

Categorical Perception and Conceptual Judgments by Nonhuman Primates: The Paleological Monkey and the Analogical Ape

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Studies of the conceptual abilities of nonhuman primates demonstrate the substantial range of these abilities as well as their limitations. Such abilities range from categorization on the basis of shared physical attributes, associative relations and functions to abstract concepts as reflected in analogical reasoning about relations between relations. The pattern of results from these studies point to a fundamental distinction between monkeys and apes in both their implicit and explicit conceptual capacities. Monkeys, but not apes, might be best regarded as “paleo-logicians” in the sense that they form common class concepts of identity on the basis of identical predicates (i.e., shared features). The discrimination of presumably more abstract relations commonly involves relatively simple procedural strategies mediated by associative processes likely shared by all mammals. There is no evidence that monkeys can perceive, let alone judge, relations-between-relations. This analogical conceptual capacity is found only in chimpanzees and humans. Interestingly, the “analogical ape,” like the child, can make its analogical knowledge explicit only if it is first provided with a symbol system by which propositional representations can be encoded and manipulated

I hope to have given you a better appreciation of our remarkable—yet largely unconscious and virtually automatic—ability to perceive one place or object or person or situation, however vast or insignificant, as “the same” as some other. It is this subtle ability, perhaps more than any other, that sets human cognition apart from any other on our planet.

R. M. French (1995, Introduction, p. xvi)

I. INTRODUCTION

French's anthropocentric perspective is one that has a long history in psychology and philosophy. It certainly was the prevailing viewpoint when Darwin applied his own subtle capacities in detecting "sameness" to challenge and ultimately to irrevocably change the assumption that the human mind was qualitatively different and superior to the rest of creation. Darwin's belief in psychological continuity between humans and animals was quite explicit, ". . . differences in mind between man and the higher animals, great as it is, is certainly one of degree and not of kind" (Darwin, 1871/1920, p. 128).

In this paper we discuss some of the evidence that primates other than humans can perceive and judge "sameness" at a categorical and conceptual level. Although our focus here is on research with nonhuman primates, we recognize that many of the same capabilities have been found in other nonhuman species (e.g., Roitblat & von Fersen, 1992; Roberts, 1998; Schusterman & Kastak, 1998; Thompson, 1995; Vauclair, 1995; Wasserman, 1995; Zentall, 1998). In addition, our discussion will not provide an exhaustive review of the primate literature (cf., Lock & Colombo, 1996; Tomasello & Call, 1997). Our intention instead is to provide a representative overview of specific aspects of conceptually mediated *behavior* in nonhuman primates.

First, we will describe what we mean by conceptually mediated behavior in nonhuman animals. Second, we will describe those methodologies commonly used to investigate concepts in nonhuman primates. We will identify those concepts most commonly attributed to nonhuman primates from results obtained using these methods, but we will focus on examining the performance criteria upon which conceptually mediated behavior can or cannot reasonably be inferred. Third, we will review recent evidence of notable, possibly qualitative, disparities among primates with respect to the range of their conceptual capacities.

Current research questions and methodologies in the study of concepts in nonhuman primates have their origins in the tradition of comparative psychology and in particular the study of discriminative control of behavior in animal learning (e.g., See Roberts, 1998; Shettleworth, 1999; Vauclair, 1995). Readers whose own scholarly roots lie in human cognitive psychology will likely note that our review is reminiscent of the study of human concepts and rule learning in the 1950s. Although that tradition has given way to other approaches it continues to be valued in animal cognition. Historically, comparative psychologists have emphasized the primacy of understanding behavior manifested in structured environments. Contemporary interest in the cognitive processes mediating functional action patterns began nearly three decades ago with the renewed studies of animal memory addressing the problem of how a formerly present, but now physically absent, stimulus could control behavior (e.g., Honig & James, 1971; Hulse, Fowler, & Honig, 1978; Medin, Roberts, & Davis, 1976). Many of these studies employed carefully measured and controlled stimuli seldom varying along more than one or two physical dimensions. However, in the intervening years these were increasingly regarded to be conceptually impoverished resulting in the present focus on categorically rich stimulus classes (e.g., see Honig & Fetterman, 1992; Roitblat, Bever, & Terrace, 1984; Zentall, 1993).

II. WHAT CONSTITUTES CONCEPTUALLY MEDIATED BEHAVIOR IN NONHUMAN PRIMATES?

From Plato to current journals in psychology and AI, discussions of knowledge and mind frequently deal with concepts, schemas, and ideas. A critical survey of all the different accounts of concepts that have been offered in philosophy, psychology, and AI would take a volume in itself.

Thagard (1992, p. 13).

As in human cognition there is no universal meaning of the term “concept” in animal cognition; it is itself a “fuzzy concept” (Chase, 1997; Lock & Colombo, 1996). Readers should not be surprised to find that researchers in this area implicitly if not explicitly use the terms concept, category, and stimulus equivalence interchangeably; it's the nature of the literature.

For present purposes we will assume that, at the very least, conceptually mediated behavior in nonhuman primates entails the ability to make explicit similarity judgments both between & within common classes of objects, states and events across multiple domains. The animal's behavior must reflect the use of an, “...abiding rule for identifying and dealing with the objects it denotes. It is the system of possible judgments about a class of things.” (Piper & Ward, 1929, p. 194). In other words, to infer that an animal “has a concept” one must provide evidence that it applies the *same judgment* in the form of an explicit response rule or cognitive (i.e., computational) operation, to individually discriminable objects or events that are perceived to be common members of the *same physical or relational class*.

Hopefully, it is self-evident that conceptually mediated behavior is both functionally adaptive and cognitively efficient in the ways that it permits animals to judge and adjust their behavior to novel objects and events by virtue of membership in an already familiar class (Cook, Wright, & Kendrick, 1990; Herrnstein, 1990; Premack, 1978; Wasserman, 1993).

Membership in a common class may be based on categorical identity founded upon shared sensory, physical or functional resemblance, but not necessarily so. Class membership may also be based on shared associative histories or relational properties including space and time such as, for example, inside-of, on-top-of, empty versus full, and earlier versus later, or simultaneous versus sequential. Perhaps the highest order of conceptually mediated behavior is the ability to judge relations-between-relations that forms the necessary foundation for analogical reasoning which many regard as the hallmark of human reasoning and intelligence (Gentner & Markman, 1997; Holyoak & Thagard, 1997; Premack, 1983a, b; Sternberg, 1977).

III. THE PALEOLOGICAL MONKEY AND THE ANALOGICAL APE

We believe, as indicated in our title, that the overall pattern of results we will review here from studies of concepts in nonhuman primates confirms a fundamental distinction between monkeys and apes in both implicit and explicit conceptual capacities. Monkeys,

but not apes, might be best regarded as “paleo-logicians” in the sense enunciated by von Domarus (1944) in his interpretation of reasoning by schizophrenics. As described by Arieti (1955), von Domarus’ principle was, “Whereas the normal person accepts identity upon the basis of identical subjects (*i.e., the conceptual equivalent*) the paleologican accepts identity based upon identical predicates (*i.e., the shared features*) (Arieti, 1955, p. 194; italic material in parentheses added).

Of course, we are not claiming that monkeys are schizophrenics. We do claim, however, the preponderance of present evidence indicates that monkeys discriminate categorical equivalence classes on the basis of perceptual featural identity or some combination, possibly configural, thereof. The discrimination of presumably more abstract relations appears to be mediated by associative processes shared by all mammals. We know of no compelling evidence that monkeys perceive, let alone judge, analogical relations-between-relations. This is not because they do not represent their world, but rather because they do not represent it propositionally. Apes, or at the very least chimpanzees, like children, perceive propositional similarities and differences spontaneously and at an early age (Oden, Thompson & Premack, 1990). Interestingly, as we shall demonstrate, the ape, like the child, can make this knowledge explicit in instrumental judgment tasks only if it is first provided with a language or symbol system by which propositional representations can be encoded and manipulated (cf., Premack, 1978; Premack, 1983; Thompson & Oden, 1993; Thompson, Oden, & Boysen, 1997).

IV. MEASURING CONCEPTS IN NONLINGUISTIC PRIMATES

Comparative psychologists and primatologists share a problem with many developmental psychologists; their subjects lack the capacity for verbal report. *How then might one ask an animal a question and how might one interpret the answer?* Traditionally, studies of concepts in nonhuman primates and other animals have almost exclusively employed instrumental tasks originally developed to investigate discriminative learning processes and sensory psychophysics in animals (e.g., see Mackintosh, 1974; Stebbins, 1969). Commonly used instrumental methods include same/different (S/D) discriminations and matching-to-sample (MTS) tasks.

Instrumental Tasks

In same/different (S/D) discrimination tasks a pair of discriminative stimuli is presented either simultaneously or successively and the animal is differentially rewarded for emitting one instrumental response in those cases where the stimuli are the same and another in those cases where they differ. In matching-to-sample tasks a subject first observes a single stimulus, the sample, which is followed by two or more comparison stimuli. In identity matching tasks, the subject is rewarded for responding to the comparison stimulus that is identical to (*i.e., matches*) the sample. In conditional or symbolic matching tasks the sample and comparison stimuli are not identical, but there is a specific, albeit arbitrary, relationship between them. For example, given a triangle sample an animal is rewarded for

choosing the comparison stimulus from category “A” and not category “B.” Given a circle sample, however, the correct choice is the comparison stimulus from category B and not category A.

Additional more comprehensive descriptions of discrete-trial instrumental and free operant methods commonly used to study concepts in nonhuman primates can be found in Lock and Colombo (1996), Thompson (1995), Tomasello and Call (1997), and Vauclair (1995).

Response Measures

Many researchers have taken advantage of the fact that nonhuman primates visually attend to that which they reach and touch with their hands. Hence, response measures, analogous to verbal report by humans, often include direct manipulation of stimulus objects themselves or touching a screen bearing an image of the stimuli. Both before and after the advent of computer technology nonhuman primates have been trained to displace stimulus objects from food wells in order to retrieve an otherwise hidden food reward. They might do this directly with their hands or more indirectly by pulling or pushing on a manipulandum, like a string, attached to the object (for a review of traditional laboratory techniques see Meyer, Treichler, & Meyer, 1965).

In recent years, nonhuman primates have been trained to register their choices by reaching out and touching the surface of computer monitors upon which stimulus materials are presented. Response measures can also entail differential movement of a manipulandum like a lever or response key. For example, depending upon whether the available stimulus is or is not a member of a particular categorical or relational conceptual class a monkey may move a lever to the left or right. Alternatively in “go/nogo” tasks the animal may be trained to depress a key within a specified time period in the presence of a positive instance of a categorical class stimulus and to withhold contact for a fixed time in its absence or in the presence of a negative instance of the stimulus class. Both monkeys and apes have even been trained to handle computer joysticks to move computer cursors towards the stimulus of their choice (e.g., Bhatt, & Wright, 1992; Neiwirth & Wright, 1994; Sands, Lincoln & Wright, 1982; Swartz, Chen, & Terrace, 1991; Tanaka, 1995; Vauclair & Fagot, 1993; Washburn, Hopkins, & Rumbaugh, 1989). Investigators of human cognition may wish to refresh their memories, or newly acquaint themselves of these and related behavioral methodologies, by consulting the sources cited throughout this paper for more procedural details.

Stimulus Presentation

Experimental stimuli used to exemplify the category or relation under study may be objects, photographs, slide projections or digitized images. Regardless of the specific response measure or means of stimulus presentation, as noted above, nonhuman primates in instrumental tasks typically are explicitly rewarded during training for correctly differentiating between positive and negative instances of the category or conceptual class in question.

V. INFERRING CONCEPTUAL KNOWLEDGE FROM INSTRUMENTAL PERFORMANCES

As noted previously, researchers in animal cognition often use the terms concept, category and class equivalence interchangeably. No such ambiguity, however exists with respect to the evidence for conceptually mediated behavior. In nonhuman primates conceptual behavior typically is inferred from the transfer of S/D discriminative or matching performances to *novel* stimuli that were not used during acquisition of the task (e.g., Herrnstein, 1990; Thompson, 1995; Wright, 1991, 1997). Successful transfer to novel exemplars is a necessary criterion because it permits one to rule out performances mediated by non conceptual factors such as rote memorization of the original stimulus materials.

Nonconceptual Rote Memorization in a Matching Task

Good evidence of memorization of complex stimulus arrays was reported by Farrar (1967) in a study of matching-to-sample by chimpanzees (*Pan troglodytes*). In this experiment each discrete trial began with one of 24 possible visual samples—varying in form and color—being presented on a backlit key. Immediately after the sample was terminated one stimulus was presented on each of four backlit keys arranged side-by-side in a line horizontally below the sample key. The chimpanzees were rewarded if they pushed the key on which the displayed stimulus was the same (i.e., matched) as what had appeared on the sample key. Importantly, although the four stimuli varied across the 24 possible matching problems, the same set of three incorrect ‘distractor’ stimuli appeared with each correct ‘match’ on any given problem. The terminal performance levels of all three chimpanzees tested by Farrar (1967) exceeded 90% correct matching responses suggesting perhaps that they had learned a generalized matching concept.

A series of stimulus manipulations by Farrar (1967), however, revealed that his animals had instead memorized the correct choice key on each of the ostensibly matching problems. Apparently, even when no sample was presented, the presence of the ‘correct’ choice stimulus for that problem in a particular spatial location plus only one other stimulus element drawn from the other three incorrect response alternatives was sufficient for an animal to respond correctly. Farrar also reported additional anecdotal information confirming that his chimps had memorized the 24 stimulus arrays used in the ostensibly matching task. “One day a technician noticed that the light bulb used to illuminate the sample stimulus was burned out. He checked each of the three animal’s records for that day and found that none of the three had suffered any performance decrement.” (as cited in Barker, 1997, p. 451).

What Constitutes Evidence of an Identity Concept?

Generalized performance to novel stimuli is a necessary, but not sufficient criterion for concluding that an animal’s performance is conceptually mediated. The most convincing evidence that a nonhuman primate has acquired a reflexive identity concept at a given

categorical or relational level entails immediate (i.e., on trial-1) transfer of matching or discriminative performance, under nondifferential reinforcement, to novel samples and comparison stimuli drawn from the same class or category, but which differ physically from the original training stimuli. Here the animal must explicitly judge the reflexive identity (i.e., “a is A”) or nonidentity (i.e., “a is not B”) of the sample and the choice stimuli (see Thomas, 1980, 1996). Such relative class concepts might be verbalized by a human as, “Is this object or event a member of the same class as that other one? If so, then I should choose it.”

A Broadly Construed Identity Concept in Chimpanzees. Good evidence of a broadly construed reflexive concept of physical identity was revealed in infant chimpanzees (*Pan troglodytes*) by Oden, Thompson, & Premack (1988) using a matching task (cf., Nissen, Blum, & Blum, 1948). Visual (and auditory) generalized matching is facilitated in both old- and new-world monkeys when a large stimulus pool of objects is used as opposed to a limited sample set (cf., D’Amato, Salmon, & Columbo, 1985; Wright, Shyan, & Jitsumori, 1990). Interestingly, there was no such limitation or constraint on object matching by the infant chimpanzees. They were initially trained to match with a single pair of objects, a metal lock and a metal cup, serving alternatively over successive trials as matching and nonmatching comparison stimuli. Once the animals reached a predetermined criterion performance with the two training objects they were given a series of transfer tests with other novel “hard” objects, “soft” cloth swatches and food items.

The matching performances of all four infant chimpanzees generalized immediately to the novel stimuli even though they were not differentially rewarded during these transfer tests. This procedure is analogous to the use of nondifferential feedback in tests of human concept learning (e.g., see Hampton, 1999). Differentially rewarding correct and incorrect choices in transfer tests with nonhuman primates may result in a learning set phenomenon (Harlow, 1949) in which performance is mediated by an absolute class concept. In this case, an animal need only respond on the implicit basis of the relative familiarity or novelty of absolute stimulus features. A human might verbalize an absolute class discrimination as, “Have I seen this specific thing before and was reward associated with it then? If so, then choose it again.”

What is Conceptually Judged?

According to our earlier provided definition (see above), evidence for conceptual understanding emerges only when the animal applies the same response rule (e.g., “match”) to individually distinctive members of a common class or relation. A remaining important question then is, what is the nature of the common class, category or relation to which the response rule is being applied?

It is one thing for a nonhuman primate to successfully match one thing with another and to do so continually with objects drawn from a large set of physically disparate objects or categories. It is quite another thing for experimenters to be able to claim, absent the appropriate transfer tests, that they themselves know which concepts, if any, are driving

their subjects' similarity judgments (see also, Chater & Heyes, 1994; Kastak & Schusterman, 1992; Thompson, 1995). Consider the following hypothetical example. A child is trained to match a pair of socks with another pair of socks and to match a pair of cups with another pair of cups. One might then wonder about the conceptual, or nonconceptual, level(s) at which the child's correct judgments are being made. Is she or he for example, matching sock with sock and cup with cup, or matching soft with soft and hard with hard? Alternatively, perhaps the child is matching clothing with clothing and utensil with utensil. Finally, the child may indeed be matching on the basis of relational identity where both pairs of socks instantiate the same relationship of identity. We leave it to the reader to test his or her own understanding of these issues by designing the appropriate 'thought' experiment to test these rival hypotheses via transfer trials.

As indicated in our earlier statements evidence for concrete or perceptual categorical concepts have been claimed for both monkeys and apes and it is to these studies we turn first. Later, we will address the question of whether monkeys or apes have concepts based on abstract relational and analogical properties which transcend physical identity.

VI. PERCEPTUAL CATEGORICAL CONCEPTS

Results from studies of matching generalized to the domain of objects per se suggest that the general class of things or events that can be judged to be identical by nonhuman primates can be very open-ended, albeit within a specific sensory modality. Given the evidence that nonhuman primates can match objects or complex sounds per se as a generic common class, then the next question is the extent to which the animals further divide open-ended classes themselves into *subordinate* categories.

Experimental Measures of Conceptual Categorization

Release from Categorical Proactive Interference. Results from a study of proactive interference effects with series of photographic slides provided indirect evidence of spontaneous categorization by a monkey of flowers and faces (Jitsumori, Wright, & Shyan, 1989). On each trial a rhesus monkey (*Macaca mulatta*) was first presented with a series of four slides followed by a single probe slide. The monkey's task was to indicate whether the probe had nor had not appeared in the initial 4-item list. The monkey's ability to correctly classify the single probe as having appeared or not appeared in the preceding 4-item list declined significantly over trials within the same category (either flowers or faces), but then improved abruptly when the category was changed.

Same/Different Discriminations. In more direct measures of conceptual categorization by nonhuman primates subjects typically are trained to discriminate exemplars drawn from the category in question from items that fall outside the category, at least as defined by the human experimenters. Hence, for example, in a Same/Different discrimination task, the subjects may be trained to discriminate slides of conspecifics from slides in which conspecifics are not present. If an animal is perceptually sensitive to the categorical

distinction in question (i.e., conspecific), then it will correctly discriminate novel exemplars of conspecifics from novel slides in which conspecifics are not present.

Multidimensional Scaling. This technique has also proven useful in as a means of identifying the natural categories of nonhumans and to answer the question of whether these natural categorical distinctions approximate those made by humans (Thompson, 1995). Results of a multidimensional scaling procedure and cluster analyses, for example, were used as evidence by Fujita (1987) that macaque monkeys categorized pictures of conspecifics and other macaque species similarly to a morphological classification of macaques. Macaque monkeys representing five different species (*M. arctiodes*, *M. fuscata*, *M. mulatta*, *M. nemestrina*, & *M. radiata*) were trained to press a lever in order to view pictures of different species. Each picture remained visible for as long as the lever was pressed. The same picture was displayed if the lever was released but pressed again within 10 s of the last press. If the interval between presses exceeded 10 s then a new picture was presented. Estimations of the perceived categorical distances among five closely related macaque monkey species correlated with their phylogenetic distances.

In an earlier study a multidimensional scaling procedure was used by Sands, Lincoln, & Wright (1982) to identify the natural object categories of rhesus monkeys (*M. mulatta*) in a Same/Different task. The monkeys were trained to move a lever in one direction if two successively presented slides were of the same item and to move the lever in the opposite direction if the content of the slides differed. The analysis of 'confusion errors' revealed that a monkey was more likely to classify two physically different slides as being the identical if they were drawn from the perceptually similar categories. Hence, human faces were more likely to be incorrectly identified as being the same as monkey faces, than they were with trees, fruits, or flowers. The monkeys, however, were more likely to confuse flowers as being the same as trees than they were with either fruits or faces.

The Psychologist's Fallacy

The actual range of natural perceptual categories studied in nonhuman primates is diverse, including, for example, both natural object classes such as plants, fruits, conspecific and nonconspecific animals, including humans, as well as conspecific vocalizations (for summaries see Lock & Colombo, 1996; Roitblat & von Fersen, 1992; Roberts, 1998; Thompson, 1995; Tomasello & Call, 1997; Zayan & Vauclair, 1998).

If natural categories like those above which have verbal labels are being studied then the behavioral primatologist or comparative psychologist, like the developmentalist, should pay careful attention to avoiding the *Psychologist's Fallacy*, (James, 1890/1950). That is, mistaking one's own conceptual understanding of the categorical class with that of the experimental animal. One cannot automatically assume that those factors determining class membership for the experimental animal are necessarily going to be the same as, or as conceptually rich as, those for the adult human experimenter. What does it mean, for example, to say that a dog knows a '*squirrel*' is up a tree (Allen, 1999). This uncertainty as to the mental content of the animal's conception has led some researchers

to suggest that one cannot meaningfully talk about nonhuman animals 'having concepts' (e.g., Chater & Heyes, 1994). But if that is true, then does it not hold true also for preverbal human infants? One way to avoid committing the psychologist's fallacy is to use artificial categories, like for example, sets of alphanumeric symbols. Here one can be assured that in most cases any intrinsic or derived conceptual meaning of the categories in question will *not* be the same for the nonhuman primate as that of the human experimenter.

Hierarchical Categorical Levels

Are All Basic Categories Alike? Human and nonhuman primates may differ in the way that they hierarchically organize natural categories. Roberts & Mazmanian (1988) for example, found that both squirrel monkeys (*Saimiri scurieus*) and pigeons (*Columba livia*), like human subjects, quickly learned to discriminate pictures of kingfisher birds (*Alcedo atthis*) from other bird species. The humans also readily learned to discriminate pictures containing animals - including insects, fish, amphibians, reptiles, and mammals - from those that did not contain any animal. In contrast to the human subjects, both the squirrel monkeys and pigeons required extended training to make this superordinate level discrimination. Finally, the squirrel monkeys, like the pigeons, failed altogether at the task of accurately discriminating the category of 'bird species' from other categories of animals even though the human subjects did so with little difficulty.

These results from Roberts and Mazmanian's (1988) study are interesting because they indicate that the supposedly intermediate *basic* categorical level for humans of 'bird' (Berlin, Breedlove, & Raven, 1973; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976) was not similarly the preferred categorical level for either squirrel monkey or pigeon. Rather, their apparent preferred level - as reflected in their discrimination performances - was instead the more concrete subordinate categorical distinction between 'kingfisher' and other bird species. The suggestion from these results that "species" may be a basic category for nonhuman primates is consistent with Fujita's results, described above, of how macaque monkeys categorize different species of that genus.

Whatever features permitted the squirrel monkeys and pigeons to discriminate kingfishers from other birds did not permit them to discriminate birds from other animals. Also, Roberts and Mazmanian (1988) themselves were unable to identify the level of resemblance by which the squirrel monkeys and pigeons eventually learned the more abstract superordinate discrimination between animals and nonanimals. Their results from the nonhuman subjects in the 'kingfisher' versus other bird species discrimination task, however, are consistent with the view that animals are predisposed to learn categorical exemplars on the basis of simple physical resemblance. And if that is the case, how then can one distinguish between instances of conceptual categorization as opposed to 'simple' stimulus generalization?

Categorization or Stimulus Generalization?

Transfer stimuli used in conceptual matching and discrimination experiments, like those described above, should be physically orthogonal to those used in acquisition training. If

they are not, then one cannot rule out the possibility that generalization of matching is mediated by stimulus generalization per se as opposed to the expression of the abstract reflexive concept of categorical or relational identity. Ideally, studies of conceptually based categorical identity judgments should include measures of an animal's ability not only to discriminate *between* categories but also to discriminate between different exemplars *within* each category (Lea, 1984; Thompson, 1995; Zayan & Vauclair, 1998). Hence, for example, if a nonhuman primate successfully discriminates between female and male faces one should await an additional demonstration that the animal can discriminate one female (or one male) from another before concluding the discrimination between females and males reflects conceptual categories.

Explicit tests of both between and within category discriminations in the same study with nonhuman primates are rare. In one such study Vauclair and Fagot (1996) first trained two baboons (*Papio papio*) to categorize alphanumeric characters using a conditional matching procedure. Both baboons learned the conditional matching task and their performances transferred to novel fonts. But could the baboons discriminate between exemplars of the same character shown in different fonts? One baboon performed this latter discrimination task with different fonts above chance for a variety of stimulus sets. This finding suggests that his behavior was indeed conceptually mediated. The other baboon, although above chance when different fonts of the Arabic numbers '2' and '3' were used, performed more poorly with the letters 'R' and 'B' represented by different fonts. The cautionary lesson from these results is that the equivalent performance levels of the two baboons on the initial categorization tasks may indeed have been mediated by different processes. Perhaps, the latter baboon discriminated on the basis of 'number' versus 'other', whereas, the former animal's performance was based on a more inclusive alphanumeric concept.

The Problem of Representational Resemblance

As noted in our introductory section, conceptual knowledge entails making the *same* judgment about members of a common class. According to most popular theories of human cognition (e.g., Rips & Collins, 1993) resemblance is what drives our knowledge about categories. Presumably this is true of nonhuman primates as well. If so, then a critical question is, "*Resemblance on what dimension or set of dimensions?*" How might we identify the properties by which an animal perceives and judges the members of a common class or category as "belonging" together. That is, what's the "Glue"?

Researchers have attempted to determine the conceptual level of resemblance by which natural and artificial categories are perceived and represented by nonhuman primates. For example, in one conditional matching experiment in the study by Vauclair and Fagot (1996), the letters 'A' and 'H' served as samples for the two baboon subjects. Transfer performance was tested using novel samples of the same letters from which segments had been systematically removed. Performance in the transfer tests by both subjects decreased systematically as a function of the number of removed segments and was reportedly controlled by several stimulus features such as the presence of a closed area or an apex.

Vauclair and Fagot concluded that their baboons were using a combination of stimulus features rather than any one single feature. Also, each subject attended to different feature combinations. Vauclair and Fagot interpreted their results as evidence against any simple template hypothesis of categorical representation by their animals, arguing that, if the baboons had formed template representations during training, then they should have failed to transfer because the altered stimuli did not match the original unaltered stimuli.

Such results show promise in addressing the problem of representational resemblance in nonhuman primates, but the precise nature and extent of those representations, however, remains unclear. Support for classical feature theory, prototype, or exemplar theories remains partial at best (Roitblat & von Fersen, 1992; Thompson, 1995).

The Search for Polymorphic Prototype Effects. The use of different multiple features by baboons (Vauclair and Fagot, 1996) implies that nonhuman primates may represent conceptual categories by using polymorphic prototypes in which no single feature is either necessary or sufficient to determine categorical membership. The prototype presumably represents the central tendency of the polymorphic features (e.g., see Dépy, Fagot & Vauclair, 1997; Jitsumori, 1994).

In one study Jitsumori (1994) found no differences in the discriminative transfer performance of rhesus monkeys (*Macaca mulatta*) with prototypical and nonprototypical artificial stimuli. The stimuli were defined by three 2-valued positive or negative dimensions of color, shape and background color. Similarly, Dépy et al. (1997), using a conditional matching procedure, trained both human and baboon subjects to discriminate two artificial categories defined as having any two out of three possible binary features. Category one (C1) comprised at least two of: blue background color, polygon elements, and positioning of the elements in the upper half of the stimulus display. Category two (C2) comprised at least two of: yellow background color, semicircular elements and positioning of the elements in the lower half of the display. In the transfer tests prototypes, comprised of all three categorical defining features, were presented as were novel two-out-of-three categorical exemplars. Humans showed no better performance with the prototypes than with the nonprototypical exemplars. In contrast, the monkeys classified the prototypes more accurately than the nonprototypical exemplars. However, detailed followup analyses revealed that the animals' performances during training were more likely controlled by the results of individual feature-exemplar learning than by the use of prototypes. Dépy et al. (1997) argued that the prototypical forms during the transfer tests resulted from enhanced attention due to stimulus novelty conjoined with a 'peak shift' effect reflecting differences in associative strength between stimuli and response choices in the conditional matching task. That is, a prototypical C1 stimulus was more closely associated to a training exemplar from C1 than nonprototypical forms of C1 because of its greater difference from C2 in terms of the number of feature values. Similar findings and interpretations have been reported also for human subjects (McLaren, Bennett, Guttman-Nahir, Kim, & Mackintosh, 1995).

Are Categories Simply Features Judged to be the Same? Results of the type described above with artificial stimulus classes (Dépy et al., 1997) support Roberts' (1998) recent

claim that, "No experiments have shown a prototypic effect with the wide ranging types of photographs used to demonstrate *natural* categories in animals." (Roberts, 1998, p. 341). As with artificial categories, the presence and possible conjoining of simple features can control the discrimination of natural categories by monkeys. In a study of the "person concept" by capuchin monkeys (*Cebus apella*), for example, D'Amato & van Sant (1988) found that the color red occurred more often in slides with humans than in those without humans. Analysis of their results further indicated that the monkeys were more likely to misclassify animal and flower slides as "person" if they contained a patch of red. Presumably, then, the feature red conjoined with some unidentified "animate" feature or features comprised the category controlling the monkey's discrimination performance.

Global versus Local Feature Control. Further evidence that monkeys are predisposed to use simple features or local cues for identifying conceptual categories comes from recent comparative tests for the global precedence effect in nonhuman primates. The global precedence effect reflects the fact that human adults selectively attend to global features of a stimulus rather than the local features (Navon, 1977). This seems counter-intuitive if we assume that the global level of processing depends on first processing the local features. However, the global precedence effect suggest that for humans at least the global pattern is perceived as a Gestalt whole, a single feature in and of itself, rather than a set of individual features. We can, of course, shift attention to local features of a display (in essence "breaking-down" the global stimulus), but this process is reported significantly more slowly than the initial global perception (Paquet, 1992; Paquet & Merikle, 1988).

Recent research with baboons and chimpanzees point to a difference between them and humans with respect to the Global Precedent Effect (e.g., Fagot & Deruelle, 1997; Fagot & Tomonaga, 1999). Fagot and Deruelle (1997) used a matching-to-sample task with humans and baboons in which the test stimuli consisted of squares, circles, diamonds or X signs. The global forms of these stimuli were constructed from 12 local elements consisting of smaller squares, circles, diamonds or X signs. In one condition, subjects were required to attend to stimulus differences at the global level. In another condition, attention to differences at the local level was required. Whereas the human subjects performed more accurately in the global matching condition, the baboons were significantly more accurate in the local matching condition. Results from other recent studies further support the conclusion that monkeys primarily process local details or features of visual forms while apes, like humans, primarily process their global structure (Fagot & Deruelle, 1997; Fagot & Tomonaga, 1999). Results from tests by Hopkins (1997) further revealed evolutionary homologous hemispheric specialization for local and global processing between chimpanzees and humans.

VII. ABSTRACT CATEGORICAL AND RELATIONAL CONCEPTS

Thus far, we have focused on those cases in which membership in a common class is based on categorical identity presumably founded upon shared sensory or physical resemblance. Class membership may also be based on shared associative histories, or

abstract properties including function, space, time, perceptual relation, or analogical relations between relations.

Abstract Functional Relations

Some investigators have claimed that baboons (*Papio anubis*) and chimpanzees (*Pan troglodytes*) can discriminate both natural categories (i.e., food items vs. nonfood items) and - in the apes' case - artificial categories (i.e., tools from nontools) on the basis of their *functional* resemblance (e.g., Bovey & Vauclair, 1998; Fabre-Thorpe, Richard, & Thorpe, 1998; Savage-Rumbaugh, Rumbaugh, & Boysen, 1978; Savage-Rumbaugh, Rumbaugh, Smith, & Lawson, 1980). Despite their success *using* tools, capuchin monkeys (*Cebus apella*) provide little evidence in transfer tests that they conceptually *comprehend* invariant cause-effect relations (Visalberghi & Limogelli, 1994). Chimpanzees also can sort collections of objects into separate categories like toys and utensils (e.g., Matsuzawa, 1990; Spinozzi, 1993). Furthermore, they can sort objects on the basis of their previous learned complimentary functional relations (Tanaka, 1995) such as that between a bottle and its cap.

Abstract Perceptual Relations

There is evidence that both monkeys and apes can discriminate classes on the basis of abstract perceptual relations like proportions, volume (Thomas & Ingram, 1979), geometric form (Burdyn & Thomas, 1984), and numerosity (e.g., Beran, Rumbaugh & Savage-Rumbaugh, 1998; Boysen & Bernston, 1989; Brannon & Terrace, 1998). For a full account of this literature see Boysen (this issue). There are numerous demonstrations also that nonhuman primates can learn transitive inference tasks and the ordinality of serially ordered items in arbitrary lists. For recent reviews see De Lillo (1996) and Terrace & McGonigle (1994).

Transitive Inference and Serial Order

The ability of nonhuman primates and other animals to infer transitive relationships between previously unpaired items is typically tested by first training them on five successive pairs of stimuli. These are presented in the form of simultaneous discriminations in which an item appearing in two successive stimulus pairs is rewarded (+) in one case and not in the other (-) as, for example, in the series: A+B-; B+C-; C+D-; D+E-. The test for transitivity involves presenting novel stimulus pairs from items that were never previously paired (e.g., BD). Here, B is the correct choice implying transitive inference which for primates has been demonstrated in humans (Chalmers & McGonigle, 1984), but also chimpanzees (Gillan, 1981; Boysen, Bernston, Shreyer & Quigley, 1993), and new- and old-world monkeys (e.g., D'Amato, & Colombo, 1988; McGonigle & Chalmers, 1977; Treichler & van Tilberg, 1996).

Resemblance by Relation or by Association?

As is the case with perceptual categories, exactly how nonhuman primates and other animals encode and represent their knowledge of these abstract relations has yet to be unequivocally determined. Associative processes likely play an important role in categorization and stimulus class formation by both animals and people (e.g., Astley & Wasserman, 1996; Mackintosh, 1995; Wasserman, DeVolder, & Coppage, 1992; Wasserman & DeVolder, 1993; Wasserman & Astley, 1994; Zentall & Smeets, 1996).

Two types of fruit, (e.g., green apple and yellow banana) which differ on the basis of distally perceived properties, like color, size, shape and texture might well be categorically associated together by immediately less obvious common proximally perceived properties such as taste coupled together with compressibility resulting from their being ingested (i.e., mastication transforms both to sweet slurries). Food classification by chimpanzees (Savage-Rumbaugh et al., 1980) has been explained in terms of 'mediated generalization' (Epstein, 1982; Pearce, 1997). "When a chimpanzee picks up an item of food it may react in some consistent way, such as by salivating. In order to solve the discrimination, therefore, all the animal has to learn is that any object which elicits this reaction must be treated in one way, and objects which do not elicit this reaction must be treated in another way" (Pearce, 1997, p. 124).

Acquisition of the food category by the chimpanzees, however, occurred with acquisition of the tool category in the context of 'language training' with initially arbitrary lexigrams. Savage-Rumbaugh et al. (1980) alternate interpretation of their findings was that they were mediated by symbolic representations. When two initially unrelated stimuli (e.g., tools) are each independently associated with the same event an emergent relation can develop between those stimuli such that they are then treated similarly or interchangeably in other contexts (e.g., Sidman, 1994; Zentall, 1998). Hence, in the case of the chimpanzees, as with humans, the arbitrary lexigrams assigned to a class of objects -food and tools - became symbolic substitutes, like words, for the objects they represented, and vice versa (e.g., Cerutti & Rumbaugh, 1993; Savage-Rumbaugh, 1986).

With respect to transitive or serial order relations some researchers have argued for a relational spatial coding hypothesis (e.g., Chen, Swartz, & Terrace, 1997). This assumes that stimulus representations are placed along a linear spatial map as has been postulated in human transitive inference studies (e.g., Sternberg, 1980). Alternative associative models of transitive inference in both primates and nonprimates have received increased attention in recent years (e.g., Delius & Siemann, 1998; Wynne, 1997). Some such models are based either on direct reinforcement histories of test stimuli (e.g., Couvillon & Bitterman, 1992) or associative value transfer in which the rewarded member of a stimulus pair transfers some of its associative strength or value to the nonrewarded pair item (von Fersen, Wynne, Delius, & Staddon, 1991). Studies of social concepts, which are addressed elsewhere in this issue by Seyfarth & Cheney, provide additional evidence of associative processes being the representation "glue" in monkeys rather than the more abstract

propositional encoding of the human investigators (cf., Thompson, 1995; Seyfarth & Cheney, 1997).

VIII. ANALOGICAL REASONING: JUDGING RELATIONS-BETWEEN-RELATIONS

Not all Identity Judgments Are The Same

Despite the above cited evidence for the discrimination of abstract relations by nonhuman primates those tasks differ fundamentally from the types of tasks which are discussed in detail in the sections that follow. The tasks commonly cited as evidence for relational concepts in nonhuman primates do not require them to *explicitly* judge one exemplar of an abstract *relation* as being the same or different from another exemplar of the same abstract *relation*. This latter ability is demonstrated, for example, when a chimpanzee spontaneously matches half an apple with half a glass of water rather than either a whole apple or a full glass of water (Premack & Premack, 1983). The capacity for judging relations-between-relations (i.e., $1/2$ [relation 1] is the *same* [relation 2] as $1/2$ [relation 1]) is further confirmed when the same chimpanzee now matches a full glass of water with a whole apple, rather than to either half a glass of water or half an apple.

This form of abstract relational judgment differs fundamentally from other abstract categorical judgments discussed thus far. Should the chimpanzee match the two water glasses or the two apples we could argue that these judgments are likely grounded on physical resemblance. If the chimpanzee matches an apple with a banana and water glass with pottery bowl we might suspect these judgments are based on functional resemblance, rule or association. But consider the case now when the chimpanzee matches half of 'any-novel-thing' with either half a glass of water or half an apple and then matches the whole or full 'any-novel-thing' with either the full glass or full apple. Then we have evidence of a truly abstract relational concept in the sense that this judgment transcends any particular perceptual attribute, rule or association (every 'any-novel-thing' is neither a fruit nor a container); this abstract relational concept is totally 'portable'.

As we shall demonstrate further on, failure to acknowledge the above distinctions has led to widespread confusion and misunderstanding of what constitutes evidence for abstract conceptual knowledge (Premack, 1983a, b; Thompson & Oden, 1996). We believe, as argued below, that the ability to match relations-between-relations (i.e., half an apple to half a glass of water and full glass to whole apple) is the cognitive primitive for *analogical* reasoning.

Some investigators have argued that analogical reasoning is the common foundation of much of human conceptual thinking including logical inference (e.g., Halford, 1992). The ability to perceive and judge abstract relations-between-relations is a prerequisite for this ability. At the very least, an analogy involves first establishing a relationship between two elements and then seeking that same relationship between two different elements. For example, the expression, dog:puppy::cat:kitten is a properly constructed analogy since the "adult -juvenile" relation appears on both the left side (for canines) and on the right side

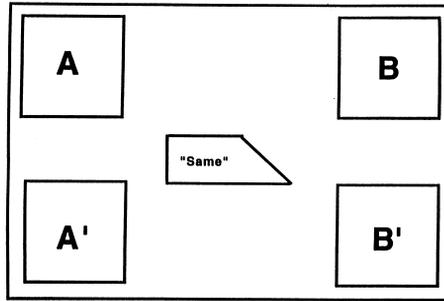


Figure 1. Matrix format for completion and construction of analogies by a chimpanzee.

(for felines). Thus analogical reasoning is about the ability to judge whether one relationship is the same as another. That is, the ability to judge relations-between-relations.

Analogical Reasoning by Apes

Analogies can, but need not, be expressed linguistically. As with human infants and children one can measure analogical reasoning abilities using nonlinguistic tests involving, for example, analogical relations between geometric forms (e.g., Goswami, 1989). Gillan, Premack, and Woodruff (1981) were the first to study analogical reasoning in a chimpanzee - Sarah, who succeeded in completing partially constructed analogies involving complex geometric forms and functional relationships. The elements of an analogy were presented to Sarah in a 2×2 matrix format as shown in Figure 1.

In Figure 1 the stimuli, labeled A and A' exemplified a certain relation, the stimuli labeled B and B' exemplified the same relation but with different items, and "same" was the plastic word for this concept from the chimpanzee's artificial language (Premack, 1976). In some of these experiments, the elements were geometric forms and the relations on the vertical dimension involved a transformation of some physical property; for example, large blue triangle/small blue triangle "same" large yellow crescent/small yellow crescent. In other experiments the elements were familiar objects and the relations were functional ones; for example, padlock/key "same" tin can/can opener.

In one set of experiments, Sarah was presented with three terms of an analogy (A, A', and B) positioned according to the 2×2 format described above and she was required to select the appropriate fourth term (B') when presented with two alternatives. In another set of experiments, four items were presented in the 2×2 analogy format. Sarah was required to choose between her word for "same" and her word for "different" depending on whether the arrangement did or did not constitute a true analogy. Sarah succeeded in solving both types of problems. Gillan et al., (1981) interpreted Sarah's successes as evidence of reasoning about relations-between-relations. That is, she presumably established the relationship "same" (or "different") *between* the two sides of the analogy by first assessing and then comparing the relationships *within* each side.

Analogy Completion and Construction Tasks

Following the original studies reported by Gillan et al. (1981), Oden, Thompson & Premack, (1998, in preparation) conducted a series of experiments where Sarah was required to not only complete, but also to construct analogies from geometric forms. The latter construction task in particular was substantially more demanding than those she faced in her earlier work; humans construct analogies as readily as they solve them. The two tasks, however, involve distinct capabilities. Completing analogies requires comparing relations which have been established whereas constructing analogies requires one to seek relations which reside among stimuli but which have yet to be specified. The materials used in these experiments were similar to those used by Gillan et al. (1981). The experimental stimuli were squares of white cardboard, each with a geometric form stenciled on it. The forms varied in shape, color, size, and outline versus solid color. Nondifferential feedback was used on all construction trials.

In the *completion* tasks A and A' were present on the display board and Sarah's task was to choose the correct B and B' geometric forms from several alternatives. When presented with only two elements of a classical analogy problem Sarah successfully chose from 3 alternatives the two elements necessary to complete the problem. More importantly however, was the finding that her spatial arrangement of these choices was guided by the relation initially established by the experimenters and not on the basis of mere similarity along any single physical dimension.

In the *construction* tasks the empty display board was presented to Sarah and her task was to arrange four elements from a randomized group of geometric forms on the board in any manner she chose. When presented with the minimum of 4 elements Sarah typically arranged them in analogical fashion. When presented with 5 elements of which 4 could be used to construct an analogy she tended to ignore the inappropriate item and typically arranged the remaining items analogically by paying attention to the number of changes between the target and base rather than the nature of the changes. Hence, these results confirm and extend the earlier reports (Gillan et al., 1981) that analogical reasoning is within the capabilities of at least one adult chimpanzee.

Matching Relations-Between-Relations: The Cognitive Foundation for Analogical Reasoning

Premack (1983b) argued that explicit analogical reasoning is implicit in the chimpanzee's ability to match relations-between-relations. As, for example, when a chimpanzee matches a pair of identical objects like, for example, a pair of locks with another pair of identical objects, like say, two cups, rather than a pair of nonidentical objects such as a pencil and an eraser. Likewise, the latter nonidentical pair should be matched with another nonidentical pair like, for example, a shoe and a ball, rather than with an identical pair. For expository purposes individual objects are represented with letters in Figure 2. The task, then, for example, is to match AA with BB (and not CD) and to match EF with GH and not JJ. Successful performance of the conceptual-relational matching task described above

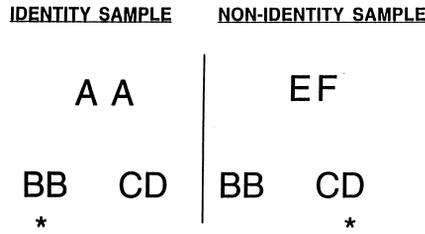


Figure 2. Conceptual-relational matching task. Note: * indicates correct choice.

requires that the animal judge one relation to be the same or different from another. In this case, the judgment is whether one example of *relational* identity (i.e., AA) is the same as another physically distinctive example of *relational* identity (i.e., BB). Alternatively, the animal must judge that an example of relational nonidentity (i.e., CD) is the same as another physically distinctive example of *relational* nonidentity (i.e., EF). The conceptual-relational matching task then is in essence a form of analogy in which all the arguments are provided for the subject.

Profound Disparities in Conceptual Relational Abilities

Abstract Relational Judgments by Language-Naive versus Language-Trained Chimpanzees. Premack (1983b) reported that conceptual-relational matching was expressed by only those of his chimpanzees who had a history of ‘language training’. This observation was further confirmed by the finding that infant chimpanzees without prior experience with a token based symbol system failed to match conceptually despite their success on a generalized matching task based on physical resemblance between objects (Oden, Thompson, & Premack, 1988; 1990). As noted previously, these animals spontaneously transferred their matching ability to novel objects after initial training with only two objects, a lock and a cup. Nevertheless, when initially trained on the conceptual-relational matching task using a minimum number of exemplars they learned only to associate one element of an identity or nonidentity pair with another element from the appropriate choice pair. Performance did not transfer to novel pairs instantiating the identity and nonidentity relations. Additional training with multiple exemplars over more than a 1000 trials per animal was no more successful. In this regard they were no different from other chimpanzees who had not been exposed to ‘language training’ with tokens symbolizing the relations same and different as described by Premack (1976) and Premack and Premack (1972).

There are two brief reports of possible conceptual-relational matching in language-naive chimpanzees after thousands of trials (Smith, King, Witt, & Rickel, 1975) and what Premack (1988) labeled ‘dogged training’. However, the limited efficacy of these procedures stands in sharp contrast to more recent research which confirmed the hypothesis that prior experience with symbols for relations per se, rather than linguistic arrays of such

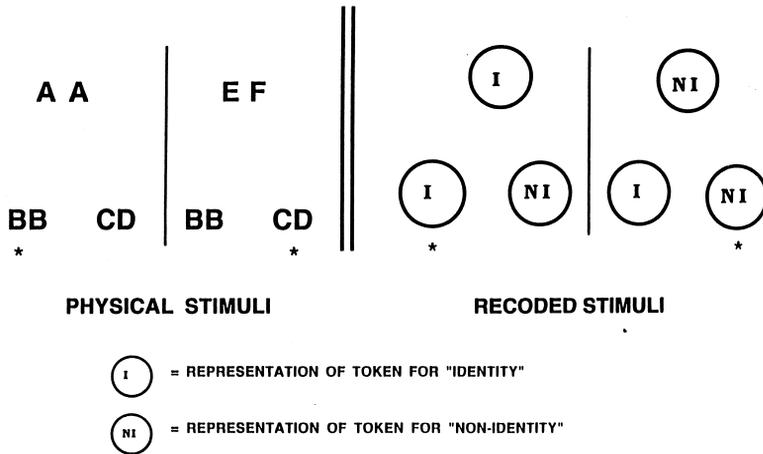


Figure 3. Recoding of conceptual-relational matching to sample task by symbol-sophisticated chimpanzee.

tokens, is sufficient for chimpanzees to *immediately* succeed in a conceptual-relational matching task (Thompson, Oden, & Boysen, 1997).

Prior to testing on the conceptual-relational matching task, the chimpanzees in the Thompson et al. (1997) study had been trained to choose a heart-shaped token when presented with an identical pair of objects and to choose a diagonally shaped token when presented with a nonidentical pair of objects. They also had prior experience matching Arabic numerals with groups of objects matching the number indicated by the numeric symbol (Boysen & Bernston, 1989). These chimpanzees had never previously encountered a conceptual-relational matching task. Nevertheless these same animals, like Sarah, spontaneously matched relations conceptually under conditions of nondifferential reinforcement. As illustrated in Figure 3, Thompson et al. (1997) hypothesized that the external tokens in the previous tasks functioned like words, providing the animals with concrete icons for computational and encoding processes involving abstract propositional representations. These external tokens were not available during the conceptual-relational matching tasks. Thompson et al. (1997) reasoned that the abstract relations of identity and nonidentity evoked covert representations of these symbols permitting the animals to explicitly judge what would otherwise be only perceptually implicit.

According to Thompson et al. (1997), "Conceptual relational matching is made possible by the chimpanzee's representational capacity to re-encode abstract relations, which are instantiated by physically disparate sample and alternative pairs, into iconically identical symbols. It follows from this analysis that prior token training reduces conceptual relational matching to a task that is functionally equivalent to physical matching." (Thompson et al., 1997, p. 42). This latter idea was reiterated recently by Andy Clark who wrote, "Learning such a set of tags and labels. . . is, I would speculate, rather closely akin to acquiring a new perceptual modality. For, like a perceptual modality, it renders certain features of our world concrete and salient and allows us to target our thoughts (and learning algorithms) on a new domain of basic objects." (Clark, 1998, p. 175).

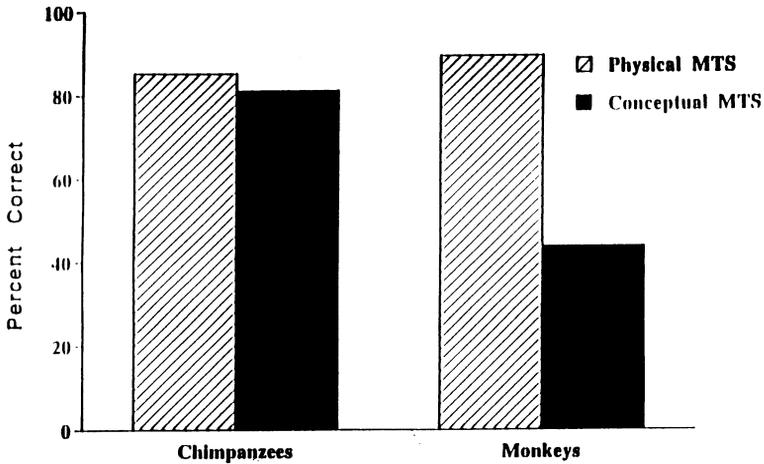


Figure 4. Perceptual and conceptual matching to sample by monkeys and chimpanzees. Chimpanzee data from Thompson et al., 1997. Monkey data from Washburn et al., 1997.

Can Monkeys Match Relations-Between-Relations?

Old-world macaque monkeys trained with symbols for same and different with procedures comparable to those experienced by chimpanzees cannot judge the analogical equivalence of stimulus pairs in an conceptual-relational matching task (Washburn, Thompson, & Oden, 1997; in preparation). Test-sophisticated monkeys in David Washburn’s laboratory (e.g., Washburn, Hopkins, & Rumbaugh, 1989) were trained to choose a circle and not a triangle cue in the presence of an identity stimulus pair. Conversely, choosing the triangle and not the circle was rewarded in the presence of a nonidentity stimulus pair. After acquisition of this task the monkeys transferred their performance to novel exemplars of identity and nonidentity. Also, the discrimination acquired by the monkeys was symmetrical. Presented with either a circle or triangle Washburn’s animals respectively correctly chose the identity or nonidentity pair. Nevertheless, as shown in Figure 4, the monkeys, unlike the chimpanzees, failed to match relations (same or different) between relations (identity or nonidentity) despite the fact that their physical matching performances did not differ from those of the chimpanzees. The disparity seen in this study is interesting because it suggests a qualitative difference in the conceptual capacities of monkeys on the one hand and apes and children on the other.

Not all Relational Conceptual Discriminations are Analogical

The disparity is all the more curious in light of prevailing interpretations of results from a study by Burdyn & Thomas (1984) with new-world squirrel monkeys. Burdyn & Thomas (1984) animals were presented simultaneously with an identity pair (AA) and a nonidentity pair (CD) separated by a conditional discriminative cue. They were rewarded for choosing the identity pair (AA) given a triangular conditional cue and for choosing the

nonidentity pair (CD) given a septagonal cue. Note that this procedure was functionally equivalent to that used by Washburn et al. (1997) with old-world macaque monkeys.

As in Washburn et al.'s (1997) later study, Burdyn & Thomas (1984) reported good transfer by their squirrel monkeys when new identity and nonidentity pairs were used. In addition, the squirrel monkeys' performance levels were maintained when novel triangles and septagonal conditional cues were presented. For Burdyn and Thomas, these results implied that their new-world monkeys had learned the concepts "relational sameness" and, as well, the abstract concepts "triangularity" and "septagonality."

Tomasello & Call (1997) similarly took Burdyn and Thomas' results as evidence of an abstract concept of relational sameness in monkeys. But if this were the case, then why did Washburn's monkeys, equally skilled on a comparable task, fail to match relations conceptually? The resolution of this apparent paradox lies in recognizing that the tasks used by Burdyn & Thomas (1984) and Washburn et al. (1997) are qualitatively different and computationally less complex than the conceptual-relational matching task (Thompson & Oden, 1996); the tasks are *not* conceptually identical.

We believe that a monkey can solve the Thomas and Burdyn task by a simple rule involving a single physical matching operation. That is, if you see a triangle, then touch the pair in which the two items match physically (A is A, or B is B). Conversely, if you see a septagon, then touch the pair in which the two items physically differ (CD or EF). As noted in a previous section of this paper, there is good evidence that monkeys demonstrate this type of generalized physical matching-to-sample.

However, as the name implies, conceptual-relational matching additionally requires an animal to map one relation on to another relation (Thompson & Oden, 1993, 1996; Holyoak & Thagard, 1995). A single matching operation doesn't identify the correct choice. For example, given an AA sample the animal has to compare A to A, encode that outcome (A matches A = Identity [I]), then looking at the two pairs of choice alternatives, carry out matching operations on them and encode the outcomes (B matches B = Identity [I]; E doesn't match F = Nonidentity [NI]). Finally, and most importantly, the animal has to compare the outcomes: (I&I) = same; (I&NI) = different; and importantly also, (NI&NI) = same.

Like Premack (1983a, b), then, we believe that the conceptual-relational matching task qualitatively differs from other tasks that measure conceptual relations in animals, including nonhuman primates (Thompson & Oden, 1993, 1996). Unfortunately, this fundamental distinction is still misunderstood, and hence its implications are not fully appreciated (cf., Tomasello & Call, 1997; Thomas, personal communication, 1997; Young & Wasserman, 1997).

Procedural Strategies are not Conceptual Relations

Nowhere in the task used by Burdyn & Thomas (1984) were their monkeys required to *explicitly* judge one identity pair as being the same as another, or to judge one nonidentity pair to be the same as another nonidentity pair. When Washburn et al. (1997) required their monkeys to make explicit judgments about the sameness of one identity or noniden-

tity relation to another in a conceptual-relational matching task, they failed to do so. In the case of those monkeys, unlike chimpanzees, the conditional cues failed to acquire the status of *symbols* representing abstract relations of identity and nonidentity. Rather they apparently functioned as discriminative stimuli associated with specific response rules of, for example, “if match, approach in the presence of triangle, and if nomatch, then approach in the presence of septagon.”

Apparently, the conditional discriminative cues in the studies using monkey subjects control the differential expression of explicit *procedural strategies* as documented, for example, also in learning-to-learn experiments where the response rule might be win/stay, lose/shift (Harlow, 1949). The same type of conditional discriminative cues used with chimpanzees, however, acquire the status of symbolic representations of conceptual relations which are functionally analogous to human words.

Problems of Instrumental Failure

Why should the same type of training have such disparate outcomes in monkeys and chimpanzees? Why should a token continue to evoke merely a response rule in a monkey and not a conceptual relationship as in a chimpanzee? We believe that the evidence described below strongly suggests that the monkeys, unlike the chimpanzees or children, do not appreciate - even perceptually - that the relation upon which the response rule is based is indeed a *relation*. Our hypothesis is that monkeys can apply broadly construed response rules to objects and events that are perceived to be categorically the same or different on the basis of physical resemblance or association between particular features and perceptual elements. As implied by our earlier discussion of the global precedent effect, we believe they have no conceptual comprehension of abstract *relations* as such. Before one can conclude that an animal ‘has the concept’ explicit judgments of relational equivalence are required.

Why Might an Animal Fail an Instrumental Conceptual Task?

Any attempt to fully comprehend and understand the processes underlying conceptually mediated behavior should account not only for the causes of success, but also causes for failure. Is it a failure of judgment or, alternatively, a failure of perception? Instrumental measures alone cannot provide an unequivocal answer. Researchers, for the most part, have not appreciated the fact that instrumental tasks confound the *implicit perceptual* and the *explicit judgmental* components of conceptually mediated behavior. Ideally, a comprehensive study of concepts in nonhuman primates should permit one to separate out the effects of the implicit and explicit components on conceptually mediated performances. We have encouraged, therefore, conjoining the use of instrumental tasks with the methodologies used to investigate perceptual capacities in preverbal human infants (Oden et al., 1988; Thompson & Oden, 1996).

IX. MEASURING PERCEPTUAL SENSITIVITY TO ABSTRACT RELATIONAL CONCEPTUAL CLASSES

Noninstrumental perceptual tasks which are becoming increasingly used with nonhuman primates, both in the field and laboratory, use preferential gaze or object manipulation as the dependent measure in familiarization/novelty or violation of expectation tasks as well as habituation/dishabituation procedures (e.g., Hauser, MacNeilage, & Ware, 1996; Oden, Thompson, & Premack, 1988; Cheney & Seyfarth, 1990; Thompson & Oden, 1996; Gunderson & Swartz, 1986).

Preference for Novelty Tasks

Typically in these tasks, there is a stimulus familiarization phase followed by a stimulus test phase. In the familiarization phase, the familiar stimulus is an exemplar from the conceptual class in question. This might be a natural or an artificial category as studied with instrumental procedures, or as in the examples used here, abstract relational concepts. Hence, in this case, the familiarization stimulus might be, for example, a pair of objects (e.g., AA) instantiating the relation "identity." In the test phase, an exemplar from a different relation (e.g., CD, instantiating "nonidentity") is presented as well as a physically novel exemplar from the familiarization relation (e.g., BB). The stimuli in the test phase might be presented simultaneously or on alternative test trials.

If an animal is perceptually sensitive to the categorical or relational distinction in question (i.e., 'identity and nonidentity') then it will attend differentially during the test phase to exemplars of the novel and familiar relational categories. This is typically expressed as a preference for the relationally novel stimulus presented in the test phase (e.g., Oden et al., 1988; Tyrrell, Stauffer, & Snowman, 1991) or as a "violation of prior expectation" (e.g., Hauser et al., 1996). If the subject is not sensitive to the relational class in question, then neither the novel nor the familiar stimulus should be preferred during the test phase.

Habituation/Dishabituation Procedures

The design and logic of habituation/dishabituation procedures are similar to those of preference for novelty procedures. But in contrast to the paired comparison tasks, the subject, rather than the experimenter, controls the total time spent processing the stimuli in the habituation/dishabituation procedure. Typically, each session consists of an initial series of habituation trials followed by a single test trial. On each habituation trial the subject is shown an exemplar of the categorical or relational class in question (e.g., AA = Identity) for a fixed period during which "Looking-time" or "Handling-time" is recorded. Following a very brief (1–2 s) intertrial-interval the stimulus is presented again. These presentations are continued over successive trials until a predetermined habituation criterion is attained. For example, the criterion might be a cumulative looking-time over two successive trials which is equal to or less than 50% of that recorded on the first two

trials. At this point the test-trial is presented following the intertrial interval. Commonly two types of test trial are used. In one case the test stimulus is a novel exemplar drawn from the same conceptual class (e.g., BB) as the stimulus used in the habituation trial series. In another case, the test stimulus is an exemplar of a novel class (e.g., CD = Nonidentity).

The interpretation of results parallels that of the preference for novelty tasks. A significant recovery in looking time on the test trial (i.e., dishabituation) is taken as evidence that the subject detects the stimulus information presented on the test trial as being different from that experienced during the habituation phase. In general, the physical novelty of the test stimuli produces some dishabituation on all test trials. If a subject were also sensitive to relational novelty then one would predict that dishabituation would be even greater when novel test stimuli also instantiated a novel class.

Is Implicit Perceptual Sensitivity Equivalent to Conceptual Understanding?

As is evidenced from the results described above, tasks, like the 'preference for novelty' test, have the power to uncover perceptual capacities unconfounded by age and species differences in motor abilities and sensitivity to reward contingencies. However, this implicit capacity per se is not sufficient evidence of conceptual understanding or knowledge. As argued earlier our criteria for attributing conceptual understanding to an animal additionally require that it provide unequivocal evidence that it explicitly judges common class members to be equivalent. This latter requirement has been overlooked, or not fully appreciated, by researchers in this area (e.g., Tomasello & Call, 1997). As the perceptual methods do not require the animal to make an explicit equivalence judgment, they do not provide unequivocal evidence for conceptual *understanding* or knowledge in nonhuman primates.

Profound Disparities in Relational Perceptual Abilities

Implicit Recognition of Relations-between-Relations by Infant Chimpanzees and Humans. Oden, Thompson, & Premack (1990) tested infant chimpanzees using a familiarization/novelty procedure with pairs of objects that were exemplars of relational identity (e.g., AA and BB) and nonidentity (e.g., CD and EF) as familiarization and test items. The infant chimpanzees spontaneously perceived whether a relation of identity or nonidentity instantiated by a pair of objects was the same as, or different from, the relation instantiated by a previously presented pair of objects.

The evidence for this conclusion lies in the finding that the time the infant chimpanzees spent handling a pair of items over a five minute trial depended on whether or not it differed, not only physically but also relationally, from the pair of items handled in the preceding trial. For example, on Trial 2 an identical pair of objects (i.e., BB) was handled less when it was preceded on Trial 1 by another identical pair (e.g., AA) than when it was preceded by a pair of nonidentical objects.

Subsequently, Tyrrell, Stauffer, & Snowman (1991) demonstrated with a paired-

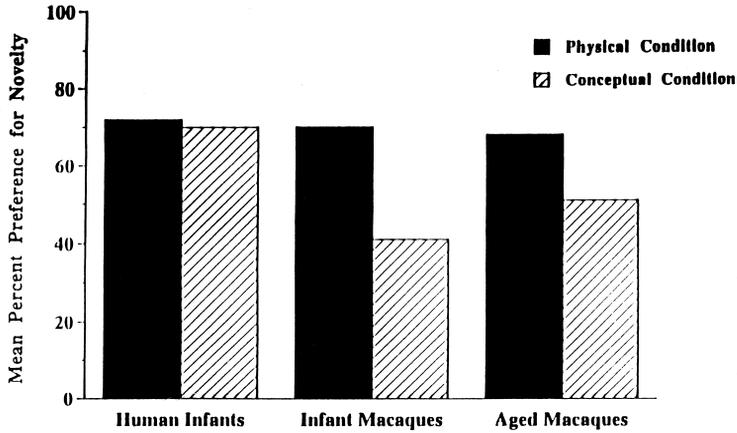


Figure 5. Percent preferences for physical/object and conceptual/relational novelty in visual paired-comparison tasks. Data for human infants derived from Tyrrell et al. (1991). Data for macaque monkey infants and adults derived from, respectively, Maninger, Gunderson & Thompson (1997), and Thompson, Oden & Gunderson (1997).

comparison familiarization/novelty test that 7-month-old human infants were similarly sensitive to novel and familiar relations-between-relations as they were to novel and familiar physical identity and nonidentity. The infants were first allowed to familiarize themselves with, say, a pair of identical objects by looking at it over a fixed period. Then the infants were presented simultaneously with a pair of identical objects and another pair of nonidentical objects, each comprised of novel items. The infants preferentially gazed longer at the relationally novel nonidentical pair than they did the relationally familiar identical pair. The effect was symmetrical; the infants gazed longer at the identical pair if first they had been familiarized with a nonidentical object pair.

Perceptual Insensitivity of Monkeys to Relations-between-Relations. In contrast to infant chimpanzees and humans, neither adult nor infant macaque monkeys showed any evidence of perceptual sensitivity to relations (novel vs. familiar) between relations (identity and nonidentity) when they were tested with the same procedure employed by Tyrrell et al. (1991). As shown in Figure 5, however, both infant and adult macaques, like human infants, were perceptually sensitive to physical identity and nonidentity (Maninger, Gunderson, & Thompson, 1997; Thompson & Oden, 1996, 1998; Thompson, Oden, & Gunderson, 1997). Thus far, subsequent tests have revealed that the adult macaque monkeys are perceptually insensitive to the similarity of relational identity and nonidentity regardless of procedure or whether preferential gaze or handling is the dependent measure (Chaudri, Ghazi, Thompson, & Oden, 1997; Thompson, Oden, Boyer, Coleman, & Hill, 1997).

Failures of Perception by Monkeys and Failures of Conceptual Judgment by Child and Ape

Given the data for monkeys, it should come as no surprise then, that on independent tests they fail the conceptual-relational matching task (Washburn et al., 1997). Monkeys lack

the perceptual foundation for the conceptual-relational matching task. Their failure on the conceptual-relational matching task is fundamentally one of perception not judgment.

Apes and human infants which implicitly can sense or recognize that a categorical or relational conceptual property is familiar or novel cannot always express that information explicitly. An inexplicable sense of “*deja vu*” based upon, “*je ne sais quoi*,” is apparently not unique to humans. The same infant chimpanzees that had previously shown that they were perceptually sensitive to the novelty or familiarity of abstract relations of identity and nonidentity were not successful on the conceptual-relational matching task (Oden et al., 1990), despite their earlier demonstration of a generalized physical matching concept (Oden et al., 1988). The chimpanzees’ failure then was fundamentally one of judgment not perception.

Why Should This Be? Apparently, as suggested by our earlier discussion of conceptual-relational matching, some prior experience with tokens which symbolize abstract same/different relations is a necessary prerequisite for the explicit expression by a chimpanzee of its otherwise only implicit knowledge about relations-between-relations (Premack, 1983b; Thompson et al., 1997). Presumably, as in connectionist computer networks (cf., Clark & Thornton, 1997), experience with external symbol systems in some way provides the necessary representational scaffolding for the complex computational operations involved in solving conceptually abstract similarity judgments, as in analogies and related tasks like conceptual-relational matching.

Representational recoding of abstract conceptual relations via symbols enable child and chimpanzee to explicitly express that which they, unlike monkeys, perceive implicitly early in life. Overall, these results suggest Lashley was correct when he wrote that, “The use of symbols depends upon the recognition of similarity, and not the reverse” (K. Lashley, 1929).

X. CONCLUSIONS

The Explanatory Role of Concepts in Nonhuman Primates

As noted in our introductory comments, comparative psychologists and behavioral primatologists commonly appeal to concepts to explain *behavior*. Paul Thagard (1992) has identified several roles concepts can play in this regard. We believe that the descriptive and explanatory roles of concepts has been justified for both monkeys and apes in six of the items included in Thagard’s list; namely, categorization, learning, memory, deductive inference, problem solving, and generalization. Our review has included instances in which nonhuman primates parse their perceptual world into *categories* and can *learn* from examples to make judgments about natural and artificial categories. Categorical concepts are implied also in both short and long-term *memorial* processes including, for example, clustering and proactive interference. *Inferential reasoning* by nonhuman primates is documented, for example, in the results from experiments on transitive inference and serial order studies.

Considerably less compelling is the evidence from nonhuman primates for the remaining items in Thagard's list of roles concepts have been deemed to play; these are, analogical inference, language comprehension, language production, and explanation. We have argued here that judgments of analogical similarity have been unequivocally demonstrated only in certain apes and not in monkeys. We believe this is because only chimpanzees, for example, like children, perceive *propositional* similarities and differences *spontaneously* and at an early age. Interestingly, like the child, the ape can make this knowledge explicit as in, for example, a conceptual-relational matching task, only if it is provided with a language or symbol system by which propositional representations can be encoded and manipulated. Absent this abstract representational capacity no animal, primate or otherwise, will ever likely satisfy the criteria for linguistically mediated conceptual comprehension, production, and coherent causal explanation.

Paleological Monkeys and Analogical Apes

We believe then that the overall pattern of results reviewed above confirms our earlier assertion that monkeys can be conceived of as "paleo-logicians" whereas, chimpanzees, like humans, are analogical. The conceptual categories of the former animals being based solely on shared predicates - absolute and relational features bound by perceptual and/or associative similarity.

As described above, chimpanzees, but not monkeys, spontaneously match conceptual-relations (analogical relations-between-relations) following acquisition of a symbolic representational system. This finding is itself an important indicator of our fundamental distinction between the analogical ape and the paleological monkey. We suspect the chimpanzee's potential for analogical reasoning per se, like that of humans, is fundamental to the development and expression of social and self-knowledge as well as a 'theory of mind' based on the analogical mapping of abstract mental states from one mind to another.

All the documented disparities between monkey and ape on tests mapping these latter attributes of, say, self-recognition (e.g., Parker, Mitchell, & Boccia, 1994) and social perspective-taking (e.g., Povinelli & Eddy, 1996) likely stem from the fundamental distinctions documented here with respect to their capacities to not only judge, but also perceive, analogical relations-between-relations.

Consilience

The ape also, unlike the monkey, demonstrates evidence of "Consilience," William Thewell's (1858) philosophical concept recently evoked by Wilson (1998). Consilience involves a "jumping together" of knowledge drawn from different groups of phenomena. The spontaneous transfer of knowledge from one domain to another is a fundamental criterion for analogical thinking. In the case of chimpanzees it originates from within the animal itself absent any explicit external prompting or instrumental training. This capacity for autonomous control is a form of cognitive expertise apparently beyond the ken of

monkeys. Even after extended instructional regimes of explicit differential reinforcement training no monkey has performed a comparable act of conceptual consilience.

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