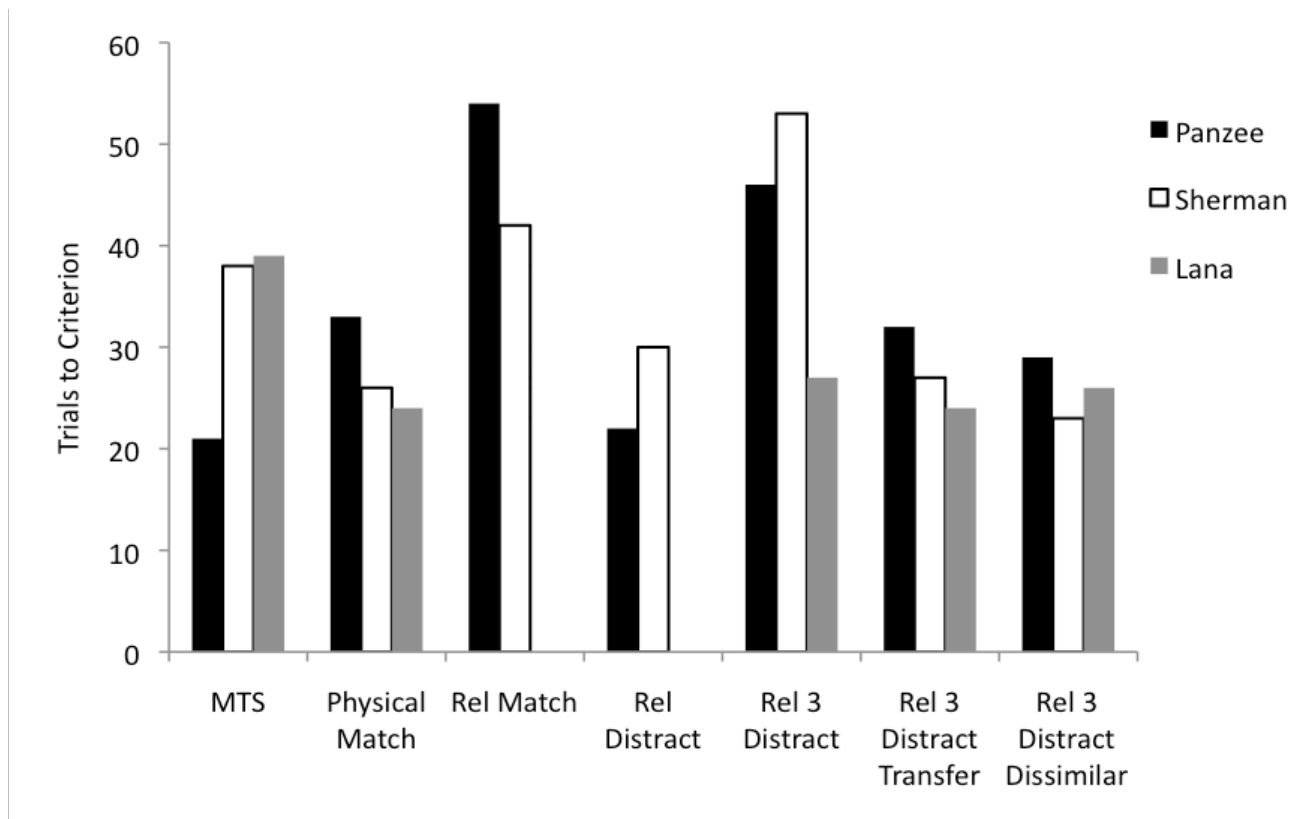


Figure 5.2. Number of trials required to reach criterion for each experimental phase. MTS = one-sample matching-to-sample; Physical Match = two-sample matching-to-sample; Rel Match = two-item relational matching; Rel Distract = two-item relational matching with distracters; Rel 3 Distract = three-item relational matching with distracters; Rel 3 Distract Transfer = three-item relational matching using all novel stimuli; Rel 3 Distract Dissimilar = three-item relational matching with novel stimuli used only in subject's set. Criterion not reached for Lana in relational matching and relational matching with distracter phases.

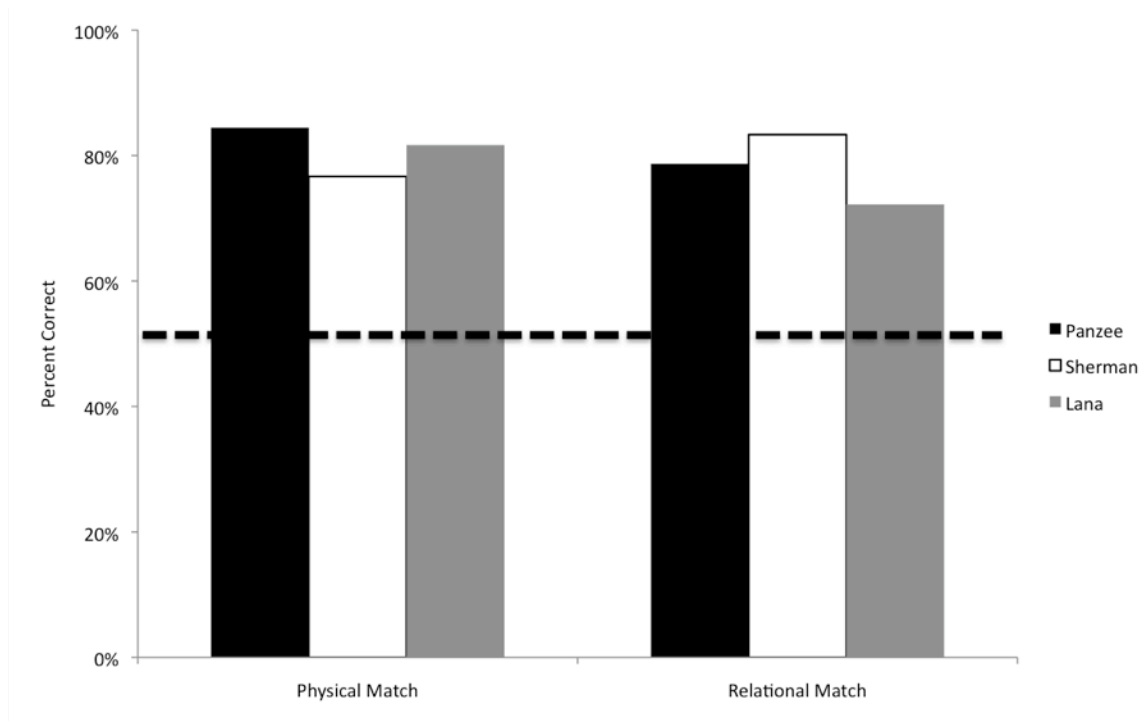


Figure 5.3. Summary across session types for all physical matching tasks (MTS and physical match) and all two- and three-item relational matching tasks (relational match, relational matching with distracters, three-item relational matching with distracters, three-item relational matching using all novel stimuli; three-item relational matching with dissimilar stimuli) for each animal.

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Chapter 6: Synthesis and Discussion

Comparative studies of the capacity for analogical reasoning have produced an important debate in the literature. I have argued here and elsewhere (Thompson & Flemming, 2008) that the difference between the cognitive operations of *same/different* discrimination and relational matching (analogy) is in fact one of degree rather than kind. Conversely, Penn, Holyoak and Povinelli (2008) remain firm in their case for the contrary. Rather than considering a computation of a higher degree for RMTS, Penn et al. (2008) attributed failure by monkeys to complete RMTS tasks to a cognitive difference of kind: a kind attributable to a specialized system of symbols for reinterpretation of relational concepts unique to humans. Whereas I understand their argument, I believe that the crux of our counter-argument was overlooked. With an abundance of recent evidence that similar symbolic systems exist in our nearest primate relatives (**Chapter 2**; Gillian, Premack & Woodruff, 1981; Harris, Gullledge, Beran & Washburn, 2010; Pepperberg, 2002; Savage-Rumbaugh, Rumbaugh, Smith & Lawson, 1980; Thompson & Oden, 1996; Thompson & Oden, 2000; Washburn, Thompson & Oden, 1997), why would it be that the mapping of relations still seems so difficult if Penn et al.'s (2008) relational reinterpretation (RR) hypothesis holds true?

The argument developed in this dissertation helps shed light on the answer: Whereas symbol systems can certainly facilitate reasoning by analogy, they are not the only modality through which the mapping of relations can be accomplished. Knowledge of relational concepts dependent entirely on contrast in perceptual variability (Fagot, Wasserman & Young, 2001), as Penn et al. (2008) suggest, seems implausible given the propensity of monkeys to discriminate *same* from *different* at the lowest level of contrast (**Chapter 3**). Additionally, even with a proto-

symbolic system in place (**Chapter 2**) rhesus monkeys still failed to complete a relational matching-to-sample task. Further, relational matching *can* be accomplished by the rhesus monkey with specific (perhaps attention re-directing) scaffolding in place (**Chapter 4**). Data from apes (**Chapter 5**) without any potential for confound with perceptual variability further implicates a more conceptual understanding as underlying reasoning by analogy in nonhuman primates, and in particular chimpanzees.

Penn et al.'s (2008) strict representational-only approach excludes nonhuman animals from analogical reasoning by definition, and this is counterproductive to a comparative psychological understanding of cognition. A more liberal view of analogy allows for the consideration of other mechanisms through which analogy can be accomplished. In fact, by more conventional definitions, analogy *need* not be accomplished by any certain modality (Gentner, 1989; Goswami, 1995; Leech, Mareschal & Cooper, 2008). In a more inclusive definition, one can establish a relationship by any means possible, so long as organisms are able to seek out and successfully find that same relationship among novel elements – a task that several species of nonhuman primates seem able to accomplish (**Chapters 4 & 5**; Fagot et al., 2001; Fagot & Parron, 2010; Gilliam, et al., 1981; Kennedy & Fragaszy, 2008; Spinozzi, Lubrano & Truppa, 2004; Thompson, Oden & Boysen, 1997; Vonk, 2003). Through a discussion of hypothesized accounts of the emergence of analogical reasoning, I will provide evidence that points to the existence of an ability to reason analogically or at least to analogical precursors that function in much the same way throughout the primate lineage.

Analogy: Just an extension of similarity?

With the consistencies between the mechanisms of conceptual and perceptual cognitive systems outlined earlier, and at length by Goldstone and Barsalou (1998), it should be clear that

the conceptual system is not only dependent upon but also likely emerged from the more basic mechanisms of perception. From a theoretical standpoint, the question then remains whether perceptual similarity and analogy are really similarity of a different kind, and if so what distinguishes them. Consideration of this possible distinction can be divided into a debate of *surface* versus *deep* similarity (Gentner, 1983) and *global* versus *dimensional* similarity (Smith, 1989).

A distinction between *surface* and *deep* similarity delineates physical from analogical similarity (Gentner, 1989). Surface similarities (physical attributes) give rise to generalizable concepts for the relations *same* and *different*. Deep similarity on the other hand refers to consistency on a level not attributable to physical similarities alone, but rather on a conceptual level, based on judgments of one's mental representations. It is noteworthy that these are contrasts in continua, not dichotomies (Gentner, 1989). The continuum on which analogy and physical similarity lie is one of the amount of overlap in physical attributes from featural to conceptual identity. With mere appearance giving rise to relational concepts, it stands to reason that a clear understanding for relational concepts then could give rise to a matching of relations, lying successively along the same continuum of similarity.

An alternative view of similarity analysis, one of *dimensional* and *global* similarity, makes clearer the consistencies as mediated by expertise in subject matter that more directly influence one's ability to generalize a similarity rule. Smith (1989) argued that differences in similarity are driven largely by knowledge about the stimuli involved. Dimensional similarity refers to that which is limited to known objects, based on any number of similarities inferred from the knowledge of those objects. Global similarity, rather, implies the application of some rule to entirely novel domains. This shift from domain-specific to domain-general is crucial for

consideration of reasoning by analogy, not unlike Gentner's (1988) description of a relational shift with human development that also emphasized an importance of expertise in knowledge for domain-specific attributes.

With the difficulties in relational matching by rhesus monkeys observed in **Chapters 2-4**, it would seem that the gap between simple perceptual similarities and analogy is quite large for nonhuman primates. Large amounts of training may be required to make the shift from domain-specific (*surface, dimensions*) to domain-general (*deep, global*) similarity. For instance, it could be the case that difficulties in analogical reasoning by animals are eased by increasing exposure to new instances upon which the same rules must be applied. Whereas more rapid learning of *same* and *different* concepts is typically observed with fewer training instances (Cook, 2002), generalizability and application of those concepts more exemplary of true conceptual understanding is observed with exposure to larger stimulus sets over a longer time span (Katz, Wright & Bachevalier, 2002). Given that gradual learning curves rather than sharp acquisition curves were observed in pigeons and several primate species in *same/different* discrimination learning (Katz et al., 2002; Blaisdell, 2005; Fagot et al., 2001), it stands to reason that there may be significant effects of exposure in generalization for first- and second-order relational concept learning. Although the gap from similarity (domain-specific) to analogy (domain-general) seems wide, the necessary shift seems bridgeable given experience with which to see the forest through the trees.

Analogy as high-level perception

In the case of multiple-icon arrays used for relational matching-to-sample tasks (Fagot et al., 2001), why is it that successful matching is often not considered exemplary of analogical reasoning (Cook, 2002; Penn et al., 2008)? Influence from bottom-up processes of perception

should not be discounted as informative to relational mapping. As adults, we do not typically rely exclusively on bottom-up processes for analogical mapping (Gentner, 1989), favoring instead structured representations and elaborate terms of relatedness (Leech et al., 2008).

Whereas top-down and bottom-up approaches may seem quite different, they often produce the same outcomes.

One theory of analogy that supports reasoning by detection of perceptual variability is a view of relational matching as high-level perception. French and colleagues (Chalmers, French & Hofstadter, 1992; French, 1995; French, 2000) provided an account for high-level perception that describes analogy as driven largely by bottom-up processes involved in the initial stages of perception. This transition from low-level (retinal input) to high-level perception begins where *concepts* play an important role, starting with object recognition and ending with relational concept acquisition. Another important facet of high-level perception is that it is extremely flexible. A given set of input data may be (and perhaps should be) perceived in a number of different ways, dependent upon context or domain of knowledge. This last point should not be overlooked, as generalizability is tantamount to the mapping of relational concepts in analogy. Chalmers et al. (1992) stated that for high-level perception to be guiding behavior, extraction of some level of meaning or true conceptual understanding is required, although they remained vague on the exact nature of this meaning, suggesting that a mental representation of said concept should be instantiated in some way.

Although they did not discount the influences of belief, goals or external contexts in which previous learning may have taken place (top-down processes), French and colleagues argued that early application of analogy in human children and even adults can be solved by high-level perception alone. From a comparative perspective, this same logic could apply for

nonhuman animals, given the significant role of entropy and other perceptual measures involved in relational concept learning (*Chapters 2-3*; Wasserman & Young, 2010), wherein the line between that which is perceptually- versus conceptually guided is blurred. Although relational matching-to-sample tasks that involve multiple icon arrays (i.e., Fagot et al., 2001) are exemplary of relational mapping, their validity as measures of understanding of analogy is argued because of a possible reliance on perceptual measures alone.

Findings from *Chapters 2* and *3* confirm that monkeys have a firm understanding of relational concepts. Both rhesus and capuchin monkeys used entropy contrast (perceptual variability detection), albeit to differing degrees, to learn the relational concepts for *same* and *different*. That rhesus monkeys subsequently failed to match these same relations presents an argument against analogy as computable by high-level perception alone. Whereas their knowledge of relations may likely be attributable to high-level perceptual skills, the mapping of one relation to another seems guided by another mechanism. In the case of relational matching-to-sample tasks, although the animal may use higher-level perception within each pair of stimulus elements, they likely are not applying that same perceptual mechanism to the entire visual pattern displays (3 pairs). If analogy could be explained by high-level perception alone, we would expect rhesus monkeys more easily to move from relational discriminations to relational mapping. The disconnect, then, seems in their ability to generalize further this relational information, suggesting a more domain-specific restriction on learned relational information.

Analogy as relational priming

In Leech et al.'s (2008) theory of analogy, reliance on perceptual abilities alone was addressed from a slightly different perspective: analogy as relational priming. Leech and

collaborators argued against an approach to analogy that involves structured representations and structure mapping. Rather than requiring additional mechanisms (higher-level reasoning), analogies were seen to grow out of the normal functioning of memory with one relation priming the next. In this way, analogy emerged as a byproduct of spreading activation. Leech and colleagues believed consideration of an implicit mapping approach was warranted given that there was no difference between response times for participants to complete the mapping of relations and subsequent analogical transfer (Ripoll, Brude & Coulon, 2003).

Additional evidence for relational priming in problems of analogy can be gleaned from the results of experiments with both human children (Gentner, 1988) and adults (Schunn & Dunbar, 1996). In both tasks, experimental participants first read one type of story and solved a problem proposed afterward with similar underlying structures as material from the story. Control participants did not read the story, but were prompted to solve the same problem. Participants in the experimental condition were significantly more likely than control participants who had not read the first story to propose an appropriate solution to the problem. Surprisingly, none of the experimental participants, neither children nor adults, made mention of the first story or similarities in resolution, even when prompted for an explanation of how they went about solving the problem. Accordingly, Schunn and Dunbar (1996) concluded that the behavior of their participants was implicitly informed due to priming.

With an absence of evidence for perceptual or conceptual priming effects for rhesus monkeys (Basile & Hampton, 2010), failure to match relations in *Chapters 2* and *4* leaves open the possibility for a model of analogy as relational priming. That priming effects are not often observed in monkeys may help to explain why, if we are to consider analogy as relational priming, they are not primed by the sample relation to inform their selection of the correct choice

relation, giving way to relational matching. Whereas the current evidence does not clearly provide support for a hypothesis equating analogy with relational priming, it is perhaps the case that comparative studies with monkeys cannot support nor deny this hypothesis, due to a lack of evidence for priming in general. If perceptual or other conceptual priming effects were commonly observed in monkeys, failures to match relations by monkeys in *Chapters 2* and *4* would further suggest that analogy is not simply explained by relational priming; the presentation of one relation does not prime selection for the correction choice relation.

The conceptual feel reexamined

The distinction between processes that may be implicit in nonhuman animals and explicitly reasoned by human subjects does not necessitate a difference of kind for the behavioral outcome. In *Chapter 4*, by using what was referred to casually as a conceptual feel, rhesus monkeys successfully matched relational concepts for *same* and *different* in one of the few demonstrations of analogical behavior by a non-ape. Suppose as in the case of the aforementioned examination of implicit relational priming in humans (Schunn & Dunbar, 1996), the choices by monkeys finding success in a relational matching-to-sample task in *Chapter 4* with differential scaffolding in place were not explicitly guided. Lending further support to an implicit judgment of relations-between-relations, the monkeys in this task did not transfer their supposed generalizable matching rule to subsequent conditions lacking differential outcomes. If their judgments were explicitly made, why then did they not retain these rules for application in future sessions? Monkeys finding success with sufficiently bold differential outcomes indeed may not have discerned the rules for matching explicitly, but nonetheless gleaned an implicit hedonically-guided gist of task demands.

Hedonic valence and differential expectancies created by differential outcomes could serve as a mechanism through which successful choice behavior was accomplished. Berridge and Robinson (2003) discuss hedonic expectation as a form of cognitive incentive that allowed for the emergence of more goal-directed strategies. In turn differential hedonic valences are produced from differential outcomes. With hedonic valence instantiated, a search between two alternate choice pairs (also hedonically enhanced) and animals' choice behavior is guided more simply by the matching of hedonic states. The magnitude of reward and punishment in the *both* condition of **Chapter 4** provides a sufficient and adequate 'cognitive incentive' to compensate for the increased cognitive cost/load of executing the series of computational steps requisite for identifying the correct choice in the RMTS task as suggested by Thompson & Oden (1996). That the relational matching by monkeys in **Chapter 4** was not sustained without differential outcomes further suggests that the hedonic cognitive incentives established were the driving mechanism through which choice behavior was independently guided. Thus, although the monkeys were not mapping one relation to another via conceptual reinterpretation (i.e., symbols) they were able map one hedonic state instantiated by a relation to another.

Motivation

An alternate explanation for successful completion of the relational matching task by rhesus monkeys is an overall increase in motivational state. As described above, a system of differential rewards and punishments in the RMTS task likely initiated the emergence of differently valenced expectancies for relational pairs. Although generally posited to be driven by the hedonic value of the reward, heightened motivation alone may produce enough cognitive incentive for increased attention to meet task demands (Astley, Peissig & Wasserman, 2001). The role of motivation for monkeys in a seemingly difficult task with irregular reinforcement

caused by incorrect choices can be substantial (Beran, Washburn & Rumbaugh, 2007). Monkeys often develop response biases on computerized tasks from which success (optimal payoff) cannot be achieved (Flemming, Beran, Thompson, Kleider & Washburn, 2008). Motivation, heightened by an increase in reward, can in turn activate goal-directed behavior. One control condition in the task in *Chapter 4* attempted to address a more generalized role of motivation and effect of reward magnitude alone. In the equalized outcome with a magnitude of 4:1 base reward, the effect of mere reward magnitude was assessed and found to be not significant in inducing successful matching of relations. If however, heightened matching performance was observed in this condition, a generalized heightened motivational state might be implicated for relational matching. Thus, a hypothesis for general heightened motivation is not supported by the data from *Chapter 4*.

Attention

With a more general effect of motivation likely not implicated for reasoning by analogy, a better explanation is that of attention as a mediating factor in motivation's influence on reasoning. It stands to reason that differential rewards and punishment in this task did not so much influence generalized motivation as they increased the level of stimulus examination, encouraging a relational shift that allowed for the emergence of relational matching. As previously reported (Fagot et al. 2001; Fagot & Parron, 2010; Flemming et al. 2008) relational matching is not only difficult for monkeys to attain, but also perceptually grounded. Thus, it seems likely that a required conceptual shift in attention, not unlike the relational shift described by Gentner (1983), may be dependent upon motivational incentive.

It is assumed that a monkey's default attentional focus under nondifferential reinforcement and punishment is on the perceptual properties (predicates) of individual stimuli

instantiating the experimental stimulus pairs (i.e., Thompson & Oden, 2000). There is good independent evidence that monkeys focus on the local properties of stimuli grouped together and, more so than chimpanzees, find it difficult to focus on the more global structures they instantiate (De Lillo, Spinozzi, Truppa & Naylor, 2005; Deruelle & Fagot, 1998; Fagot & Deruelle, 1997; Fagot & Tomanaga, 1999; Spinozzi, De Lillo & Truppa, 2003). Thus, a generalized motivational incentive system guiding choice behavior may operate to shift and maintain the animals' attentional focus from the local features of the individual stimuli within pairs to the more global relational properties of the stimulus pairs.

Another level on which attention may operate in a relational matching task is in the ability perceptually to separate the elements of paired stimuli. Baboons (Deruelle & Fagot, 1998; Fagot & Parron, 2010) and rhesus monkeys (Hopkins & Washburn, 2002) tend to process compound stimuli locally, being largely driven by the distance between them. This is critical in consideration of stimulus arrangement in the relational matching-to-sample task where distances are great between pairs, but not within, thus encouraging comparison of grouped stimulus conglomerates, rather than a comparison between pairs distinctly composed of two elements each. Increased attentional focus to the stimulus elements may allow for a global processing both within and between the pairs. Thus, attention is critical in encouraging the proper structuring of the task as one of a comparison between pairs of stimuli likely not present without motivational incentive by differential outcomes. Improper structuring then is a result of a binding failure (Treisman, 1991) wherein relations are not the most salient feature.

The existence of species differences in perceptual processing provides support for the differences observed in propensity for relational matching between rhesus monkeys and chimpanzees. Hopkins and Washburn (2002) reported not only that rhesus monkeys exhibited a

local-to-global approach to processing visual stimuli (where global processing is relevant to relational concept extraction), but also that, like humans (Fujita & Matsuzawa, 1988), chimpanzees employed global-to-local processing strategies (Hopkins & Washburn, 2002). A global approach to visual processing brings to the forefront of a relational matching-to-sample trial the relational concepts instantiated by pairs of elements, rather than features of individual stimuli. This important difference in approach for chimpanzees affords a seemingly default analogical mechanism whereby relational matching is observed quickly and without difficulty (*Chapter 5*) relative to rhesus monkeys (*Chapter 4*).

For rhesus monkeys, a local-to-global approach in visual processing results in a focus on perceptual features of stimuli, disrupting the formation of relational concepts and certainly the recognition of relations-between-relations. Fagot and Parron (2010) attributed previous failures on relational matching-to-sample tasks by rhesus monkeys to spatial discontinuity of stimuli. Because of the distance between stimuli within pairs in traditional relational matching tasks, Fagot and Parron (2010) suggested that *same* and *different* relational concepts simply were not formed, rendering the subsequent mapping of those relations impossible. Successful performance by baboons in recent experiments with compound stimuli provides support for this argument (Fagot and Parron, 2010), but does not discount the finding that other factors (e.g. differential outcomes) also provide means through which monkeys form relational concepts and subsequently match relations. Rather, the proper structuring of the task is accomplished even in light of these spatial discontinuities through other means of focusing attention (*Chapter 4*).

Why analogy still seems so difficult

Analogical reasoning is clearly a multi-faceted ability requiring the selection of information that is relevant and rejecting the information that is not. Richland, Morrison and

Holyoak (2006) took a somewhat different approach to why analogy is often perceived as difficult in that it is cognitively demanding and likely requires a significant degree of executive function to integrate a multitude of relations. Thibaut, French and Vezneva (2010) favored Richland et al.'s (2006) argument over other accounts that implicated domain knowledge as driving the relational shift for analogy in human children (Gentner, 1988; Goswami & Brown, 1990; Rattermann & Gentner, 1998). In large measure, the Richland et al. (2006) hypothesis excels because specific cognitive mechanisms involved in *the shift* are not specified and not easily quantified due to differences across domain knowledge. The mechanism, according to Thibaut et al. (2010) is one of executive function brought about by competition between relations and attributes of objects involved. With age, and presumably greater executive control, Thibaut et al. (2010) concluded that children were increasingly able to use analogy to solve non-semantic relational matches based on a variety of shape transformations. Younger children seemed to lack control of inhibition (one of the primary components of executive functioning) in both responding to and searching of the entire solution space for correct alternatives, implicating a continuum of executive control.

Tests of executive control in rhesus monkeys reveal even larger deficits in inhibition relative to humans. For example, macaques manifest larger Stroop effects, or disruptions from irrelevant but prepotent competing response cues that could not be inhibited, than do humans when both species are directly compared (Washburn, 1994). To the degree that a task requires increasing levels of executive control, monkeys tend to have decreasing levels of success. Attention-shifting, task-switching, planning, monitoring, and response inhibition testing paradigms are measures of executive function that when presented to monkeys implicate not only behavioral but also functional differences in the prefrontal cortex relative to humans (Stoet

& Snyder, 2003). In relational matching-to-sample, within- and between-pair stimulus evaluations require independent computation before choice selection. In addition, an attentional shift from perceptual features to relational-conceptual focus is required. With increased difficulty and cost in response inhibition and attention shifting, it stands to reason that for monkeys, relational matching tasks requiring a high degree of executive function will be especially demanding and likely require other means through which attentional focus can be achieved (i.e., differential reward scaffolding, *Chapter 4*).

Representation and the language “requirement”

Without any explicit token-training as once implicated necessary for analogy (Premack, 1981), three monkey species have recently been shown to pass tests of relational matching-to-sample with or without other specialized scaffolding in place (*Chapter 4*; Fagot et al., 2001; Fagot & Parron, 2010; Kennedy & Frigaszy, 2008; Spinozzi et al., 2004). What then is the role of language and/or token training in analogy? Without question, the use of language gives way to a broader generalization of the analogical rule in humans (Gentner, 1989; Holyoak & Hummel, 2001; Premack & Premack, 2010). In fact, one of the main reasons for consideration of the role of language in analogy was their co-emergence throughout development (Goswami, 1995; Piaget, 1977). A collection of evidence that token- and symbol-trained chimpanzees succeed in reasoning by analogy (usually utilizing these very same tokens within exemplary tasks) does not implicate language as a sole contributing factor. Rather, it is at least suggestive that symbols and representation may expedite the realization of a problem as solvable by analogy, at least in humans and chimpanzees capable of learning specialized symbols systems.

Evidence from the studies included in this manuscript do not lend particular support to a role of symbols or language in reasoning by analogy, unless we are to assume that any failures to

match relations are due to a failure of representation by symbol systems. Data from the study provided in Appendix directly addressed the potential facilitative and confounding roles of meaning for nonhuman animals. Whereas the meaningfulness of stimuli seemed to have no effect on the ability of rhesus monkeys to match relations, the representational value instantiated by meaningful stimuli proved a hindrance for one chimpanzee, but assistance for another chimpanzee, making conclusive determination of the role of meaning and/or language in particular difficult.

By conventional definition, and of importance in defining this or any other cognitive construct, mechanisms involved in reasoning by analogy require the representation of relations. This is the crux of Penn et al.'s (2008) argument that, by definition, analogy requires the reinterpretation by mental representation of relational concepts via symbols (see also Holyoak & Hummel, 2001). This stance by definition limits the study of, or even consideration of capacity for analogy to animals without evidenced symbol systems.

All of the above discussion of analogy then seems for naught if relational reinterpretation cannot be sufficiently evidenced in any nonhuman animal. Clearly I disagree with this claim of Penn et al.'s (2008) in light of evidence from **Chapter 2** that monkeys that are actually capable of relational reinterpretation (at least to a minimal extent) subsequently fail the RMTS task. Penn and colleagues' proposed difference in kind then cannot hold true, as Penn et al. (2008) themselves perhaps inadvertently admitted when they noted that the representation of a relational concept for animals may simply not be strong enough to operate in the same way as it may for humans. This continuum of representation then should implicate a difference in degree for the re-encoding of relational concepts. Throughout this manuscript, I have extended this logic to analogical reasoning, arguing that the analogical precursors observed in nonhuman animals show

sufficient evidence for a claim of cognitive continuity and emergence of analogical reasoning within the primate lineage.

Emergence of analogical reasoning

Whereas evidence for analogical reasoning in species other than humans is sparse and controvertible, precursors to reasoning by analogy in nonhuman primates presented here add to the growing body of evidence in support of an emergent theory for analogical reasoning. In Rumbaugh's (2002) account of rational behaviorism, emergents are defined as behaviors not attributable to classical or operant conditioning, but rather to "integrative processes" in cognition (p. 9). Emergents are new behaviors or capabilities such as those attributed to insight by Köhler (1925). Reasoning by analogy is one such emergent behavior that exemplifies the important shift in learning processes from associative to relational. Another characteristic of emergent behaviors in Rumbaugh's (2002) account is a positive correlation between an animal's relative cranial capacity and its propensity for the emergent capability. Evidence provided in this manuscript finds itself in accord with this posited relationship. Limited by evidence from only four primate species and an unstandardized measure of analogy, a general trend nonetheless exists from capuchin and rhesus monkeys to chimpanzees and humans whereby increases in propensity for analogical reasoning skills and/or analogical precursors is observed.

The future of analogy for comparative psychologists

With several hypotheses outlined illustrating the causes of our analogical paradox in nonhuman primates (see Table 6.1), there is great opportunity for comparative psychologists investigating both the paradox and pervasive nature of analogy throughout the animal kingdom. In light of evidence for and meaningful failures in relational concept acquisition and judgment of relations-between-relations provided in this dissertation, future investigations of analogical

Table 6.1
Summary of discussed hypotheses in analogical reasoning for nonhuman primates

<u>SUPPORTED</u>	<u>Evidence</u>
1. Analogy as an Emergent	<i>Chapters 2-5, Appendix</i> Analogy is not attributable to S-R learning. A trend of increasing ability to reason analogically with recency of common ancestor is observed.
2. Local-to-global attentional shift	<i>Chapters 4 & 5</i> Chimpanzees with global-to-local visual processing match relations with relative ease. Attention of monkeys must be shifted by differential scaffolding.
3. Executive function / control of inhibition	<i>Chapters 2 & 4</i> Monkeys lacking control of inhibition cannot succeed on a 2-item RMTS task that requires the inhibition of a local/perceptual predisposition.
4. Implicit judgments based on hedonic valence	<i>Chapter 4</i> Monkeys succeed on the RMTS task only with differential outcome scaffolding in place.
<u>DISCOUNTED</u>	<u>Evidence</u>
5. Relational reinterpretation (<i>RR</i>) via symbols (Penn et al., 2008)	<i>Chapters 2 & 5, Appendix</i> Monkeys with an understanding of symbols failed to succeed on RMTS tasks. Chimpanzees, albeit a history of generalized symbol use, succeed on a relational matching task not employing symbol use. Further, chimpanzees show mixed results on tasks despite the inclusion of symbolic stimuli.
6. Analogy as relational priming	<i>Chapters 2-4</i> Monkeys clearly acquire S/D relational concepts. If they were primed by these relations, they could be successful in RMTS tasks without additional scaffolding. <i>Caveat:</i> There is little evidence for priming effects in nonhuman primates.
7. High-level perception	<i>Chapters 2-3</i> Monkeys may use high-level perception to learn relational concepts but subsequent failure on RMTS tasks indicates that they likely do not apply this same mechanism to problems of analogy.
8. Generalized motivation	<i>Chapter 4</i> With heightened equalized incentive for correct trials on RMTS, monkeys failed to succeed. Monkeys only succeeded on RMTS trials in the experimental condition offering differential rewards.

reasoning should continue to recognize the posited perceptual predisposition of monkeys. Those studies not confounded with entropy as a controlling factor in relational matching will provide the best insight into the nature of representation in reasoning by analogy.

Studies in recent years (i.e., Fagot & Parron, 2010; Fagot et al., 2001) as well as those included in this dissertation have largely attempted to outline the difficulties that monkeys face in the mapping of one relation to another. In a more optimistic light, researchers may choose to shift the focus of their attention to applications of problem-solving by analogy wherein monkeys are more likely to find success. For instance, it is perhaps the case that analogical relations are simply more salient in other domains such as social hierarchy organization. For example, individuals able to understand their role in relation to individuals within a hierarchy (e.g., matriline) may greatly benefit from mapping those relationships from one matriline to another to avoid interactions detrimental to their survival. By examining new applications for analogical reasoning in nonhuman animals (all the while recognizing that these observations may not be completely domain-independent) the willingness of researchers to attribute these skills may continue to broaden, along with our definition of analogy in comparative psychology.

Prior to the work included in this dissertation project, the dominant view by comparative psychologists of analogical reasoning in nonhuman primates was one of dichotomy between apes (including humans) and monkeys: the distinction between the *analogical ape* and *paleological monkey* (Thompson & Oden, 2000). Whereas evidence for analogy proper by representational reinterpretation in monkeys is sparse and debated, the gap between that which is analogic and paleologic has been narrowed by the studies presented here. In conclusion, the studies in this dissertation provide further evidence of the potential cognitive mechanisms involved in

analogical reasoning for nonhuman primates. Several included studies outline meaningful failures that in part help to explain patterns of emergence of this skill along the primate lineage. Representation of relational concepts important for analogy proves difficult for rhesus and capuchin monkeys without the ability to rely on a greater amount of perceptual variability, implicating a perceptually-bound predisposition in problem-solving (*Chapters 2-3*). Like human children, this shift in attention from perceptual features to abstract concepts for employment in relational matching is again difficult, but not impossible given cognitive incentive in the form of differential outcomes to refocus attention on conceptual properties (*Chapter 4*). Finally, chimpanzees, unlike monkeys, appear more apt to reason by analogy, perhaps due to more default conceptual focus (*Chapter 5*). Taken together, these studies provide an account for the emergence of analogical reasoning skills throughout the primate lineage in contrast to views regarding analogy a hallmark of human intelligence.

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APPENDIX

What meaning means for same and different: Analogical reasoning in humans, chimpanzees, and rhesus monkeys⁸

Abstract

Thus far, language and token-trained apes (e.g. Premack, 1976; Thompson, Oden, & Boysen, 1997) provide the best evidence that nonhuman animals can solve, complete, and construct analogies, thus implicating symbolic representation as the mechanism enabling the phenomenon. In this study, we examined the role of stimulus meaning in the analogical reasoning abilities of three different primate species. Humans, chimpanzees, and rhesus monkeys completed the same relational matching-to-sample (RMTS) tasks with both meaningful and nonmeaningful stimuli. This discrimination of relations-between-relations serves as the basis for analogical reasoning. Meaningfulness facilitated the acquisition of analogical matching for human participants, whereas individual differences among the chimpanzees suggest that meaning can either enable or hinder their ability to complete analogies. Rhesus monkeys did not succeed in the RMTS task regardless of stimulus meaning, suggesting that their ability to reason analogically, if present at all, may be dependent upon a dimension other than the representational value of stimuli.

Keywords: MEANING, REPRESENTATION, SAME/DIFFERENT, ANALOGICAL REASONING, PRIMATE

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Analogical reasoning, Halford (1992) argued, is the mechanism that allows for conceptual thinking, including logical inference. Knowledge about analogies forces explicit expression of conceptual knowledge, unlike simple discriminations that rely on implicit types of conceptual knowledge (Premack, 1976). In an analogy, a relationship must be established between the first two elements in the series (i.e. the base relation). Then, and only then, can one continue to the second set of elements (i.e. the target relation) and seek the same relation instantiated in the base (Genter, Rattermann, & Forbes, 1993; Thompson & Oden, 2000). If one matches two abstract relations, one has in essence recognized the analogical equivalence of relations.

Evidence of this ability is very rare in nonhuman animals, although the chimpanzee, Sarah, provided perhaps the best evidence of analogical reasoning (Gillan, Premack & Woodruff, 1981; Premack, 1983; Oden, Thompson, & Premack, 2001). Sarah was given a variety of analogical reasoning problems using arrays of meaningful plastic chips of different colors and shapes. Two tangible plastic objects that varied on one dimension (color, shape, or size) were placed to the left of a center chip which signified the concept *same*. This plastic chip with specialized symbolic meaning seems to be the impetus by which Sarah was capable of judging the relations between those relations. To the right of the *same* symbol was placed only one object. The task thus required the chimpanzee to perceive the relationship between the shapes on the left and recreate its analog to the right of the center chip. Not only did Sarah complete the task with flat geometric shapes, but she also was successful when the items presented were everyday three-dimensional objects (Gillan, Premack, & Woodruff, 1981).

Whereas it is often difficult for humans to describe identity/nonidentity relations, for which nonhuman primates possess some knowledge, without using the words *same* and *different*,

these abstract concepts have no linguistic prerequisites (Premack, 1976). These words can be applied to objects that themselves do not have names. Moreover, in relation-level problem solving, the names of the objects are irrelevant. Rather, the relation *between* the objects is the only relevant information. In relational matching tasks, an individual must abandon ordinary matching entirely and move to a different level of problem solving--the relational level (Premack, 1986; Thompson & Oden, 1996).

Premack (1976, 1983, 1986) suggested that, at least in the case of abstract relations, acquisition of conceptual knowledge depends upon language. Accordingly, it should come as no surprise that while language-naïve nonhuman animals show varying degrees of perception-based conceptual knowledge, they lack the capacity to understand abstract concepts such as *same* and *different* to the same extent as humans understand them (Premack, 1983, 1986; Thompson, 1995; Thompson & Oden, 2000). Symbolic representation of relations has further been implicated as the main mechanism responsible for the judgment of relations-between-relations—that is, second-order relations (Premack, 1976, 1983; Thompson & Oden, 2000).

As Thompson & Oden (1996, 2000) posit, to complete a relational matching-to-sample problem successfully, participants must recognize the relationship between the members of each pair as the critical aspects of the problem. How might one go about recognizing these relations? Acquisition of concrete symbolic tokens of otherwise abstract relationships may be the necessary (and perhaps sufficient) component to any relational match-to-sample task (Oden, et al., 2000). Thompson, Oden, and Boysen (1997) hypothesized that the judgment of relations-between-relations is made possible by an animal's representational capacity to re-encode abstract relations into iconically equivalent symbols. They presented adult chimpanzees with a Relational matching-to-sample task after they had learned to choose a heart-shaped token when presented

with a pair of identical objects and to choose a diagonally shaped token when presented with a nonidentical pair of objects. In the RMTS task, the chimpanzees viewed paired random junk objects as identical or nonidentical sample pairs and pictorial paired stimuli on a touch screen as the target choice stimuli. The goal was to indicate the target that conveyed the same relation between the objects as in the base sample. Four of five chimpanzees spontaneously judged the conceptual equivalence of relations-between-relations in the absence of the symbolic tokens. The fifth chimpanzee differed in his learning history; unlike the other chimpanzees, he was naïve with respect to both numeric problem solving and symbolic token training. Therefore, it seems that this experience with symbols may have played a functional role in the acquisition of abstract concepts in these chimpanzees. Thompson and Oden (1996) suggested that the critical role of these symbols was to provide animals with a concrete icon for encoding a propositional representation that is otherwise abstract. Thompson et al. (1997) also suggested that conceptual-relational matching is akin to covert symbol matching. It should follow then, that such symbolic training produces a system for universal computation (Clark & Thornton, 1997).

Can abstract relations be labeled without symbolic representation? If the answer to this question is “no,” then we should not be surprised by Premack’s (1983) suggestion that participants, human or nonhuman, cannot complete a relational matching task without extensive language training. However, if effective labeling for relational information can be accomplished without language *per se*, and in particular, symbolic representation, then we should expect that language-naïve nonhuman species could also succeed on tasks requiring analogical reasoning, if they have the truly relevant cognitive mechanisms necessary for such reasoning.

Acquisition of, and discrimination between, abstract relations has been investigated in several species of old-world monkeys. Fagot, et al. (2001), for example, demonstrated that at

least two baboons had marked difficulty with a relational identity/nonidentity matching-to-sample (RMTS) task with multiple icons. Multiple item displays were used as stimuli in a matching-to-sample task. One stimulus array (composed of 16 or fewer identical or nonidentical items) served as the sample. One choice pair was composed of identical images (but different from any of those present in the sample pair) and the other was made of numerous images that differed physically from each other. Baboons were required to choose the array that matched the relation (either same or different) of the sample array. Baboons completed the task successfully until stimulus arrays contained 4 or fewer items, providing evidence that entropy detection most likely underlied same-different discrimination abilities (Fagot, et al., 2001). Thus, the relational matching strategy in this task was more perceptually bound.

By contrast, some judgments of identity are conceptually bound. Baboons also proved proficient in the judgment of conceptual identity. Bovet & Vauclair (2001) trained baboons to discriminate between food and nonfood stimuli. In tests of conceptual matching, baboons were able to identify pairs of food or nonfood items as same or different based on their conceptual relationships. For instance, if one apple and one banana were presented, baboons responded by pulling the rope indicating same because they both belong to the food category. Importantly, those judgments, in contrast to ones made by baboons in the Fagot et al. (2001) study, could not be made on the basis of physical similarities because “sameness” in that task required that baboons generalized amongst different items within a category. In addition, these types of discriminations are exemplary of first-order relations only, as opposed to second order relations as outlined by Thompson & Oden (2000).

Flemming, Beran, and Washburn (2007) investigated the role that entropy measures, discriminative cues, and symbolic knowledge play for rhesus monkeys in the acquisition of the

concepts of *same* and *different* in a computerized relational matching-to-sample (RMTS) task. After repeatedly failing to discriminate relations between pairs of stimuli in a two-choice discrimination paradigm, monkeys rapidly learned to discriminate between 8-element arrays. Subsequent tests with smaller arrays, however, suggested that, although important for the initial acquisition of the concept, entropy is not a variable on which monkeys are dependent. Not only did the rhesus monkeys choose a corresponding equivalent relational *pair* in the presence of a discriminative cue, but they also chose the cue itself in the presence of the relational pair--in essence, labeling those relations. Subsequent persistent failure in the judgment of relations-between-relations in the RMTS task (a non-perceptually based matching strategy), however, suggested that perhaps an as yet unidentified qualitatively different cognitive component exists that prevents monkeys from behaving analogically.

The purpose of the current study was to determine the role of stimulus meaning in the analogical reasoning abilities of three primate species. Such comparisons outline further our understanding of the cognitive capacities of various species and further our knowledge about concepts and mechanisms of concept learning in general. By implementing a more conceptual variable, meaning, into perceptually-based judgments, one might expect conceptual strategies for the task to emerge more quickly than they otherwise might.

Rhesus monkeys, chimpanzees, and human participants completed an identity/nonidentity relational match-to-sample (RMTS) task composed of meaningful and nonmeaningful stimuli. It is important to discern what we mean by “meaningful.” We define meaningful stimuli as those that function as a cue to evoke representations of external objects or concepts. Meaningful stimuli in this experiment, unlike linguistic equivalents in previous research (e.g. Premack, 1976; Thompson, et al., 1997) did not represent relational categories such as *same* and *different*, but

rather reference concrete objects or numerical quantities, making more overt the relational concept of which they are a part. Without using a symbolic token for the relational concept itself, we were further able to investigate the role of earlier “linguistic” prerequisites amongst the three primate species.

Method

Participants

Three groups of participants were tested on the analogical reasoning task: adult humans (*Homo sapiens*), chimpanzees (*Pan troglodytes*), and rhesus monkeys (*Macaca mulatta*).

Eighty-two undergraduates (67 females) were recruited from Georgia State University’s psychology research pool with half assigned to each stimulus condition (meaningful and nonmeaningful stimuli) in the relational match-to-sample task. The mean age of the participants was 20 years and 60% were minority students. All participants completed an informed consent form and received debriefing instructions upon completion of the task.

Four chimpanzees (18 to 34 years of age) housed at Georgia State University’s Language Research Center (LRC) also were tested. The chimpanzees previously had participated in experiments involving the matching-to-sample paradigm with joysticks (Beran & Washburn, 2002), but were naïve to the specific testing procedures involving the S/D concepts. Individuals were randomly assigned to receive one of two conditions (meaningful and nonmeaningful lexigram stimuli) first, followed by completion of the remaining condition. For three of the four chimpanzees, the meaningful stimuli were the lexigram symbols that they learned when young (Brakke & Savage-Rumbaugh, 1995, 1996; Savage-Rumbaugh, 1986, Rumbaugh, 1977) and have used for all of their lives. The fourth chimpanzee, Mercury, received no lexical training at all; therefore both conditions were essentially nonmeaningful, providing an additional control.

The LRC chimpanzees have been shown to retain the meaning of these symbols for more than 20 years (Beran, Pate, Richardson, & Rumbaugh, 2000). In addition, the animals sorted lexigrams into labeled groups more accurately than they do real-world objects and photographs (Savage-Rumbaugh, Rumbaugh, Smith & Lawson, 1980). The chimpanzees were not food or water deprived. Individuals worked at mobile testing systems at their home cages for designated 1-hour sessions each day.

Five male rhesus monkeys (10 to 20 years of age) housed at the LRC also completed the RMTS task. All monkeys began this study with previous experience on other tasks involving the same-different paradigm. In the Flemming et al. (2007) study, monkeys discriminated between arrays composed of identical or nonidentical clipart images. In the presence of a discriminative color cue, monkeys successfully discriminated same from different displays of 8, 6, 4, and 2 items. In addition, monkeys completed but failed RMTS tasks similar to those in the current study when only nonmeaningful clipart images were used. The monkeys were not food or water deprived for purposes of testing, and allowed to work *ad libitum* throughout the day in their home cages.

Stimuli

Meaningful stimuli for human participants were composed of 3- to 7-letter words that referred to concrete objects such as foods and places. Nonmeaningful stimuli were composed of 3- to 7-letter strings of illegal nonwords generated by the program WordGen® (Duyck, Desment, Verbeke & Brysbaert, 2004). Illegal nonwords were utilized as nonmeaningful stimuli because they carry with them no inherent referential value, and they cannot be recoded into sensible phonemes in the English language. Both sets of stimuli appeared as white letters inside a black

rectangle. Figure A.1 *a-b* provides example displays presented to human participants. A total of 50 unique words or 50 unique nonwords were presented throughout a testing session.

For chimpanzees, only lexigrams with which they have had extensive experience and have been shown to retain meaning were presented during the meaningful condition. Lexigrams may function more like whole words for the animals carrying with them a specialized meaning (Rumbaugh & Washburn, 2003). Exemplars from an unknown, never before seen subset of lexigrams were used as nonmeaningful for chimpanzees (see Figure A.1 *c-d*). One chimpanzee, Mercury, had no such experience, and therefore both conditions for him consisted of nonmeaningful stimuli. Each individual has a unique vocabulary subset. Consequently, the number of unique known lexigrams differs across individuals, and we used only concrete lexigrams that were part of each chimpanzee's larger unique vocabulary [Panzee = 65, Sherman = 28, Lana = 19; Mercury's stimulus sets each included 30 randomly chosen lexigrams]. The number of nonmeaningful stimuli was balanced for each individual.

There is sufficient evidence that monkeys can use some types of symbols as labels for certain concepts. In tasks presented to the rhesus monkeys at the LRC, Arabic numerals have been paired with specific numbers of pellets, allowing the animals to associate these numeric symbols with quantity information (Washburn & Rumbaugh, 1991). Thus, Arabic numerals were utilized as meaningful stimuli. In addition to simple quantity information that numerals may convey, Arabic numerals have also produced Stroop-like effects in rhesus monkeys at the LRC (Washburn, 1994). Because meaning of the numerals interferes with judgments about amount, numerals mean amounts, and thus can be said to have symbolic representation for the monkeys.

These numerals also control other types of responding. Harris & Washburn (2005) presented the monkeys with series of reinforced and nonreinforced maze trials in which Arabic

numerals indicated the number of reinforced mazes that could be completed before a nonreinforced maze trial was presented. Monkeys developed a pattern of responding slower on nonreinforced trials than the preceding reinforced trial; they used the Arabic numeral as a cue to the number of reinforced maze trials that would occur in a series (Harris & Washburn, 2005). These previously learned Arabic numerals were utilized in paired stimuli in the meaningful condition (see Figure A.1 *e-f*).

In the nonmeaningful condition, stimuli consisted of Latin alphabet letters. Special attention was given so that letters used in previous tasks for specific choice responses were not included in the subset of letters used in this task. Choice of letters and numerals controlled for perceptual qualities of the stimuli by balancing their basic physical properties. Monkeys were randomly assigned to receive one of two conditions (meaningful and nonmeaningful stimuli) first, followed by completion of the remaining condition.

Although there are components of both meaningful and nonmeaningful stimuli that are familiar in the words, lexigrams, letters, and numerals presented to the three species (i.e. individual letters, lines, and shapes), it is the combination of individual familiar stimulus features that makes them meaningful. Pilot experiments using the same stimuli over many trials still failed to show any evidence of relational matching in rhesus monkeys even though by the end of the experiment those stimuli certainly had become familiar. Thus, familiarity is not the issue but rather meaningfulness is the issue in this study. Of course, meaningful stimuli must be familiar stimuli, and so one cannot completely dissociate these two things.

Apparatus

The LRC's Computerized Test System (LRC-CTS) consists of an IBM-compatible desktop personal computer (Washburn et al., 1992). This same apparatus was used throughout all

parts of the project, with slight variations for each species. Undergraduate students at Georgia State University were tested at a desktop computer using a hand-held joystick. Each nonhuman animal had access to its own testing station. During tasks, monkeys controlled a cursor on a 17-inch SVGA monitor via a vertically-mounted joystick. The monitor was positioned approximately 15 cm from the home cage behind a transparent Lexan plate. Chimpanzees controlled a horizontally-mounted joystick within a port attached to their home cages; stimuli were presented on a monitor approximately 1m outside of the home cage on a mobile cart.

Speakers provided auditory feedback for all tasks, including a low buzzing sound for incorrect choices and an increasing crescendo sound for correct choices. These sounds have been paired with these outcomes on many previous tasks used with the nonhuman primates. For the current tasks, the increasing crescendo sound was always accompanied by the dispensing of a 94-mg banana-flavored pellet to rhesus monkeys and small portions of fruit or 1-g pellets to the chimpanzees.

Task

In the RMTS task, stimuli were presented in pairs with one sample pair (base) and two choice pairs (targets). At the initiation of a trial, one pair of stimuli (either two identical or nonidentical clipart images) was centered at the top of the computer screen; stimuli were approximately 5 cm x 3 cm. Participants were required to contact this sample pair with the cursor in order for the choice pairs to appear. Once contact with the sample pair was made, the joystick cursor was re-centered on the screen, and the choice pairs appeared in the bottom half of the screen on the left and right sides. One choice pair contained two identical items, whereas the other contained two physically nonidentical items. Importantly, no stimulus in the choice pairs was ever physically identical to stimuli in the sample pair and choice stimuli were randomly

assigned to position on the screen. Thus, the task required participants to either match a pair of the form AA with a pair of the form BB (and not CD) or to match a pair of the form EF with a pair of the form GH (and not JJ). Similar testing paradigms have been frequently utilized (Flemming et al., 2007; Premack, 1976; Thompson et al., 1997). Successful performance of the conceptual-relation matching task required that the participants judge one relation to be the same or different from *another relation*.

To make a response, the cursor was moved either left or right toward the choice pairs. Once contact was made with a choice pair, a feedback sound was played (an increasing tone if the choice was correct or a buzzing sound if incorrect). Reward was provided on correct trials for nonhuman animals and a short intertrial interval (ITI) then was presented before the sample pair for the next trial appeared. For correct choices, rewards were automatically dispensed to the animals accompanied by a 2-s ITI. When choices were incorrect, no food reward was dispensed and longer ITIs were imposed (15 s for rhesus monkeys and 5 s for chimpanzees).

Nonhuman primate participants completed varying numbers of trials per session, and thus a different number of total sessions. The total number of trials for each animal in both conditions are presented in Tables 1 and 2. Chimpanzees completed sessions of 25 trials each unless attention became diverted and side biases emerged. Only data from trials when attention was focused on the computer screen were analyzed. Rhesus monkeys completed sessions of 200 trials each. Testing was aborted after side biases emerged and only data from trials before side biases became evident were analyzed.

Humans received instruction as to the meaning of the feedback sounds. This was the only instruction they received. Thus, tasks were very well equated between species. Rather than telling humans to do what animals must learn, humans also had to learn the task in a similar trial-

by-trial fashion. In addition, humans received no food reward and 2-s ITIs for both correct and incorrect choices. After the ITI, the next trial was automatically initiated and the next sample pair appeared at top of the screen. Human participants completed a total of 100 trials in one session.

Human participants were randomly divided into two groups, each receiving one condition.⁹ Three monkeys received nonmeaningful stimuli (letters) first and the other two monkeys receiving meaningful stimuli (numerals) first. Two chimpanzees received nonmeaningful stimuli (pseudo-lexigrams) first and the other two chimpanzees received meaningful stimuli (lexigrams) first.

Results

Humans

Accuracy-by-condition was assessed by comparing the average performance for the entire 100-trial block between the two groups of participants (*meaningful/ nonmeaningful*). Participants in the meaningful condition completed the task with a significantly higher number of trials correct ($M = 93.86$, $SE = 1.73$) than participants in the nonmeaningful condition ($M = 87.48$, $SE = 2.47$); $t(80) = 2.13$, $p < .05$, $d = 6.38$.

Because accuracy was generally high for participants in both conditions, the number of trials-to-criterion was assessed to determine how long participants needed to learn the analogical rule. Trials-to-criterion for each participant was calculated by summing the total number of trials until eight out of the previous ten trials attempted were completed correctly. Within a 100-trial

⁹ Pilot studies revealed that a within-subjects design was not feasible for human participants. Participants were debriefed after the first condition and articulated full understanding of the analogical rule. All participants began the second condition utilizing the same rule across categories of stimuli. Beginning with trial 1 of the second condition, all participants achieved 100% accuracy.

testing session of either the meaningful or nonmeaningful stimuli, 76 of 82 participants met the criterion (correct responses to 8 out of the previous 10 trials attempted) for sufficient acquisition of an analogical rule. Two participants who received the meaningful condition never met a criterial level of accuracy; four participants assigned to the nonmeaningful condition did not perform at levels significantly above chance (50%) after 100 trials. These six participants were removed from analysis for trials-to-criterion and response time. Participants in the meaningful condition met criterion on average within 14.35 trials ($SE = 1.38$), fewer than the number of trials required for the participants in the nonmeaningful condition ($M = 19.08$; $SE = 2.60$); however, this difference was not statistically significant, $t(74) = 1.65$, $p = .10$, $d = 4.73$.

Chimpanzees

There were individual differences in performance by the chimpanzees on the RMTS task. Table A.1 presents performance summaries for the chimpanzees. Two chimpanzees (Lana and Mercury) never performed significantly above chance in any condition—meaningful or nonmeaningful—after at least 130 trials in each condition.

Panzee completed trials with meaningful stimuli before receiving the nonmeaningful condition. She performed at levels above chance in the meaningful condition completing 66% of 202 trials correctly, $z = 4.64$, $p < .01$, but failed to perform above chance levels in the nonmeaningful condition (55% of 227 trials, $z = 1.53$, $p > .05$). Figure A.2 presents Panzee's percentage of correct responses as a function of trial block for both conditions.

Panzee's accuracy on *same* trials and *different* trials was statistically equivalent in the meaningful condition: $\chi^2(1, 202) = 2.06$, $p > .05$. In the nonmeaningful condition (which yielded overall chance performance), her accuracy was significantly higher on *different* trials (65%) than on *same* trials (49%), $\chi^2(1, 186) = 4.61$, $p < .05$.

Sherman completed trials with nonmeaningful stimuli before receiving the meaningful condition. He performed at levels above chance in the nonmeaningful condition, completing 65% of 263 trials correctly, $z = 4.99$, $p < 0.01$. However, he failed to reach significance in the meaningful condition (54% of 186 trials, $z = 1.17$, $p > .05$). Figure A.3 presents Sherman's percentage of correct responses as a function of trial block for both conditions.

Sherman's accuracy on *same* trials and *different* trials was statistically equivalent for the meaningful condition, $\chi^2(1, 227) = 0.48$, $p > .05$. In the nonmeaningful condition his accuracy was significantly higher on *different* trials (80.6%) than on *same* trials (50%), $\chi^2(1, 263) = 27.18$, $p > .05$.

Rhesus Monkeys

The monkeys completed an average of 1,937 trials in each condition, but no monkey achieved levels of performance significantly above chance in either condition, regardless of which was presented first. Performance summaries of the rhesus monkeys are shown in Table A.2, with illustrative accuracy levels displayed in Figure A.4 for Hank (although any monkey could be shown with nearly identical results). The trends of the learning curves presented in Figure 4 with Hank are representative of the performance of all other monkeys in this study. Performance failed to improve across trials, and position biases emerged for every animal and condition.

If performance gradually improved across trials, eventually approaching significance, we could conclude that the animals slowly learned an analogical rule through trial-and-error. This was not the case, as no monkey ever reached a level of performance significantly different from chance. To illustrate that there was no evidence that performance improved across trials, blocks of 100 trials were analyzed independently for Hank for the first 1,000 trials in both conditions.

Percent correct was not significantly different from chance in any trial block except for trials 601-700 (60% correct; $z = 2.0$, $p < 0.05$) in the nonmeaningful condition. Subsequent trial blocks rebounded to near chance performance.

All but one monkey completed same and different trials with equivalent levels of accuracy in every condition; their treatment of same and different trials was symmetric (Murph-numerals $\chi^2(1, 2766) = .92$, $p > .05$; Murph-letters $\chi^2(1, 779) = .24$, $p > .05$; Lou-numerals $\chi^2(1, 1826) = .07$, $p > .05$; Lou-letters $\chi^2(1, 3599) = .03$, $p > .05$; Willie-numerals $\chi^2(1, 3242) = .87$, $p > .05$; Willie-letters $\chi^2(1, 1100) = .05$, $p > .05$; Gale-numerals $\chi^2(1, 1306) = .23$, $p > .05$; Gale-letters $\chi^2(1, 1174) = 2.43$, $p > .05$; Hank-numerals $\chi^2(1, 2399) = 2.12$, $p > .05$). In the nonmeaningful condition, Hank completed same trials (56.12%) with significantly greater accuracy than different trials (48.70%) ($\chi^2(1, 1178) = 6.60$, $p > .05$).

Discussion

Robust differences in performance emerged across species in this analogical reasoning task. For humans, meaningfulness of stimuli had overall positive effects on their ability to reason analogically, whereas this was not uniformly the case for the chimpanzees and completely absent in the case of the monkeys. There also was another major disconnect between the performance of humans and nonhuman animals. Although meaningfulness facilitated statistically higher performance for humans, success was also observed in the RMTS task with nonmeaningful stimuli (and at a rather high overall level). Overall, the nonhuman primates not only failed to show *facilitation* from meaningful stimuli, but they also showed no evidence of solving the RMTS task with similarly high rates of success. It seems to be the case that numerals for monkeys and lexigrams for chimpanzees do not operate at the same conceptual level as words do for humans in terms of facilitating analogical reasoning. Not only did human participants

outperform chimpanzees and monkeys, but the role of meaning when completing an analogy was also dissimilar across species. According to these data, stimuli with representational value can facilitate, hinder, or have no effect on the completion of an analogy of *same* and *different* objects.

Taken together, the results of this comparative study both lend support and opposition to the previous suggestion that language-like abilities and symbolic training are integral to the capacity of analogical reasoning. Premack (1983) concluded that language-like training is necessary based on his experiments with a chimpanzee. Similarly, Thompson et al. (1997) posited that labeling of relational information is a necessary component of analogical thinking. Whereas the results of the current study do not allow for the conclusion that human and chimpanzee participants were labeling the related pairs of stimuli, individual differences that arose between the chimpanzees urge the consideration of an alternate hypothesis.

For human participants, the known, discrete meaning of stimuli appeared to facilitate responding in the RMTS task. Although performance was generally high across conditions, participants in the meaningful condition performed at significantly higher rates of accuracy than those in the nonmeaningful condition. For those participants in the meaningful condition, the analogical rule was also learned in fewer trials, albeit this difference was not statistically significant.

The representational value of each stimulus may have enabled the relational concepts of sameness and difference to be more salient to the human participants in the meaningful condition than to those who completed the task with nonmeaningful stimuli that had no inherent representational value. The discrete meaningful value of a stimulus not only enhanced its own

uniqueness, but may also have removed extraneous associations it may have had to the stimulus with which it is paired.

It is especially noteworthy that some human participants failed to learn the analogical rule under any condition. On their debriefing forms, these participants noted that they simply “never figured it out” or “tried to match similar things, but that didn’t work.” Therefore, relational similarities and differences never became salient as part of a rule-learning strategy for these participants. Like children (Gentner, 1988), these adult participants may have been distracted by the *surface* similarities between the components of one trial (e.g., using the same elements). Whereas failure to learn the analogical rule may have been due to differences in motivation to participate, it is likely that if *structural* similarities (i.e., the matching rule) were disclosed to the participants at the beginning of the experiment, success would be instantaneous.

In experiments with children and adult humans, researchers agree that surface similarities are the key to whether participants will think of using an analogy to solve a problem when not explicitly told to do so (Gentner, et al., 1993; Rattermann & Gentner, 1998). In addition, human participants are particularly distracted by surface similarities in analogous problems, even when they are unimportant (Ross, 1987). In the current study, only structural (e.g. content) similarities exist across trials. The repeated presentation of individual stimuli (albeit in various locations and combinations of pairings) could be interpreted as surface similarities which act as confounds not related to the application of analogical knowledge. If stimulus X is present in the sample pair, not only may the subject attempt to search for stimulus X amongst the choice pairs, but he or she may also retain knowledge of the role of stimulus X for future trials. Thus, if stimulus X is encountered again, regardless of current location or pairing, rules previously associated with it may be incorrectly applied to the current scenario.

For chimpanzees, the meaning of meaningfulness is more ambiguous. Rather than facilitating the acquisition of the analogical rule, one chimpanzee failed to apply the analogical rule at all unless the stimuli had discrete meaning. Even after completing the meaningful sessions first, Panzee failed to perform above chance levels during nonmeaningful sessions. This would indicate that what she learned during the meaningful sessions was not as broad an analogical rule as humans might conceive it. If that were the case, she should have transferred her knowledge across categories. The analogical rule that she learned may be specific to those stimuli with external representation and thus the rule could not be applied in instances in which meaningful symbols are not present.

With respect to the effect of meaningfulness Sherman's performances were the complete opposite of Panzee's. He completed trials only in the nonmeaningful condition above chance levels. That he could correctly complete only nonmeaningful trials may indicate that his analogical rule was confounded by the meaningfulness of the stimuli. Perhaps he attended more to the perceptual qualities of a stimulus in order to determine its relatedness both within the pair and between target and choice pairs. However, if using a purely perceptually bound relational matching strategy, it should follow that Sherman could succeed in the meaningful condition as well. This valuable error lends even more support that meaningfulness plays an integral role in analogical reasoning. Perhaps it is the case that meaningful stimuli add a layer of confusion to what, for Sherman, could have been a more perceptually bound task.

Our chimpanzees seemingly are not as analogical by nature as was the chimpanzee Sarah (Oden, Thompson & Premack, 2001). The main difference between Sarah and the chimpanzees in this study is the employment of special tokens or symbols for the relational concepts themselves. While Panzee, Sherman and Lana have been trained with lexigrams, no lexigrams

specifically connote meaning of relational concepts such as same and different. Rather, they refer to concrete objects, people, and places. Sarah, however, had exactly those two tokens for sameness and difference. Perhaps to more fully apply an analogical rule one must have the capacity to recode relational concepts symbolically.

For both Panzee and Sherman, poor performance on subsequent conditions may be indicative of the inflexibility of their application of the analogical matching rule to a categorically novel relational stimulus set. Asymmetric performance by Sherman on *different* trials in comparison to *same* trials in the condition yielding overall success (nonmeaningful) indicates that the analogical rule he may have acquired applied only to differently related pairs of items. Rather than using the rule to match relations flexibly across trial types, asymmetric performance indicates that the strategy used may not be as broadly conceived so that a consistent rule could be applied to *same* relations.

Both people and pigeons are predisposed to notice differences rather than similarities (Young & Wasserman, 2002). Like people and pigeons, chimpanzees exhibited some differences in performance on *same* versus *different* trials, sometimes performing better on *different* trials. If we suppose that chimpanzees are predisposed to noticing only differences, it is likely that an analogical rule was realized only through experience matching differently related pairs with other differently related pairs. In subsequent trials, when similarly related pairs were presenting, the limited analogical rule that had been learned no longer was applied.

Although conclusions about individual differences between and within species are speculative, it may be the case that the richness of the symbol systems for the animals plays an important role. For chimpanzees, lexigrams are most likely not as seamlessly integrated into the cognitive system as words, symbols, and other linguistic tools are for humans. Certainly for

rhesus monkeys, numerals convey some meaning, but not at a level equivalent to words for humans or even lexigrams for chimpanzees. Therefore, the inequity of meaning between the species may account for some of these disparities.

A within-species comparison may follow similar logic. There are significant differences between the usage of lexigrams by Panzee and Sherman that relate back to rearing history and early experiences. Panzee's current vocabulary includes many more lexigrams than does Sherman's vocabulary (Beran, Savage-Rumbaugh, Brakke, Kelley, & Rumbaugh, 1998). Panzee uses a wider range of lexigrams and seems to have a better understanding of what they may afford her. It may be the case that Panzee's use of lexigrams may be better integrated in cognitive systems that allow for analogical reasoning, thus accounting for her success with meaningful lexigrams.

The inconsistencies in the performances of our chimpanzees also are contrasted with other recent evidence that is relevant to relational matching. Vonk (2003) provided evidence that four orangutans and one gorilla without any symbol or language training succeeded in a similar non-matching-to-sample task. By making judgments between pairs of stimuli that matched on only one dimension (*color* or *shape*), Vonk claimed that the non-symbol trained great apes were capable of abstracting relations between relations that were not as dependent on perceptual processing. However, the apes in that study may have been dependent on an even lower level of perceptual processing. That is, those apes may have been choosing the match choice that was perceptually less similar to the sample pair. For instance, if a sample pair consisted of two items that were the same shape, the subject could have selected a choice pair in which there was only one unique shape. Likewise, if color were the critical dimension, subjects viewing a sample in which color was the same for both shapes could simply have responded to a choice pair in which

there was only one color present. Following this reasoning, when stimuli can differ on only two dimensions, the judgment process may be even more tightly perceptually conceived in contrast to more complex stimuli that vary on several perceptual dimensions.

Failure by the rhesus monkeys in the current study to match relational pairs correctly in this task could be the result of one or more of a variety of reasons: the monkeys could not extract the necessary relational information from a pair of objects; relational knowledge was not encoded in such a way that it was accessible for application to novel behaviors; or perceptual properties of stimuli could not be ignored in a matching paradigm.

From their performance on previous tasks (e.g., Flemming et al., 2007), we know that monkeys can extract relational information from a pair of objects. In a two-choice discrimination paradigm, monkeys chose either a pair of identical or nonidentical objects in the presence of a discriminative cue. It may be the case that the monkeys' ability to extract relational information is reliant on a discriminative cue; the discriminative cue prompts the search for relational information present in the given sample. In the current task, no discriminative cue was offered, perhaps not enabling the search for a relation between the items in the pair.

The relational matching paradigm utilized throughout this study tests analogical reasoning skills by forcing explicit expression of conceptual knowledge for identically and nonidentically related pairs. One may argue that the RMTS task may be solved using perceptual judgments of uniformity and regularity as in entropy-infused displays (i.e. Fagot et al., 2001). Perhaps it is the case that humans have a greater ability to detect small variations in entropy (*same* pairs have an entropy value of 0 whereas *different* pairs have an entropy of 1). If this were true, however, we would expect to find no differences between condition for humans or chimpanzees. In fact, differences between meaningful and nonmeaningful conditions, regardless

of which condition allows for higher levels of success, indicates that there is an inherent conceptual component to the task as it is presented in the current study. If one can detect small variations in entropy with meaningful words, one should also be able to do so with nonmeaningful combinations of letters. Furthermore, monkeys can detect these small variations in entropy [0 vs. 1] but nonetheless fail the RMTS task (e.g., Flemming et al., 2007). There is no logical reason for this failure without the consideration of an analogical component to the RMTS task.

Analogy completion assumes (and relies on) conceptual knowledge of same and different. It may also be important, as evidenced by nonhuman primate performance on the task, to have concrete symbolic tokens of otherwise abstract relationships as Oden et al. (2001) posit. Certainly, human participants in this study have a very broad conception of same and different, as humans regularly classify objects into groups based on similarities and differences. Perhaps our propensity to do so is driven by the salience of relations. Whereas it is clear that other animals have the capacity to perceive the relations of same and different (Bovet & Vauclair, 2001; Cook, Cavoto, & Cavoto, 1995; Flemming et al. 2007; Katz, Wright, & Bachevalier, 2002; Vonk, 2003; Wasserman, Frank, & Young, 2002), the acquisition of these concepts for birds and monkeys does not emerge for sometimes hundreds or thousands of trials. Human participants as young as 3 years old provide evidence that the identity/nonidentity concept emerges in significantly fewer trials (Rattermann & Gentner, 1998).

If the concepts of *same* and *different* are not as salient to nonhuman primates as they are to humans, then their accessibility when the former search for an already abstract matching rule (in RMTS) will not be readily available as a strategy. Pigeons and monkeys that have been shown to rely on arrays of multiple items in order to glean relational information (e.g., Fagot, et

al. 2001; Wasserman, et al., 2002) may rely on more possibly ecologically valid perceptually based strategies (i.e., colors and shapes) when presented with a matching-to-sample task. Unlike simple discriminations that are founded upon only on implicit types of conceptual knowledge, the analogical paradigm carried throughout this study requires the explicit use of the same/different strategy. Because the same/different concept is less salient and possibly more narrowly construed by nonhuman primates, it stands to reason that the application of the concept would be more difficult, if not impossible, for such an animal.

Despite the ambiguity of the exact mechanism by which analogies are realized, the present study does provide a comparison of the capacity for the acquisition of an analogical rule across three species of primates. Results from the present study reveal both common threads and disparities in the analogical reasoning skills of members of the old-world primate lineage. Whereas meaningful stimuli act as facilitators for humans in making more salient the relational information presented and consequently the nature of an analogical rule, meaning can take on various roles for other primate species. Symbolic representation of categorical content, unlike relational representation, seems to have little or no facilitatory role at all for nonhuman primates. These data may reflect one fundamental way that nonhuman primates differ from humans in how they represent their worlds.

Table A.1
Performance summaries of chimpanzees

<u>Subject</u>	<u>Condition</u>	<u>Order of Presentation</u>	<u># of Trials Completed</u>	<u>Percent Correct</u>	<u>z</u>
Lana	Meaningful	1 st	238	52	0.65
	Nonmeaningful	2 nd	166	54	1.09
Mercury	Meaningful	2 nd	191	49	-0.21
	Nonmeaningful	1 st	133	56	1.47
Panzee	Meaningful	1 st	202	66	4.64*
	Nonmeaningful	2 nd	186	54	1.17
Sherman	Meaningful	2 nd	227	55	1.53
	Nonmeaningful	1 st	263	65	4.99*

* $p < 0.05$

Note. Number of trials for each individual and condition varies as a result of how many trials each chimpanzee was able to complete in a given testing session. When chimpanzees showed lasting position biases or no longer attended to the task, testing was aborted. This also affected the number of trials completed by each animal when refusal to work on the task persisted. These data represent approximately 12 sessions per animal over the span of 21 weeks of testing.

Table A.2
Performance Summaries of the Rhesus Monkeys

<u>Subject</u>	<u>Condition</u>	<u>Order of Presentation</u>	<u>Trials Completed</u>	<u>Percent Correct</u>	<u>z</u>
Murph	Meaningful	1 st	2,766	50	.99
	Nonmeaningful	2 nd	779	48	.61
Lou	Meaningful	2 nd	1,826	51	.94
	Nonmeaningful	1 st	3,599	48	-2.15*
Willie	Meaningful	1 st	3,242	50	.21
	Nonmeaningful	2 nd	1,100	48	-.78
Gale	Meaningful	2 nd	1,306	49	-.44
	Nonmeaningful	1 st	1,174	47	-1.40
Hank	Meaningful	1 st	2,400	50	.08
	Nonmeaningful	2 nd	1,178	52	1.75

* $p < 0.05$

Note. Number of trials for each individual and condition varies as a result of how many trials each monkey was able to complete in a given testing session. These data represent approximately ten sessions over the span of two weeks.

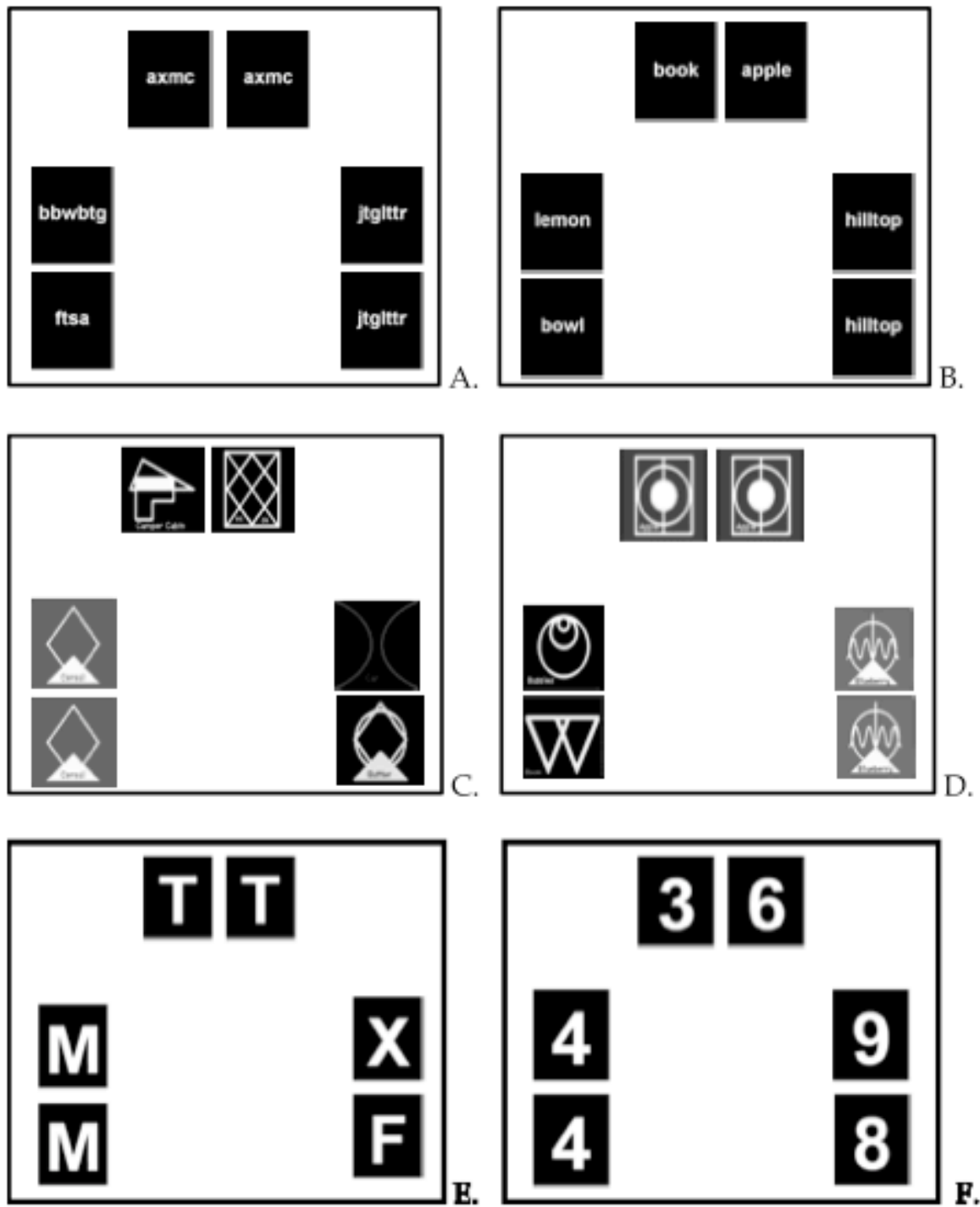


Figure A.1. Screen captures from RMTS task for human participants (a) same-nonmeaningful (b) different-meaningful, chimpanzees (c) different-nonmeaningful (d) same-meaningful, and rhesus monkeys (e) same-nonmeaningful (f) different-meaningful.

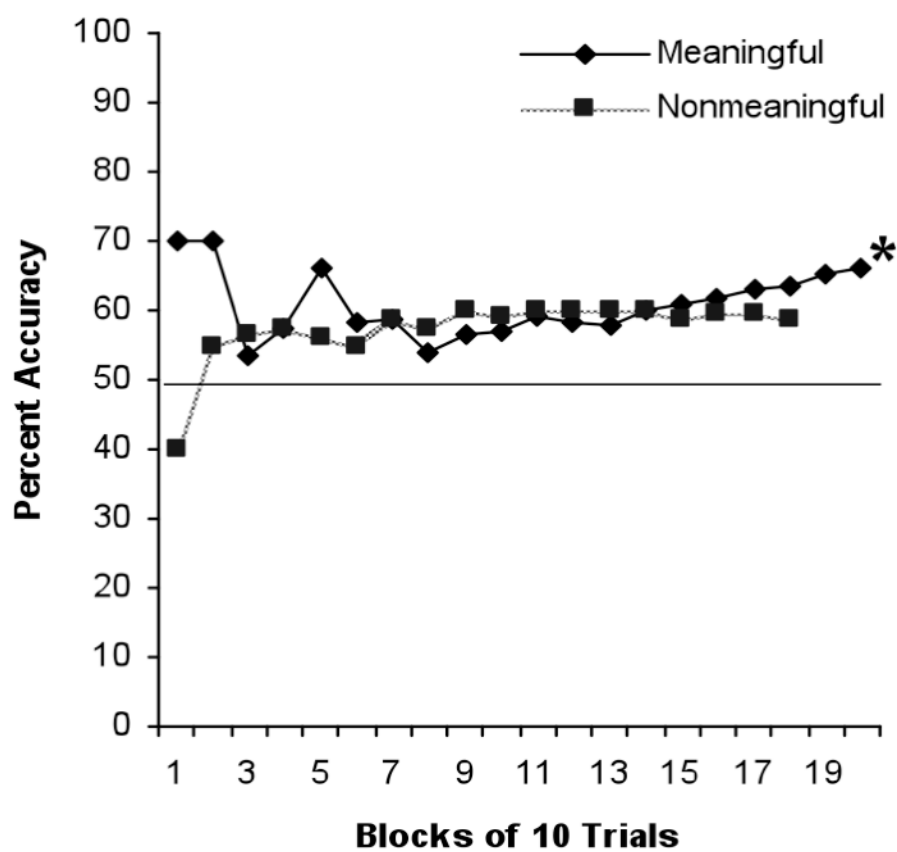


Figure A.2. Performance summary for Panzee (*Pan troglodytes*). Percent accuracy is displayed in blocks of 10 trials for both meaningful and nonmeaningful stimuli. The horizontal line at 50% represents chance performance. Asterisks represent a performance level significantly different from chance.

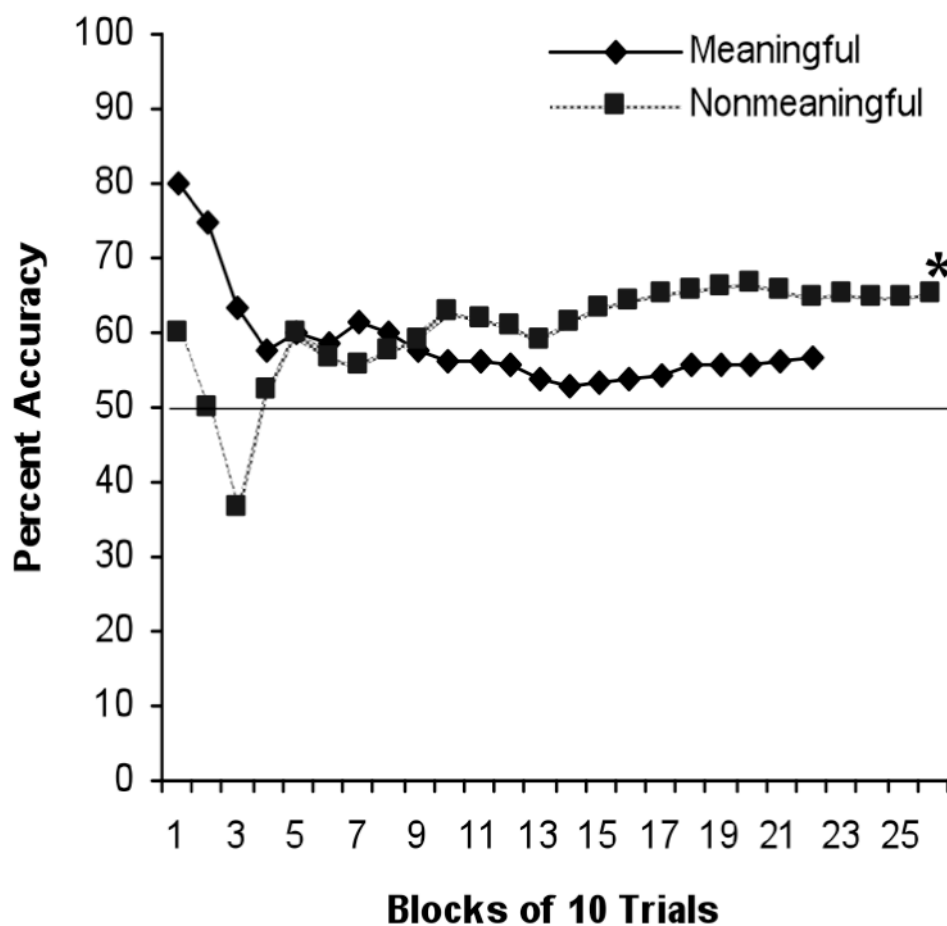


Figure A.3. Performance summary for Sherman (*Pan troglodytes*). Percent accuracy is displayed in blocks of 10 trials for both meaningful and nonmeaningful stimuli. The horizontal line at 50% represents chance performance. Asterisks represent a performance level significantly different from chance.

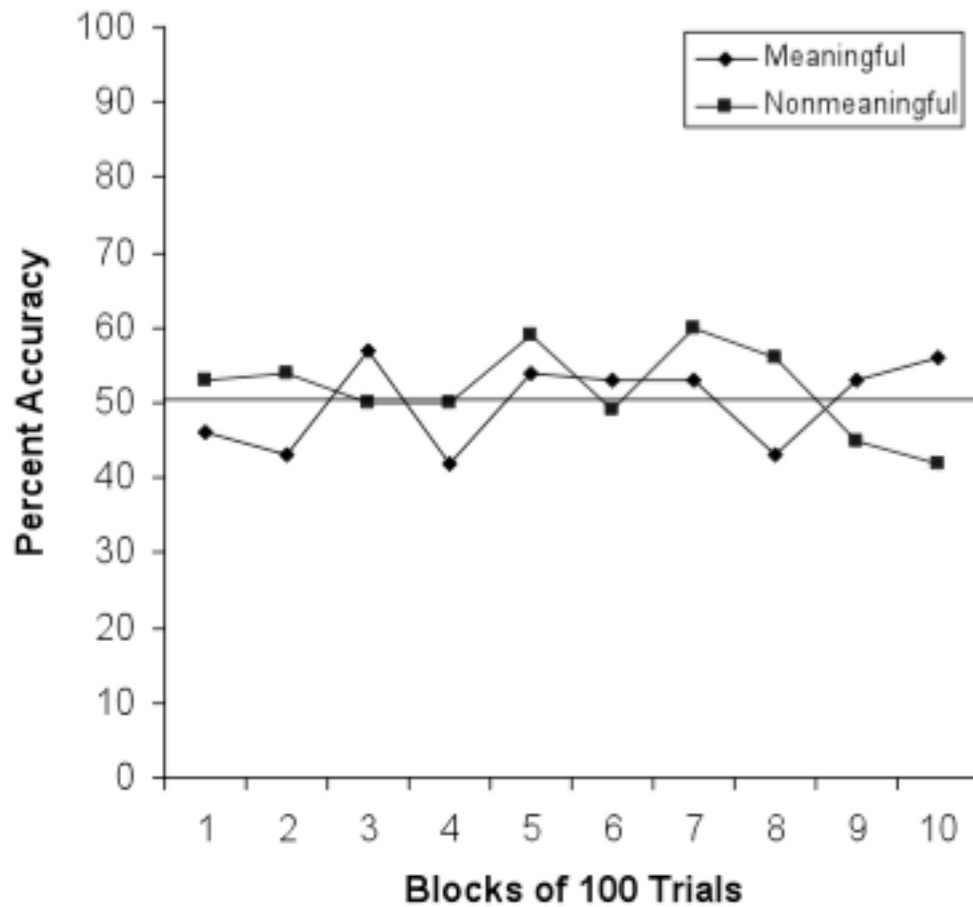


Figure A.4. Performance summary for Hank (*Macaca mulatta*). Percent accuracy is displayed in blocks of 100 trials for both meaningful and nonmeaningful stimuli. The horizontal line at 50% represents chance performance. Performance is similar to and indicative of performance outcomes for all monkeys tested. Subsequently, graphical depictions of the nonsignificant results for all monkeys is not presented. No performance levels on any trial block were significantly different from chance.

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