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In Search of King Solomon's Ring: Cognitive and Communicative Studies of Grey Parrots (*Psittacus erithacus*)

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KEYWORDS

birds, cognition, communication, Grey parrots

ABSTRACT

During the past 24 years, I have used a modeling technique (M/R procedure) to train Grey parrots to use an allospecific code (English speech) referentially; I then use the code to test their cognitive abilities. The oldest bird, Alex, labels more than 50 different objects, 7 colors, 5 shapes, quantities to 6, 3 categories (color, shape, material) and uses 'no', 'come here', wanna go X' and 'want Y' (X and Y are appropriate location or item labels). He combines labels to identify, request, comment upon or refuse more than 100 items and to alter his environment. He processes queries to judge category, relative size, quantity, presence or absence of similarity/difference in attributes, and show label comprehension. He semantically separates labeling from requesting. He thus exhibits capacities once presumed limited to humans or nonhuman primates. Studies on this and other Greys show that parrots given training that lacks some aspect of input present in M/R protocols (reference, functionality, social interaction) fail to acquire referential English speech. Examining how input affects the extent to which parrots acquire an allospecific code may elucidate mechanisms of other forms of exceptional learning: learning unlikely in the normal course of development but that can occur under certain conditions.

Introduction

Most studies that examine animal-human communication use species that have either a close phylogenetic relationship to humans, such as the great apes [e.g. see Gardner and Gardner, 1969; Sarich and Cronin, 1977; Miles, 1983; Premack, 1983; Savage-Rumbaugh, 1984], or that are large-brained, such as marine mammals [e.g., Russell, 1979; note, however, Morgane et al., 1986; see Herman, 1987]. Thus when I first proposed working with Grey parrots, a species evolutionarily far-removed from humans and with brains the size of a walnut, my colleagues generally responded with disbelief. Not only were parrots thought to be mindless mimics [e.g., Lenneberg, 1967] but, prior to the 1970s, researchers had shown that birds lacked, to any great extent, a cerebral cortex [the so-called mammalian organ of intelligence; e.g., Jerison, 1973], had examined few avian species other than pigeons in studies that concentrated primarily on topics such as delayed match-to-sample [e.g., Blough, 1959; Berryman et al., 1963; Smith, 1967; Maki and Leuin, 1972; Roberts, 1972], and the general consensus was that avian

abilities were inferior to those of mammals [Premack, 1978]. Moreover, several researchers [e.g., Mowrer, 1950, 1952, 1954; Grosslight and Zaynor, 1967], using the standard operant conditioning techniques of their time, had tried and failed to establish any form of referential communication with mimetic birds. So why did I believe that I would succeed?

I have reviewed the reasons in detail elsewhere [Pepperberg, 1999]. In brief, despite all the negative evidence concerning avian abilities, researchers (a) had already demonstrated striking parallels between the ontogeny of vocal learning in birds and humans [e.g., Marler, 1970, 1973; Nottebohm, 1970, 1976]; (b) provided considerable evidence that Grey parrots at least could learn the kinds of symbolic and conceptual tasks that are generally considered pre- or co-requisites for complex cognitive and communicative skills [e.g., Koehler, 1950, 1953, 1972; Mowrer, 1950, 1954; Braun, 1952; Lögler, 1959; Thorpe, 1964, 1974]; (c) were beginning to report behavior patterns in other parrots, such as cooperative alarm signaling and individual recognition [Lawson and Lanning, 1980; Levinson, 1980; Rowley, 1980] that, when observed in nonhuman primates, are considered evidence for human-like intelligence and communicative abilities [Savage-Rumbaugh, 1986]; (d) had shown that communication within psittacine communities seemed to be mediated by complex vocalizations, apparently learned through social interactions with conspecifics or other organisms [Power, 1966a,b; Nottebohm, 1970; Busnel and Mebes, 1975; note Tenaza, 1976]; and (e) were finding information processing, vocal control and storage pathways in the brain that were analogous to those of humans [e.g., Cobb, 1960; Portmann and Stingelin, 1961; Nauta and Karten, 1971; Stettner, 1974; Nottebohm, 1980; Paton et al., 1981]. Such findings suggested that the psychologists' failures to achieve meaningful communication with their birds or to find complex cognitive processing might be a consequence of inappropriate training techniques, rather than any inherent lack of intelligence in their psittacine subjects, and that human-parrot communication might be possible. If so, such communication would be, as Griffin [1976] had proposed, a particularly powerful tool for assessing intelligence because it provides a simple, direct means for testing subjects.

My research has been a test of these premises. Starting in the late 1970s, I developed techniques that integrated the experimental rigor of the laboratory with what little was then known about psittacine communication in nature; I also borrowed ideas form projects that examined the bases for human social learning [see reviews in Pepperberg, 1985, 1988a, 1990a, 1999]. I have used these techniques successfully to establish a form of interspecies communication with Grey parrots. The data demonstrate that at least one avian species is capable of interactive, referential communication [Pepperberg, 1999]. My students and I, moreover, have used the learned communication code to test the extent of the initial subject's intelligence, and we have begun to replicate the research with additional Grey parrots [Pepperberg, 1999]. The following sections provide details of the procedures and the results.

Materials and Methods

All procedures used in this work were in accordance with the guidelines of the Animal Behavior Society and the American Psychological Association.

Subject of the Initial Study

The primary experimental subject, a Grey parrot named Alex, has been the focus of my studies on interspecies communication and avian intelligence since June, 1977. At the start of the project he was approximately 13 months old and had received no prior formal vocal instruction. He has free access to the laboratory room while trainers are present (F8 h/day), but is confined at other times to a cage and the desk upon which it rests. Water and a standard psittacine pellet (Harrison's Bird Diet) are continuously available throughout the day; fresh fruits, vegetables, specialty nuts (cashews, almonds, walnuts), cereals, sprouted grains, and pasta are provided at his vocal requests; toys are used in training.

Training Techniques

The Model/Rival (M/R) Technique

The primary training system, called the *model/rival*, or M/R technique [Pepperberg, 1981], is based on a protocol developed by Todt [1975], an ethologist interested in social learning in parrots. Todt's procedures, in turn, derived much from the work of Bandura [1971], who studied the effects of social modeling on learning in humans. The M/R procedure involves three-way interactions between two competent human speakers and the avian student. M/R training is used primarily to introduce new labels and concepts, but also aids in shaping correct pronunciation; it uses *social interaction* to demonstrate a targeted vocal behavior.

During M/R training, humans portray to the bird the types of interactive responses that are to be learned. A typical interaction proceeds as follows: Alex is seated on his gym, his cage, or the back of a chair, and observes two humans handling one or more objects in which he has already demonstrated an interest. In his presence, one human acts as a trainer of the second human. The trainer presents the object(s), asks questions about the object(s) (e.g., 'What's here?', 'What color?', 'What shape?'), and gives the human model praise and the object(s) in question as a reward for a correct answer. Disapproval for incorrect responses (erroneous answers that are similar to those being made by the bird at the time: unclear vocalizations, partial identifications, etc.) is demonstrated by scolding and temporarily removing the item(s) from the model's sight (and, depending up on the angle, sometimes the parrot's sight as well). Thus, the second human not only acts as a model for the parrot's responses and as a rival for the trainer's attention, but also allows the bird to observe effects of an error: The model is asked to try again or talk more clearly if the response was (deliberately) incorrect or garbled, thereby allowing a bird to observe 'corrective feedback' [Goldstein, 1984; Vanayan et al., 1985]. A bird is included in interactions and rewarded for successive approximations to a correct response; thus training is adjusted to its level.

Unlike the modeling procedure developed by Todt [and several other researchers, review in Pepperberg and Sherman, 2000], our protocol also involves repeating the interaction while *reversing* the roles of the human trainer and model, and occasionally includes the parrot in the interactions. We thus demonstrate that the interaction is indeed a 'two-way street': that one person is not always the questioner and the other always the respondent, and that the procedure can be used to effect changes in the environment [Pepperberg, 1981]. Inclusion of role reversal in M/R training appears to counteract what would be, for our project, the drawbacks associated with Todt's method: Todt's birds, whose trainers always maintained their respective roles, would not respond to anyone other than the human who posed the questions. In contrast, Alex responds to, interacts with, and learns from all of the trainers with whom he comes in contact.

An important feature of the M/R technique is the consistent, exclusive use of *intrinsic reinforcers* – that is, as we teach Alex labels for particular items, his reward for producing the correct label is the object to which the label or concept refers. Thus, if Alex correctly identifies a cork, that is what he receives. This procedure insures, at all times, and at every interaction, the closest possible correlation of the label or concept to be learned and the object or task to which it refers [Pepperberg, 1981].

In contrast, programs such as Mowrer's [1950] relied on *extrinsic* rewards. Thus, on the few occasions when his subjects correctly labeled food or nonfood items, or made appropriate responses to various specific commands, they received a single, particularly favored food that neither directly related to, nor varied with, the label or concept being taught. I believe that extrinsic rewards may delay label or concept acquisition by confounding the label of the exemplar or concept to be learned with that of the food reward [Pepperberg, 1981; see also Greenfield, 1978; Miles, 1983]. Alex therefore never receives extrinsic

rewards. Note that use of intrinsic rewards also demonstrates the *functionality* of the label: Initially, use of the label is a means to obtain a desired object.

On occasion, Alex may receive a more general form of reward: Because we sometimes have difficulty maintaining his interest in the set of objects that are being used to train a particular concept, we taught him to use 'I want X' [i.e., to separate labeling and requesting; Pepperberg, 1988b] so that he may be rewarded with the right to request vocally a more desirable item than the one he has identified. Such a protocol provides some flexibility but maintains the referentially of the reward: Alex will never, for example, automatically receive a slice of banana when he identifies a cork. The banana must specifically be requested ('I want banana'), and trainers will not respond to such a request until there appropriate prior task is completed. Note that training the use of 'want' provides two interesting advantages: First, such a protocol could eventually be used to reward Alex for responding to queries about objects he could not be given, such as trees. Second, once a bird uses 'want' appropriately, trainers are able to distinguish incorrect labeling from appeals for other items; that is, during a test a bird that did not use 'want' could simply be asking for a more desired object rather than be making an error. Test scores might thus decline for reasons unrelated to a bird's competence [Pepperberg, 1990b].

Testing Procedures

To evaluate what the parrot has learned we regularly administer tests that simultaneously include questions on all of the tasks that have been trained [Pepperberg, 1981]. Test questions for each topic therefore occur only on average one to four times per week. Our detailed test procedure can be found in any of several prior publications [e.g., Pepperberg, 1981, 1990a, b, 1999]. But, because confidence in our results requires confidence in both our controls against cuing and our method of scoring Alex's responses, I will review those aspects of our procedures in some detail.

Precautions Against Trainer-Induced Cuing

Two procedures are used to avoid this type of cuing [Pepperberg, 1981, 1990a, b, 1999]. One procedure is a design that prevents either the subject or the principal trainer from predicting which questions (or answers) will be tested on a given day. To construct a test, the trainers proceed as follows: The principal trainer first lists all of the possible questions about objects or combinations of objects for the topics that are to be examined. A student who will not administer a test then arranges the objects that are involved in the question, e.g., forms the pairs (for questions on same/different) or collections (for numerical and comprehension questions), and randomly orders all the questions. The principal trainer then acts as a 'blind' evaluator (see below) while other students present questions intermittently during training sessions on current (and thus unrelated) topics over the course of several days until all the questions on the test have been presented. At the same time that we were conducting the studies on number concepts and same/different, for example, we were training and testing additional labels [Pepperberg, 1987a, b, 1988c], training photograph recognition, and testing object permanence [Pepperberg and Kozak, 1986]. Test questions such as 'How many?' were thus as likely to occur during training sessions on photograph recognition as during tests on 'Where's the key?' The opportunity for any particular object or collection of objects to appear on a test might occur only once per week and therefore could not be predicted. A second precaution against cuing is to ensure that trials on a particular topic are conducted by students who had never trained the parrot on that topic. The same student could, however, test several other topics, so that the presence of a specific student would not serve as a cue as to which particular topic would be tested [Pepperberg, 1981].

Precautions Against 'Expectation Cuing

Intermingling different types of questions (e.g., 'How many?', 'What's this?', 'What color?', 'What's same?', 'What's blue?') on tests or during training on other topics not only prevents cuing by the trainers,

but also ensures against ‘Expectation cuing’ that may occur when a subject ‘expects’ questions to concern a single topic. If a subject uses contextual information in single-topic tests to limit its responses to a small subset of its repertoire, the *range* of knowledge being tested will be much more limited than the experimenter assumes, and this limit could enable the subject to perform at a level higher than would otherwise be justified by its real knowledge of the topic. Alex, however, is never tested exclusively on questions on a single topic (e.g., number labels) in one session, and, more importantly, is never tested successively in one session on similar questions (‘What’s same?’) or ones that would have one particular correct response (e.g., ‘three wood’). A question is repeated in a session only if his initial answer is incorrect [Pepperberg, 1981]. Thus, even though the range of correct responses to questions of, for example, ‘What’s same?’ or ‘What’s different?’ was limited initially to three labels (‘color’, ‘shape’, or ‘matter’), and responses to questions about number were initially limited to the labels ‘one’ through ‘five’, in any session Alex also had to choose form among many possible responses to other queries such as ‘What’s that?’, ‘Where’s the chain?’, or ‘What color?’ in order to be correct [Pepperberg, 1983, 1987a, b, 1988c; Pepperberg and Kozak, 1986].

Maintaining the Subject’s Attention

Concurrent work on a variety of tasks not only prevents expectation cuing, but is also an important experimental protocol because Alex becomes restless during sessions devoted to a single task [Pepperberg, 1983, 1999]. He ceases work, begins to preen, or interrupts with many successive requests for other items (‘I want X’) or changes of location (‘Wanna go Y’). Similar ‘boredom’ behavior has been observed in several other animals [Moran et al., 1983; Davis, 1984; Putney, 1985; Davis and Bradford, 1986].

Additional Controls

Although our formal procedures adequately protect against inadvertent cuing, two other circumstances provide additional controls. The first circumstance involves those trials in which the examiner errs: In about one in 20 trials (particularly during student exam periods), an examiner will err and scold Alex for a correct response. Alex will repeat his correct response, despite our procedures, which encouraged a lose-shift strategy. The examiner then usually recognizes her error, and Alex gets his reward. The examiner, were she producing inadvertent cues, would in these cases have been cuing Alex to respond with an incorrect answer, and thus the effect would be the same as a blind test [Pepperberg, 1999]. The second circumstance involves informal questioning by naive visitors who are unfamiliar with the several idiosyncratic labels that Alex uses for certain objects [e.g., ‘banerry’ for apple, ‘truck’ for toy metallic cars, ‘rock corn’ for dried corn, ‘wheat’ for cereal, ‘cork nut’ for almond; see Pepperberg, 1999 for a review of Alex’s lexical innovation and sound play]. People unfamiliar with Alex and with these labels have queried him about these objects; he has been correct on 190% of such trials.

Determining Accuracy and the Correction Procedure

As noted above, the number of times an object or collection is presented to Alex depends upon his accuracy, which is determined as follows [Pepperberg, 1981]: The questioner (a student trainer), presents to the bird in a variable, but previously determined order, the object(s) about which he will be queried. The principal trainer sits in a corner of the room, does not look at Alex or the examiner during presentation of the tests object(s), and thus does not know what is being presented. The student trainer asks one of the many possible different questions, to which the bird responds. The principal trainer then repeats out loud what she heard the parrot say. (This repetition prevents the examiner form accepting an indistinct, incorrect vocalization that was similar to the expected, correct response, e.g., ‘gree’ for ‘three’.) If what the principal trainer heard was correct (e.g., the appropriate category label), Alex is rewarded by praise and the object(s). There are then no additional presentations of the same material during that test; that is, there is only a single, ‘first trial’ response. If Alex’s identification was incorrect or indistinct, the examiner

removes the object(s), turns his/her head (a momentary 'time-out'), and emphatically says 'No!' The examiner then implements a correction procedure in that the misnamed object or collection is immediately (re)presented until Alex gives the correct identification or a total of four attempts are made; errors are recorded.

Alex has learned, too, that repetition of an incorrect identification (e.g., repeated substitution of the label of a more desired object for the one presented) is fruitless; instead, a quick, correct identification allows him to request the preferred item [Pepperberg, 1981]. Because immediate re-presentation of an object or collection during a test occurs only when the response to the initial presentation is incorrect, the testing protocol penalizes a 'win-stay' strategy: Repetition of a previously correct response (e.g., the name of the previous exemplar) elicits no reward. The testing procedure thus provides a definite contrast to training protocols that rely on, and occasionally reinforce, repetitive behaviors.

Scoring Procedure and Competence

Alex's test scores are used to evaluate his cognitive capacities on the various tasks. For most tasks, the test scores have been calculated in two ways [Pepperberg, 1981]. The overall test score for each task (results for 'all trials') is obtained by dividing the total number of correct identifications (i.e., the predetermined number of objects or collections by the total number of presentations required; such data track self-correction as well as overall accuracy). 'First trial' results (% of first trials that are correct) are reported for comparison and used for statistical analysis. Alex consistently responded with a high degree of accuracy on all questions; p values on first trials are consistently less than 0.005, and for most tests less than 0.0001. The following sections describe the different topics, the different tasks used to study these topics, the results of testing, and the implications of the data for determining Alex's cognitive capacities.

Results

Labeling and Basic Requests

Using the techniques described above, my students and I have taught Alex tasks that were once thought beyond the capability of all but humans or, possibly, certain nonhuman primates [Premack, 1978]. Alex has learned labels for more than 50 different objects. He has functional use of 'no', and of phrases such as 'come here', 'I want X' and 'Wanna go Y' where X and Y are appropriate labels for objects or locations [Pepperberg, 1981, 1999]. Incorrect responses to his requests by a trainer (e.g., substitution of something other than what he requested) generally result in his saying 'No' and repeating the initial request [Pepperberg, 1987c, 1988b]. He has labels for 7 colors and identifies five different shapes by labeling them as 'two-', 'three-', 'four-', 'five-', or 'six-corner' objects [Pepperberg, 1983]. He uses the labels 'two', 'three', 'four', 'five', and 'six' to distinguish quantities of objects, including collections made up of novel objects, heterogeneous sets of objects, and sets in which the objects are placed in random arrays [Pepperberg, 1987b, 1994a]. He combines all the vocal labels to identify proficiently, request, refuse, categorize, and quantify more than 100 different objects, including those that vary somewhat from training exemplars. His accuracy averages ~80% when tested on these abilities [Pepperberg, 1981, 1983, 1987b, c, 1988b, 1994a, 1999].

Concepts of Category

We have specifically examined Alex's capabilities to comprehend the concept of 'category'. Not only have we taught Alex to label any one of a number of different hues or shapes, but to categorize objects having both color and shape with respect to either category based on a vocal query of 'What color?' or 'What shape?' [85.5%, all trials; for detailed breakdown of results, see Pepperberg, 1983, 1999]. Thus he understands that 'green', for example, is a particular instance of the category 'color', and that, for any object that is both colored *and* shaped, the specific instances of these attributes (e.g., 'green' and 'three-

corner') represent *different* categories. Thus he learned that there exists a set of responses – his color labels – that form the class 'color' and another set of responses – his shape labels – that form the class 'shape' [Pepperberg, 1996]. Success on such a task shows that Alex has a higher-order class concept, because the color labels have no intrinsic connection to the label 'color' nor do the shape labels have an intrinsic connection to the label 'shape'. Because the protocol often requires Alex to categorize the same exemplar with respect to shape at one time and color at another, the task involves flexibility in changing the basis for classification. Such flexibility, or capacity for reclassification, is thought to indicate the presence of 'abstract aptitude' [Hayes and Nissen, 1971].

Concepts of Same/Different and Absence

In the 1970s, comprehension of same/different was singled out as requiring abilities not typically attributable to nonprimates and specifically not to birds [Premack, 1978, 1983; Mackintosh et al., 1985]. The argument was that comprehension of the *concept* of same/different is more complex than learning to respond to match-to-sample and nonmatch-to-sample or oddity-from-sample, or homogeneity and nonhomogeneity. According to Premack [1983], the first requires use of arbitrary *symbols* to represent *relationships* of sameness and difference between sets of a objects *and* the ability to denote the attribute that is different. Specifically, Premack [1983] thus claims that animals need symbolic representation – at least some elementary form of language – to succeed. The other tasks, in contrast, require only that a subject show a savings in the number of trials needed to respond to B and B as a match (or as a homogeneous field) after learning to respond to A and A as a match (and likewise by showing a savings in trials involving C and D after learning to respond appropriately to A and B as nonmatching or nonhomogenous). Subjects in match-to-sample and nonmatch-to-sample studies might even be responding based on 'old' versus 'new' or 'familiar' versus 'unfamiliar' [Premack, 1983], that is, on the relative number of times they experience the A sample versus the number of times they see different B samples. A subject that understands same/different, however, not only knows that two nonidentical red objects are related in the same way as are two nonidentical blue objects – in terms of color – but also knows that the red objects are related to each other in a different way than are two nonidentical square objects, and, moreover, can transfer this understanding to *any* attribute of an item [Premack, 1978, 1983]. Likewise, a subject would have to understand the concept of difference in an equivalent manner.

Alex has learned abstract concepts of 'same', 'different', and to respond to the *absence* of information about these concepts if nothing is same or different. Thus, when presented with two objects that are identical or that vary with respect to some or all of the attributes of color, shape, and material, Alex can respond with the appropriate *category* label as to which attribute is 'same' or 'different' for any combination [80.8%, all trials; 76.0%, first trials; Pepperberg, 1987a], or 'none' if nothing is same or different [83.9%, all trials; 80.9%, first trials; Pepperberg, 1988c].

He can respond equally accurately to instances involving objects, colors, shapes, and materials not used in training, including those for which he has no labels. Furthermore, we have shown that Alex is indeed responding to the specific questions, and not merely responding on the basis of his training and the physical attributes of the objects: His responses were still above chance levels when, for example, the question 'What's same?' was posed with respect to a green wooden triangle and a blue wooden triangle. If he were ignoring the question and responding on the basis of his prior training, he would have determined, and responded with the label for, the one anomalous attribute (in this case, 'color'). Instead, he responded with one of the two appropriate answers [i.e., 'shape' or 'mah-mah' (matter); Pepperberg, 1987a].

Alex's use of 'none' is of particular interest because the ability to understand and comment upon nonexistence, or even the slightly more basic notion of absence, although seemingly simple, denotes a relatively advanced stage in cognitive and linguistic development [Brown, 1973]. An organism reacts to

absence only after acquiring a corpus of knowledge about the expected *presence* of events, objects, or other information in its environment, that is, only when a discrepancy exists between the expected and actual state of affairs [e.g., Skinner, 1957; de Villiers and de Villiers, 1979; Hearst, 1984]. (Note that such behavior is qualitatively different from learning what type of stimulus leads to the absence of reward [e.g., Astley and Wasserman, 1992]: In these cases the subjects may simply be learning what to avoid.) Many animal species have been tested on absence using a Piagetian paradigm (object permanence), and some animals do react to the disappearance or nonexistence of specific items they expect to be present [e.g., Funk, 1996; Pepperberg et al., 1997]. Evidence also exists from studies of wild birds. Some songbirds, for example, react to absence of signs of territorial defense (e.g., song) from conspecific neighbors with positive acts of territorial invasion [Peek, 1972; Krebs, 1977; Smith, 1979]. Bloom [1970], however, suggests that not only comprehension but also verbal production of terms relating to nonexistence is necessary before an organism can be considered to have acquired the *concept* of nonexistence. Experimental demonstration of the concept of nonexistence thus can be difficult, even in humans, and Alex's capacities are therefore particularly notable.

Numerical Concepts

The question then arose as to whether Alex could form an entirely new categorical class consisting of labels for quantity. Could he be trained to reclassify a group of wooden objects known until now simply as 'wood' or 'green wood' so that he could identify them as 'five wood'? To succeed on this task, he would have to understand that a new set of labels, 'one', 'two', 'three', 'four', 'five', and 'six' represented a novel class: a means to categorize objects based on a combination of physical similarity within a group and the group's quantity, rather than by the physical characteristics of the group members. He would also have to learn how to generalize this new class of numerical labels to sets of novel objects, to objects in random arrays, and to heterogeneous collections. The study would specifically provide information on a nonhuman's concept of number. Note that Koehler [1943, 1950, 1972] and his colleagues [Braun, 1952; Lögler, 1959] had already demonstrated Grey parrots' sensitivity to quantity and basic concepts of numerosity and numerousness; Koehler's birds learned to open boxes randomly containing 0, 1, or 2 baits until they obtained a fixed number (e.g., 4). The number of boxes needed to be opened to obtain the precise number of baits varied across trials, and the number being sought depended upon independent visual cues: black box lids denoted 2 baits, green lids 3, etc. Koehler claimed that his birds learned four different problems of this kind simultaneously. He did not state, however, if different colored lids were presented randomly in a single series, and thus whether colors may indeed have 'represented' particular quantities [see Pepperberg, 1987b]. Lögler [1959] transferred such behavior to flashes of light and notes of a flute, thus going from simultaneous visual representations to sequential auditory ones. But could Alex, like Matsuzawa's [1985] chimpanzee, could go beyond these tasks and use number as a categorical label?

Although our research on numerical concepts does not demonstrate that Alex has an understanding of number comparable to that of a human child [Fuson, 1988], the data suggest that he does comprehend some concept of quantity. Thus, although we have yet to show conclusively that Alex can, for example, without having been trained, transfer from enumerating visual simultaneous displays to enumerating sequential auditory ones (e.g., transfer to count sequential metronome clicks to tell us that he has heard 'three'), he can recognize and label different quantities of physical objects up to and including 6 [78.9%, all trials; Pepperberg, 1987b]. The sets of objects need not be familiar, nor need they be placed in any particular pattern, such as a square or triangle. Furthermore, if presented with a heterogeneous collection – of X's and Y's – he can respond appropriately to questions of either 'How many X?' *or* 'How many Y?' [62.5%, all trials; 70.0%, first trials; Pepperberg, 1987b]. His level is therefore beyond what might be considered subitizing in young children, who are generally given only homogeneous sets [e.g., Starkey and Cooper, 1995], and who, if asked about subsets, generally label the total number of objects in a

heterogeneous set if, like Alex, they have been taught to label homogeneous sets exclusively [see Siegel, 1982; Greeno et al., 1984]. Our work with other types of heterogeneous collections has suggested even more advanced skills. Alex can be shown a ‘confounded number set’ (collections of four groups of items that vary in two colors and two object categories – e.g., blue and red wood and blue and red wool, fig. 1) and be asked to label the number of items uniquely defined by the combination of one color and one object category (e.g., ‘How many blue wood?’). His accuracy [83.3%; Pepperberg, 1994a] replicates that of humans in a comparable study performed by Trick and Pylyshyn [1989]. We cannot claim that the mechanisms that Alex uses are identical to those of humans, but the data suggest that a non-human, nonprimate, nonmammalian subject has a level of competence that, in a chimpanzee, would be taken to indicate a human level of intelligence [Pepperberg, 1999].

Relative Size

All of the research discussed up to this point involves the formation of categorical classes based at least indirectly on absolute physical criteria rather than relative concepts. Although items such as color and shape labels are symbolic and thus abstract, their references are to concrete entities [Pepperberg, 1996]. Demonstrating that animal subjects, and birds in particular, can respond to relative concepts is not a simple matter: Studies that did manage to demonstrate such behavior suggested that response on an absolute basis was always used in preference to response on a relative basis and that the latter response was often apparent only if the former was blocked in some manner [e.g., Page et al., 1989; Hulse et al., 1990; cf. Weisman and Ratcliffe, 1989; Hurly et al., 1990]. Might Alex’s training on categorical class formation enable him to learn to respond readily on a relative basis, specifically that of bigger/smaller? Such data would provide direct comparisons with research on marine mammals [Schusterman and Krieger, 1986].

After M/R training on ‘What color bigger?’ and ‘What color smaller?’ with a limited number of colors and objects (yellow, blue, green; cups, woolen felt circles, Playdoh rods), we tested Alex on a variety of familiar and unfamiliar items. Our data showed that Alex had indeed classified objects with respect to relative size; his overall test scores were 78.7% [p varied between 0.044 and 0.0001 for the different types of transfer tests; see Pepperberg and Brezinsky, 1991]. Although we did not examine whether he could (or would) transfer this concept to a different modality (such as amount of sound), whether the acquisition of this concept might help him learn a different relationship (e.g., relative darkness), or how close in size two objects must be before he could not discriminate a difference, our data suggested that Alex demonstrated a level of understanding at least equivalent to that of certain marine mammals [e.g., Schusterman and Krieger, 1986]. Not only did he transpose the size relationship to stimuli outside of the training domain with an accuracy of 80% [binomial test, $p = 0.044$; Pepperberg and Brezinsky, 1991], but because he was responding with the label for an attribute other than size (i.e., color), we could remove many absolute stimulus cues by working with objects that were entirely different from those used in training [see discussions in Pepperberg, 1987a, 1990a]: He transferred his knowledge to objects of novel shapes and sizes, and colors not used in training, with an accuracy of 77.3% [binomial test, $p < 0.0001$; Pepperberg and Brezinsky, 1991]. These objects were often of shapes or materials that he could not label (e.g., hand-dyed styrofoam stars). Of particular interest were our findings that he could also, without any training, indicate when the exemplars did not differ in size by responding ‘none’ and answer questions based on object material rather than color [Pepperberg and Brezinsky, 1991]. Such data suggest that he was not limited to responding within a single dimension, that he was attending to our questions, and that he was able to transfer information learned in one domain (the same/different study) to another. Such ability to transfer is, as noted above, a mark of complex cognitive processing [see Rozin, 1976].

Fig. 1. Example of a 'confounded number set' of red and blue balls of wool and wood. Alex must view such a collection and respond to questions such as 'How many blue wood?'.

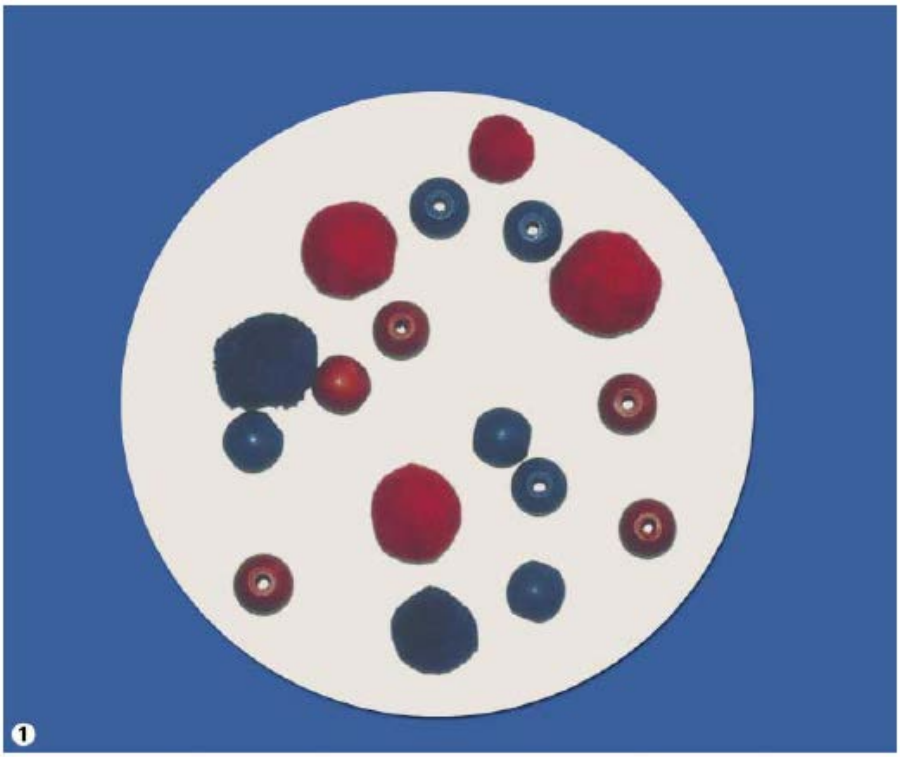

Fig. 2. Example of a collection used in the recursive, conjunctive comprehension test. Here Alex must respond to the question, 'What material is green and three-corner?'.

Comprehension via Recursive and Conjunctive Tasks

We then determined formally how similar Alex's comprehension abilities are to those of marine mammals that have also been trained to use a system of interspecies communication [e.g., Herman, 1987; Schusterman and Gisiner, 1988]. Most of the work with cetaceans and pinnipeds uses the comprehension mode; that is, researchers assess competence in cognitive and communicative skills by demonstrating how well their animal subjects understand the communication code by acting appropriately upon various commands. In contrast, much of the work with nonhuman primates up until the early 1990s and all of the prior work with Alex, although clearly involving comprehension (e.g., the difference between queries of 'What's same?', 'What's different?', 'How many?', 'What color bigger/smaller?', etc. with respect to any two objects), emphasizes instead the productive mode; that is, how accurately and appropriately the subjects can *produce* the code [Gardner and Gardner, 1969; Pepperberg, 1981; Miles, 1983; Savage-Rumbaugh, 1984]. To maintain our vocal paradigm but provide the necessary comparisons, my students and I chose to train and test Alex on a recursive task similar to those used with other animals [Pepperberg, 1990b; see also Granier-Deferre and Kodratoff, 1986]. In a recursive task, a subject is presented with several different objects and one of several different possible questions or commands concerning the attributes of these objects. Each question or command contains several parts, the combination of which uniquely specifies which object is to be targeted and what action is to be performed. The complexity of the question is determined by its context (the number of different possible objects from which to choose) and the number of its parts (e.g., the number of attributes used to specify the target and the number of actions from which to choose). The subject must divide the question into these parts and (recursively) use its understanding of each part to answer correctly. The subject thus demonstrates its competence by reporting on only a single aspect (e.g., color, shape, or material) of, or performing one of several possible actions (fetching, touching) on, an object that is one of several differently colored and shaped exemplars of various materials. Alex was therefore shown trays of seven unique combinations of exemplars and asked questions of 'What color is object-X?', 'What shape is object-Y?', 'What object is color-A?', or 'What object is shape-B?' His accuracy for all questions, which was better than 80% [84.2%, all trials; 81.3%, first trials; Pepperberg, 1990b] was comparable to that of marine mammals (and also nonhuman primates) that had been tested on similar tasks.

My students and I took this work one step further, by adding a conjunctive condition to the recursive task [Pepperberg, 1992]. Here Alex was again shown a 7-member collection but was now asked to provide information about the specific instance of one category of an item that was uniquely defined by the conjunction of two other categories; for example, 'What object is color-A *and* shape-B?' (see fig. 2). Other objects on the tray exemplified one, but not both, of these defining categories. Alex responded with an accuracy of 76.5%, which indicated that he understood all the elements in the question. Again, his data was comparable to that of marine mammals that had been similarly tested.

Research on Three Additional Subjects

Despite the successes that Alex had achieved, his data did not allow me to answer two long-standing questions: Why had M/R training enabled him to learn so many communicative and cognitive skills when other researchers' paradigms had failed? Was he particularly adept? That I had succeeded with Alex, and that other projects had failed, was not in dispute. But was it the technique or the bird? I needed to determine whether some specific aspect of the M/R technique was crucial for engendering learning. If other birds replicated Alex's success with M/R training, but failed with other protocols, I would have some answers. Thus, in April, 1991, we acquired two new male African Grey parrots: Kyaaro, 3.5 months old, and Alo, 7 months old; in June, 1995, we obtained Griffin, a 7.5 week old male. Using these birds, we began to test the relative importance of the three major aspects of input that make up the M/R training procedure: (1) reference, (2) context/function, and (3) interaction. Reference is generally defined as the

meaning of an utterance, that is, the relationship between a label and the object to which it refers and is exemplified by our use of referential rewards. Context/function involves the particular situation in which an utterance is used and the effects of using the utterance; our initial use of the label as a request for the object gives the bird a reason to learn the unique and unfamiliar set of sounds. Social interaction signals which components of the environment should be noted, emphasizes common attributes – and thus possible underlying rules – of diverse actions, and allows input to be continuously adjusted to the level of the learner. Interaction not only serves to engage the subject directly, but also provides a contextual explanation of the reasons for the actions and demonstrates the consequences of the actions. Note that such studies to examine the effects of different forms of input had to await the acquisition of additional subjects: Had we changed Alex's training protocols, he might have ceased to learn simply because we had made a change, and not because of the quality of the change. Our new subjects, with no history of training, would not be influenced by prior experience.

Initial Studies Eliminating Aspects of Input

I first studied the relative effects of simultaneously giving Alo and Kyaaro three types of input: (1) audiotapes of Alex's sessions, which were nonreferential, not contextually applicable, and noninteractive; (2) videotapes of Alex's session, which were referential, minimally contextually applicable, and noninteractive; and (3) the usual M/ R training that was referential, contextually applicable, and interactive. In the first two experiments, the birds listened to or watched the tapes in social isolation. Neither Alo nor Kyaaro learned anything from the audio or videotapes. Both birds, however, learned to comprehend as well as produce several labels from the M/R training [Pepperberg, 1994b].

Further Studies on Elements of Input

My students and I then completed five experiments that more carefully teased out the effects of various elements of input. In the first, juveniles' video sessions were repeated with 'co-viewers' who merely ensured that the birds attended to the monitor [Pepperberg et al., 1998]. Trainers provided social approbation for viewing and pointed to the screen, making comments like 'Look what Alex has?', but did not repeat new labels, ask questions, or relate the content to other training sessions. Such a procedure was based on data from young children that suggested that learning from video (e.g., from televisions shows such as 'Sesame Street') increased when the child watched with an interactive co-viewer [Lesser, 1974; Salomon, 1977; Corder-Bolz and O'Bryant, 1978; Watkins et al., 1980; Lemish and Rice, 1986; but see Rice et al., 1990]. For this experiment, any attempt the bird made at producing the label would be rewarded with vocal praise and not the object. Thus the amount of social interaction was limited and the amount of functional meaning was the same as in the basic videotape session. In the second study, we increased the amount of interaction, so that the trainer now repeated the new labels and asked questions [Pepperberg et al., 1999]; the rationale for this protocol was additional data from children showing that the extent of interaction might be crucial for learning from video [St. Peters et al., 1989]. In the third study, my students and I ensured that lack of reward for an attempt at a targeted vocalization did not prevent learning from video [Pepperberg et al., 1998]. We used the basic videotape protocol, but included a reward system that enabled a parrot, in the absence of social interaction, to receive the item if it attempted to produce the label. The system was controlled by a student in another room who monitored the parrot's utterances through headphones. In the fourth study, the model/rival procedure was amended to eliminate some functionality and as much social interaction as possible [Pepperberg and McLaughlin, 1996]. Here we replicated the studies with children that demonstrated the effect of an adult jointly focusing (with the child) on the object that is being labeled: For children, lack of joint attention prevented label acquisition [e.g., Baldwin, 1995]. In our study, a single trainer sat with her back to the bird, who was seated on a perch within reach of an object (e.g., key) suspended form a pulley system. The trainer repeated various phrases about the object, e.g., 'Look, a shiny *key*!', 'Do you want the *key*?', etc. [sentence frames; Pepperberg, 1981], but did not make eye contact with the parrot nor did she ever

present the object directly to the bird. She would reward any attempt at the targeted label with vocal praise. In the fifth study, we tested whether the bird might have become habituated to the single tape that was used. Although the tape contained many different interactions with Alex and all the different responses that he and the trainers made, the bird might have ignored the material after a number of sessions. We therefore replicated the study using live video input from Alex's sessions [Pepperberg et al., 1999]. In none of these experiments did the parrots learn referential use of the labels being taught, but did learn labels simultaneously being trained in the standard M/R procedure. Our results provide clear evidence for the importance of training procedures that involve reference, a demonstration of contextual use/functionality, and social interaction if a parrot is to communicate with humans and not simply mimic human speech.

One further set of experiments tested what would happen if we eliminated just the modeling aspect of training; that is, what would happen if only a single student labeled the object, asked a bird questions, jointly attended to the object, and thus interacted fully with the bird and the object? Griffin did not learn labels trained in this manner after 50 sessions [Pepperberg et al., 2000]. When we switched the label to M/R training, however, he produced the labels with complete clarity after one or two sessions. Latent learning may have occurred: Girffin apparently had acquired the label, but did not use it until he saw its use modeled. Note that in other instances when we had made similar switches (e.g., after 50 video sessions to M/R training), birds needed F20 sessions before producing the label clearly [Pepperberg et al., 2000]. Thus the specific demonstration of the functionality of the label also appears to be a vital aspect of the training.

Mutual Exclusivity: Study of a More Subtle Form of Input

Despite these data that clearly support the importance of social and pragmatic input for label learning in Grey parrots (and parallels with studies on children [e.g., Baldwin and Tomasello, 1998]), in yet another study, my students and I found support for learning theories that argue for inherent constraints that shape learning [e.g., Markman, 1990]. We found that context-dependent input is responsible for a form of mutual exclusivity during label learning by Greay parrots; our data parallels findings for some young children [Pepperberg and Wilcox, 2000]. For human children, mutual exclusivity refers to their assumption during early word learning that an object has one, and only one, label [e.g., Liittschwager and Markman, 1991, 1994; Merriman, 1991]. Along with the whole object assumption [that a label likely refers to an entire object rather than some partial aspect; Macnamara, 1982; Soja et al., 1985; Markman and Wachtel, 1988], mutual exclusivity supposedly guides children in initial label acquisition. Mutual exclusivity may also help children overcome the whole object assumption by helping them interpret a novel word as something other than an object label [Markman, 1990], but for very young children, any second label for an object can initially be more difficult to acquire than the first, because the second label is viewed as an alternative [Liittschwager and Markman, 1991, 1994]. We found that if a Grey parrot is taught object labels for items, then presented with color or shape items as additional, rather than alternative labels (i.e., 'Here's a key; it's a green key'), they show little evidence for mutual exclusivity [Pepperberg, 1981]. If, however, they are given color or shape labels as alternative labels (i.e., 'Here's a key' and only later 'It's green'), they have considerable difficulty learning to use these modifier labels with respect to a previously labeled item. Griffin, trained in the latter manner, thus persistently responded to 'What color?' with the previously learned object label in over 50 training sessions [Pepperberg and Wilcox, 2000]. Such data show that even small changes in how input is presented can affect label acquisition.

Note that such data is also consistent with the interpretation that mutual exclusivity *initially* simply blocks new information – an evolutionarily widespread phenomenon not unique to humans – and that it is not a linguistic or even a cognitive process to help acquire attributes and concepts [Markman, 1992]. If the presence/absence of initial mutual exclusivity is consistently determined by the form of input, blocking is a

more likely explanation. We are therefore continuing research on this topic. Clearly, our results suggest that learning theories should incorporate a number of different approaches [see Hirsh-Pasek et al., 2000].

Discussion

Implications of the Results

These results have several implications concerning a parrot's ability to perform numerous complex cognitive tasks, and unlike marine mammals and some nonhuman primates, both to produce *and* comprehend complex labels, including ones with small phonological distinctions [e.g., labels that differ by a single phoneme, such as 'tea' and 'pea', 'cork' and 'corn'; [Patterson and Pepperberg, 1994, 1998]: What are the mechanisms that a nonhuman, nonprimate, nonmammalian creature uses to learn what are more than simple associations, to transfer knowledge learned in one domain to another, to make subtle phonological distinctions? Neurobiologists are attempting to determine the brain areas that are involved in such processing in psittacine birds [e.g., Striedter, 1994; Jarvis and Mello, 2000]; other researchers are trying to determine how a Grey parrot manipulates its vocal tract to produce human phonemes [Patterson et al., 1997], and studies in my laboratory continue to determine the extent of psittacine cognitive processing and how input affects such exceptional learning in a bird. The critical results of my research are not simply that parrots can learn to perform tasks that were once thought the exclusive domain of humans or nonhuman primates, but that we must be open to the idea that animals that appear small-brained and that are evolutionarily remote from humans are nevertheless capable of complex, cognitive processing.

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