Chapter 12
Interspecies Communication with Grey Parrots: A Tool for Examining Cognitive Processing

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Abstract For over 35 years, I have examined Grey parrot cognition via a modeling technique, whereby birds are trained to use elements of English speech referentially, so they can be questioned vocally, much like young children. The oldest bird, Alex, labeled >50 objects, seven colors, five shapes, quantities to eight, three categories (color, shape, material) and used "no," "come here," "wanna go X," and "want Y" (X, Y being appropriate location or item labels) intentionally. He combined labels to identify, request, comment on, or refuse >150 items and to alter his environment. He understood concepts of category, relative size, quantity, presence or absence of similarity/difference in attributes, showed label comprehension and a zero-like concept; he demonstrated some understanding of phonological awareness and a numerical competence more like that of young children than other nonhumans. He could be queried about optical illusions in ways directly comparable to humans. Younger birds are acquiring similar competence.

1 Introduction

Many studies have aimed to establish symbolic interspecies communication. The best-known primarily used nonhuman primates and marine mammals (e.g., Gardner and Gardner 1969; Kellogg 1968; Miles 1978; Premack 1976; Richards et al. 1984; Rumbaugh 1977). Of these, Premack seemed most interested in using this communication system as a means to examine nonhuman cognitive processing, as suggested by Griffin (1976). The idea of replicating such studies with an avian subject such as a Grey parrot, a species evolutionarily far-removed from humans and with a brain the size of a shelled walnut, was initially met with skepticism (Pepperberg 1999, 2012b). Not only were parrots considered mindless mimics (e.g., Lenneberg 1967)

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but investigators using what were then-standard operant conditioning techniques had already tried and failed to establish any form of symbolic communication with mimetic birds (e.g., Grosslight and Zaynor 1967; Mowrer 1950, 1952, 1954). Furthermore, prior to the 1970s, researchers argued 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, and generally agreed that avian abilities were inferior to those of mammals (for a review, see Premack 1978). My rationale for attempting to counter all these objections, my initial choice of subject (the Grey parrot, Alex) and training procedure, have been discussed in detail elsewhere (e.g., Pepperberg 1999, 2012b); my goal in this chapter is to describe (briefly) the techniques that I adapted and developed, and the cognitive abilities of these birds that were consequently uncovered.

2 Training Techniques

2.1 Model/Rival (M/R) Procedures

The primary instructional procedure, described in detail elsewhere (Pepperberg 1981, 1999) and known as model/rival or M/R training, is based primarily on methods developed by Todt (1975) and Bandura (1971). It involves three-way *social* interactions among two humans and a parrot to demonstrate the targeted vocal behavior. The parrot watches and listens as one trainer presents objects and queries the other trainer about them (e.g., "What's here?", "What color?"), giving praise and transferring the named object to the human partner to reward correct answers. Incorrect responses are punished by scolding and temporarily removing items from sight. Thus the second human is both a model for the parrot's responses and its rival for the trainer's attention, and illustrates consequences of errors. The model must try again or talk more clearly if the response was deliberately incorrect or garbled; that is, the model is subject to corrective feedback, which the bird observes. The parrot is included in interactions, being queried and rewarded for successive approximations to correct responses; training is adjusted to its performance level. If a bird is inattentive or accuracy regresses, trainers threaten to leave.

Unlike other modeling procedures (reviewed in Pepperberg and Sherman 2000, 2002), the M/R technique exchanges roles of trainer and model. The parrot thus sees how questioner and respondent interchange roles, and how their interactions result in environmental change. Role reversal also counteracts an earlier methodological problem: birds whose trainers always maintained their respective roles responded only to the human questioner (Todt 1975). Here, birds respond to, interact with, and learn from any human.

To ensure the closest possible link between labels or concepts to be learned and their appropriate referent, M/R training uses only *intrinsic reinforcers*: Reward for uttering "X" is X, the object to which the label or concept refers. Earlier unsuccessful attempts to teach birds to communicate with humans used *extrinsic* rewards: a single food neither relating to, nor varying with, the label or concept being taught (see Pepperberg 1999). This procedure delayed label and concept acquisition by confounding the label of the targeted exemplar or concept with that of the food reward. Initial use of labels as requests also demonstrates that uttering labels has functionality; later, birds learned "I want X," to separate requesting and labeling (Pepperberg 1988a) and to enable them to request preferred rewards while learning labels for items of little interest.

Notably, in subsequent studies with additional birds, use of techniques that eliminated aspects of M/R training—reference, functionality, or various levels of social interaction (i.e., omitting joint attention of humans and bird on the targeted item, or using a single trainer)—failed to engender symbolic communication. Thus, when birds were exposed to audiotapes, videotapes (with and without human co-viewers, with and without live feeds), one model with various levels of interaction, or the use of Alex as a semicompetent model (i.e., as one who, at the time, could not exchange roles and act as questioner), they failed to acquire referential labels but learned labels taught simultaneously during standard M/R training (see Pepperberg 1994b, 1999, 2012b; Pepperberg and McLaughlin 1996; Pepperberg et al. 1998, 1999, 2000) (NB: Alex did eventually learn to exchange roles fully, and thereby helped train a younger bird, Griffin).

2.2 Indirect Training Procedures

My Grey parrots also actively engaged in learning outside of formal training. Students and I tracked one such form of Alex's learning, sound play (Pepperberg et al. 1991), in which he derived novel targeted speech patterns from existing ones. He seemed able to separate specific phonemes from the speech flow *and* produce them so as to facilitate production of upcoming phonemes ("anticipatory co-articulation"; Patterson and Pepperberg 1994). In humans, these abilities are taken as evidence for top-down processing (Ladefoged 1982), necessary for segmentation and phonological awareness (see later). He also practiced some utterances privately, specifically those completely-formed new labels or entire phrases that materialized after minimal training and without practice in his trainers' presence (Pepperberg et al. 1991). After learning to produce questions, he occasionally learned labels by asking us about the color, shape, or material of objects in his environment (Pepperberg 1999). He also often produced new vocalizations in the presence of trainers by recombining existing label parts, notably in their corresponding orders (Pepperberg 1990b). When we *referentially mapped* these spontaneous utterances—providing relevant objects to which they could refer—Alex rapidly integrated these labels into his repertoire. After acquiring "grey," for example (by asking "What color?" to his mirror image), he produced sound variants (e.g., "grape," "grate," "grain," "chain") that we mapped to appropriate referents (respectively, fruit, a nutmeg grater, seeds, a paper-clip ring; see Pepperberg 1990b, 1999). In contrast, he abandoned sounds whose combinations we couldn't map (e.g., "shane," "cheenut"), or for which mapped referents weren't of interest (e.g., dried banana chips used for "banacker"; Pepperberg 1990b). Thus, our bird's spontaneous utterances that initially lacked communicative, symbolic value could, as they do for children, acquire this value if caretakers interpreted them as such (Pepperberg 1990b). Alex and younger birds might also use a familiar label in a novel instance (e.g., Arthur, stating "wool", trained to a woolen pompon, as he pulled at a trainer's sweater, or Alex calling a piece of popcorn "paper"), learning either by approbation or by our providing instead an appropriate label (Pepperberg 1999).

3 Results

Using these techniques, Alex acquired significant symbolic communication. His early capacities are summarized fairly briefly, having been published elsewhere (e.g., Pepperberg 1999, 2012b); I discuss his and the younger bird, Griffin's, more recent data in somewhat greater detail.

3.1 Alex's Use of Labels

Alex acquired labels for over 50 objects, seven colors and six different shapes ("X-corner"); he used English number labels to distinguish quantities of objects, including collections of novel items, heterogeneous sets of objects, and sets in which items were placed in random arrays (see later). He combined vocal labels to identify proficiently, request, refuse, categorize, and quantify over 100 different items, including those varying somewhat from training exemplars. He had functional use of "no" and phrases such as "come here," "want X," and "wanna go Y" (X, Y being appropriate object or location labels). The requests, initially acquired via M/R training (Pepperberg 1988a), were spontaneously extended to any newly acquired labels. Requests were also intentional (Pepperberg 1987c, 1988a): If trainers responded incorrectly (e.g., substituting alternative items), he generally said "no" (86 % of the time), often coupling his refusal with a repetition of the initial request. His accuracy averaged ~80 % on tests of these abilities (for details and statistics, see Pepperberg 1981, 1987b, 1988a, 1994a, 1999).

3.2 Comprehension of Categories/Categorical Labels

Alex had a higher-order, hierarchical understanding of class concepts (Pepperberg 1983, 1996): he learned that various sets of responses—each of his color, shape, material, or object labels—could be subsumed under specific, different category labels, and that the labels for these categories had no intrinsic connection to the individual labels constituting the categories. He therefore could, depending on the question, describe the same item with respect to different categories (e.g., “What matter?”: “wood”; “What color?”: “green”; “What shape?”: “4-corner”; “What toy?”: “block”).

3.3 Concepts of Same-Different

Understanding the concept of same/different requires more than learning match-to-sample or oddity-from-sample, identity or non-identity, or determining homogeneity versus nonhomogeneity; it requires understanding abstract relationships—ones that, although dependent upon absolute, perceptual qualities (e.g., color, shape), can be abstracted across any domain (Premack 1978, 1983). The subject must understand, for example, that the *same* relationship holds between the *different* pairs A-B and C-D, where A and B could be different colors and C and D could be different sounds. Such understanding also requires use of arbitrary *symbols* to represent *relationships* of sameness and difference between sets of objects *and* the ability to denote the attribute that is same or different (Premack 1983). Alex did learn abstract concepts of same/different. After M/R training to respond to queries of “What’s same/different?” to a small subset of item pairs with the appropriate *category* label, he could respond appropriately to any two other objects that might vary with respect to all possible attributes of color, shape, and material, including objects/colors/shapes he could not label (Pepperberg 1987a). Notably, his responses were still above chance when, for example, the question “What’s same?” was posed with respect to a green wooden triangle and a blue wooden triangle. If he had ignored the question and responded on the basis of prior training, he would have determined, and produced 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 matter; Pepperberg 1987a).

3.4 Understanding Absence

Understanding absence relies on recognizing a discrepancy between the expected and actual state of affairs (e.g., Hearst 1984; Skinner 1957) and actively *reporting* the situation, not simply learning to avoid stimuli leading to absence of reward (e.g., Astley and Wasserman 1992). It may involve symbolic communication: Bloom (1970), for example, suggests that verbal production of terms relating to nonexistence is needed before an organism can be considered to have acquired the concept.

Alex was tested on his concept of absence in the context of same/different (Pepperberg 1988b). After training to respond “none” to an absence of similarity and difference for a small subset of, respectively, totally different or identical item pairs, he replied appropriately for a large variety of novel object pairs for which responses could now be "color," "shape," "matter," or "none." As before, objects could be items or have attributes he could not label.

3.5 Relative Size

Relational concepts are difficult: By definition, the basis for relative categorization changes constantly—what is the darker or smaller or heavier choice in one trial can be the brighter, bigger, or lighter exemplar in the next; choices based on specific, absolute criteria would be erroneous. Alex did succeed on this task. After M/R training on "What color bigger/smaller?" with a limited set of colors and objects, he was tested on a variety of familiar and unfamiliar items (Pepperberg and Brezinsky 1991). He transferred to objects of novel shapes, sizes, and colors not used in training, and that he often could not label. He also, *without training*, indicated when exemplars did not differ in size by responding "none," and answered questions based on object material as well as color (Pepperberg and Brezinsky 1991). Thus he was not limited to responding within a single dimension, was attending to our questions, and transferred information learned in one domain ("none" from the same/different study) to another. Such ability to transfer is a mark of complex cognitive processing (see Rozin 1976).

3.6 Comprehension of Vocalizations

Despite Alex's demonstrated label production and question comprehension, he had never specifically been tested on comprehension of individual labels. Some "language"-trained apes had demonstrated differences in production versus comprehension (note Savage-Rumbaugh 1986). Thus Alex was also tested. In this iterative task (see Granier-Deferre and Kodratoff 1986; Pepperberg 1990a), a subject is given one of several different possible queries or commands concerning the attributes of several different items shown simultaneously. Each query or command contains several parts, the combination of which uniquely specifies which item is targeted and what action is to be performed. Question complexity is determined by context (number of different possible items from which to choose) and the number of its parts (e.g., number of attributes used to specify the target and number of actions from which to choose). The subject must divide the question into these parts and (iteratively) use its understanding of each part to answer correctly. The subject demonstrates 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 shown trays of seven unique combinations of exemplars and asked “What color is object-X?” “What shape is object-Y?” “What object is color-A?” or “What object is shape-B?” (Pepperberg 1990a). His accuracy on label comprehension was equal to that of production and comparable to that of marine mammals tested on similar tasks (dolphins, Herman 1987; sea lions, Schusterman and Gisiner 1988).

Alex also succeeded when a conjunctive condition was added (Pepperberg 1992). Here he 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?” Other objects on the tray exemplified one, but not both, these defining categories. His accuracy, again comparable to those of marine mammals (Herman 1987; Schusterman and Gisiner 1988), indicated that he understood all elements in the question. The implications, that truly advanced cognitive process are involved, are discussed fully in Pepperberg (1999). (NB: Herman (1987) claimed that this task is recursive and thus demonstrated not only label comprehension but also linguistic competence—i.e., an understanding of embedded clauses with layered, hierarchical meaning. Premack (1986) argued, correctly, that the task is merely iterative. Following Herman, I used the term *recursive* in Pepperberg (1992), but did not make claims of linguistic abilities.)

3.7 Phonological Awareness

Alex’s sound play (see earlier) showed spontaneous combination of parts of existent labels to create new ones; was he also capable of true segmentation—understanding that his existent labels are comprised of individual sound units (phonemes, morphemes) that can be *intentionally* recombined in novel ways to create novel vocalizations? Such behavior would also imply some level phonological awareness (*sensu* Anthony and Francis 2005). Segmentation is not only considered basic to human language development (Carroll et al. 2003), but also a uniquely human trait by some researchers (e.g., Lenneberg 1967). Little evidence exists for such behavior in any nonhuman, including those taught elements of human communication systems (reviewed in Pepperberg 2007).

To determine what Alex might learn about morphemes and phonemes, he had received M/R training to associate the wooden or plastic graphemes B, CH, I, K, N, OR, S, SH, T with their corresponding appropriate phonological sounds (e.g., /bi/ for BI); the graphemes, which he would chew, were his reward. Although his accuracy was above chance ($p < 0.01$, chance of 1/9), it was never high enough (i.e., ~80 %) to claim he had mastered the task. Nevertheless, he demonstrated unexpected abilities with respect to sounds and labels after our youngest bird, Arthur, had acquired the label “spool” to refer to plastic and wooden bobbins.

Unlike Arthur, who used a whistle-like sound for the first part of the label (sonagrams in Pepperberg 2007) and unlike his usual form of acquisition (Patterson and Pepperberg 1994), Alex began by using a combination of existing phonemes and labels to identify the object: /s/ (trained independently in conjunction with the physical letter, S) and wool, to form “s” (pause) “wool” (“s-wool”;/s-pause-wUl/; figure 2 in Pepperberg 2007). The pause seemingly provided space for the absent (and difficult) /p/ (see Leonard 2001; Peters 2001). Note that Alex knew no labels containing /sp/, nor did he know “pool” or “pull,” or any other label that included /Ul/; he did know “paper,” “peach,” “parrot,” “pick,” and so forth, producing a viable /p/ via a form of esophageal speech (Patterson and Pepperberg 1998); /sp/ may have been even more difficult. He knew /u/ from labels such as “two” and “blue” (Pepperberg 1999, 2007). He retained this “s-wool” formulation for almost a year of M/R training, although normally only about 20–25 M/R sessions (at most, several weeks of training) were sufficient for learning a new label (Pepperberg 1999).

At the end of this year-long period, Alex spontaneously produced “spool,” perfectly formed (/spul/; see figure 3, in Pepperberg 2007). Thus, Alex added the sound—which humans heard, sonagraphically viewed, and transcribed, as—/p/ and also shifted the vowel toward the appropriate /u/. His utterance sounded distinctly human, differed from Arthur’s whistled version, and clearly resembled mine (Pepperberg 2007), although students had performed 90 % of the training.

Alex exhibited a similar pattern for “seven” (first in reference to the Arabic numeral, then to an object set; see later). His first production of the label could best be described as “s…..n”, a bracketing using the phonemes /s/ and /n/; he then quickly progressed to “s-one” (Pepperberg 2009; /s/-pause-/wən/) which looked sonagraphically quite different from my “seven,” but followed the form of “s-pause-wool.” Eventually, “s-one” became “sebun,” much closer to my “seven” (Pepperberg 2009).

Alex’s data demonstrate a functional understanding that his existent labels were comprised of individual units that could intentionally be recombined in novel ways to create referential, novel vocalizations (Pepperberg 2007, 2009). His combinatorial rule system was relatively limited, but was exceptional for a nonhuman.

3.8 Numerical Concepts

Alex also learned various numerical concepts over the course of many studies. The original question was whether he could learn a symbolic representation for exact quantity comparable to that of young children. The work actually took several decades, because the task has multitude components. Not only must nonnumerical perceptual mechanisms (e.g., contour, density, mass) be ruled out, but many other issues also must be addressed.

3.8.1 Initial Concepts: Basic Quantities, Simple Heterogeneous Sets

Alex would first have to learn that a new set of labels, “one,” “two,” “three,” etc. represented a novel classification strategy—one based on both physical similarity within a group and a group’s quantity, rather than solely by physical characteristics of group members (i.e., a set of “three” keys, no matter what kind). Unlike children, he was not trained in an ordinal manner but first learned to label sets of three and four, then five and two, then six and one (Pepperberg 1987b, 1994a). He was trained this way for two reasons. First, when number studies began, he knew "three" and "four" from his shape training ("three-corner" for a triangle, "four-corner" for a square), so that beginning with those numbers and existent vocal labels made practical sense. Second, lack of training in an ordinal manner was planned to avoid giving any cue that could be obtained by a number line; the initial goal was to ensure that only a direct connection existed between the number label and the appropriate set (Pepperberg 1987b).

Alex did indeed learn to label small sets of familiar different physical items, up to six, exactly (Pepperberg 1987b); his error patterns did not show a peak near the correct responses, which would have suggested only a general sense of quantity ("approximate number system"). Rather, his most common errors across all sets was to label just the object involved—to respond, for example, "key" rather than "four key." We could not however claim that Alex was "counting", because we could not yet show he understood the counting principles as would a child: that a stable symbolic list of numerals exists, numerals must be applied to individuals in a set to be enumerated in order, they must be applied in 1:1 correspondence, that the last numeral reached in a count represents the cardinal value of the set, and that each numeral represents one more than the previous numeral (Carey 2004; Fuson 1988; Gelman and Gallistel 1978; Mix et al. 2002; Pepperberg 1999). Nevertheless, items that Alex quantified need not have been familiar, nor been arranged in any particular pattern, such as a square or triangle; he maintained an accuracy of about 75–80 % on novel items in random arrays.

Moreover, if presented with simple heterogeneous sets—a mixture of X's and Y's, different exemplars of various sizes and of both familiar and novel textures and materials (e.g., corks and metal keys) often presented by simply tossing them in random arrays on a tray—he responded appropriately to "How many X?" "How many Y?" *or* "How many toy?" (Pepperberg 1987b). The design ruled out cues such as mass, brightness, surface area, odor, object familiarity, or canonical pattern recognition (Pepperberg 1987b, 1999). Alex was more advanced than some children, who, if they, like Alex, have been taught to label homogeneous sets exclusively, usually label the total number of items when asked about subsets in a heterogeneous set (see Greeno et al. 1984; Siegel 1982). These tests did not, however, determine if Alex had, for the smallest collections, used a noncounting strategy such as subitizing—a perceptual mechanism that enables humans to quickly quantify sets up to ~4 without counting—or, for the larger collections, a strategy of "clumping" or "chunking"—a form of subitizing (e.g., perception of six as two groups of three; see von Glasersfeld 1982)—to correctly label quantity without counting. The mechanisms that Alex was using were thus still unspecified.

3.8.2 Complex Heterogeneous Sets

To tease apart subitizing/clumping versus counting, we adapted tasks designed for humans (Trick and Pylyshyn 1989, 1994), who had to enumerate of one set of items embedded within two different types of distractors: (1) white *or* vertical lines among green horizontals; (2) white vertical lines among green vertical *and* white horizontals. Humans subitized for 1–3 in only the first condition, but counted, even for such small quantities, in the second. Subitizing thus fails when items to be quantified are defined by a collection of competing features (e.g., conjunction of color *and* shape; see Pepperberg 1999). Adapting our conjunction study (see earlier), we could ask Alex about the quantity of a similarly defined subset—e.g., how many red blocks in a set of red and blue balls and blocks.

Notably, Alex's accuracy (Pepperberg 1994a) matched human data (Trick and Pylyshyn 1989). His scores could be analyzed for subitizing because a subject with high accuracy on small numbers but lower accuracy for larger ones is likely subitizing small sets and using some other noncounting procedure for larger sets. So, if Alex were, for example, subitizing and clumping, rather than counting, he would make no errors for 1 and 2, few for 3, and more for larger numbers. Sequential canonical analysis, however, showed that errors were random with respect to number of items targeted (see Pepperberg 1994a). In fact, most errors seemed unrelated to numerical competence, but rather involved misinterpreting the defining labels, then correctly quantifying the incorrectly targeted subset: Eight of his nine errors were the correct number for an alternative subset (e.g., the number of blue rather than red keys). In those cases, the quantity of the designated set usually differed from that of the labeled set by two or more items, demonstrating that Alex's response was not simply a close approximation to the correct number label (Pepperberg 1994a). However, if Alex's perceptual capacities were more sophisticated than those of humans, the data, although impressive with respect to exact number, still would not justify claiming that he was counting.

3.8.3 Number Comprehension

Alex clearly labeled numerical sets, but had not been tested on number label comprehension. The issue is important, because young children who can label sets may still not comprehend the exact meaning of the number labels (Wynn 1990). He was thus tested with a variation of the previous task involving simultaneous presentation of several quantities, of 1–6, of different items—for example, X red cork, Y yellow cork, Z green cork, or X red paper, Y red wood, and Z red cork; queries were of the type, respectively, "What color Z?" or "What matter X?" (Pepperberg and Gordon 2005). Success required him to comprehend the auditorially presented numeral label (e.g., X = "six") and use its meaning to direct a search for the exact cardinal amount specified by that label (e.g., six things). Controls again eliminated issues of contour, mass, etc. Each query also retested his ability to identify the item or color of the set specified by the numerical label. To respond correctly, he had to errorlessly process all types of information. Some or all of this behavior likely occurred as separate steps, each adding to task complexity (Premack 1983). Our tests showed that, unlike young children (up to ~3 years old) described earlier, Alex understood the meaning of his number labels (accuracy close to 90 %, Pepperberg and

Gordon 2005). Most of his errors seemed to be a consequence of color perception or phonological confusion, not numerical misunderstanding.

3.8.4 A Zero-Like Concept

During the comprehension study, Alex spontaneously transferred use of "none," learned during the same/different task with respect to attributes (see earlier, Pepperberg 1988b) and spontaneously transferred to relative size (see earlier, Pepperberg and Brezinsky 1991), to the absence of a set of a particular quantity—a zero-like concept. On one query, when asked "What color three?" to a set of two, three, and six objects, Alex replied "five"; the questioner asked twice more, each time Alex replied "five." Finally, the questioner said "OK, Alex, tell me, what color five?", to which he immediately responded "none." He had never been taught about absence of quantity nor to respond to absence of an exemplar. Notably, Alex not only provided a correct, novel response, but had also manipulated the trainer into asking the question he apparently wished to answer (Pepperberg and Gordon 2005). He also correctly answered additional queries about absent sets, showing that his behavior was intentional and meaningful. Unlike chimpanzees, for example Ai, who had to be trained on the label "zero" (Biro and Matsuzawa 2001), Alex's use of "none" was spontaneous. Still, he might not have understood the concept of *zero* at the same level as do humans.

3.8.5 Addition of Small Quantities

Study of addition was based on that of Boysen and Berntson (1989) with chimpanzees, and used to examine further Alex's understanding of zero (Pepperberg 2006a). The only nonhuman to demonstrate true addition—the summation of two or more separate quantities *and* exact symbolical labeling of the sum—had been Boysen and Berntson's chimpanzee, Sheba; quantity, however, never totaled more than four. Other studies (summarized in Pepperberg 2012b) had important procedural differences so that no information was obtained on whether their subjects had "…a digital or discrete representation of numbers" (Dehaene 1997, p. 27).

Alex was shown a tray on which two small, upside down cups had been placed, each holding items such as randomly shaped nut or cracker pieces, or differently sized jelly beans. We occasionally used identical candy hearts to see if accuracy was higher when mass/contour cues were available. The experimenter brought the tray to Alex's face, lifted the left cup, showed what was under the cup for 2–3 s in initial trials, replaced the cup over the quantity, then replicated the procedure for the right cup. For reasons described later, in the last third of the experiment, Alex had ~10 s to view items under each cup sequentially before sets were re-covered. The experimenter then made eye contact with Alex, who was asked, vocally, and without any training, to respond to "How many total?" He was also queried with nothing under both cups. No objects were visible during questioning. To respond correctly, Alex had to remember the quantity under each cup, perform some combinatorial process, and then produce a label for the total amount. Appropriate controls were, as usual, in place. When nothing was under both cups, the goal was to see if he would use "none" without instruction (Pepperberg 2006a).

Alex scored above 80 %; identical tokens did not improve accuracy. Interestingly, when given only 2–3 s, he always labeled the 5 + 0 sum as "6"; when given ~10 s, however, his accuracy went to 100 %. Differences in accuracy between the shorter and longer intervals was significant *only* on the 5 + 0 trials. His data are comparable to those of young children (Mix et al. 2002) and more advanced than those of chimpanzees (Boysen and Hallberg 2000). His responses on 5 + 0 trials suggest, although cannot prove, that he actually used a counting strategy for 5: Only when beyond the subitizing range of 4 did he, like humans, need time in order to label the set exactly (details in Pepperberg 2006a). A final addition study showed he could add three sets of small items whose total summed up to eight (Pepperberg 2012a).

Alex failed to state "none" if nothing was under any cup. He refused to respond or said "one." He never said "two", the number of cups (Pepperberg 2006a). His responses of "one" suggests comparisons to the chimpanzee Ai, who confused "one" with "zero." Alex, unlike Ai, was never trained on ordinality (Biro and Matsuzawa 2001) but, like Ai, seemed to grasp that "none" and "one" represented the lower end of the number spectrum. Apparently, Alex's use of "none" was zero-like, but unlike his number labels (Pepperberg 1987b), did not denote a specific numerosity or empty set.

3.8.6 Ordinality and Equivalence

Alex's use of "one" for "none" in the addition study suggested knowledge about an exact number line—i.e., ordinality, which intrinsic to *formal* counting (Fuson 1988; Gelman and Gallistel 1978). To count, an organism must produce a standard sequence of symbolic number tags and know the relationships among and between these tags—i.e., that "two" not only comes before "four" in the sequence but also represents a quantity less than "four." Few animals use numeric symbols; thus symbolic ordinality is difficult to demonstrate. Even for chimpanzees that referentially used Arabic symbols, ordinality did not emerge as it does in children but had to be trained as a separate ability (e.g., Biro and Matsuzawa 2001; Boysen et al. 1993; Matsuzawa et al. 1991). Children learn cardinality for numbers <4 and a sense of "more versus less" while acquiring a meaningless, rote ordinal number series, then associate their knowledge of quantity in the small sets with this number sequence to form 1:1 correspondences that can be extended to larger amounts for both cardinal and ordinal accuracy (e.g., Carey 2004). Children may learn 1:1 associations that suggest full understanding of cardinality before they actually do, but cannot do so for ordinality (e.g., Bruce and Threfall 2004; Teubal and Guberman 2002).

Given Alex's background, might ordinality emerge as with children? A task involving equivalence relations tested this possibility (Pepperberg 2006b). Alex, after learning English labels for Arabic numerals (production and comprehension) in the absence of the physical quantities to which they referred, and without any training on a number line, used the commonality of these English labels to equate quantities (sets of physical objects) and Arabic numerals. He had to identify the *color* of one of a pair of Arabic numerals that was *numerically* (not physically) bigger *or* smaller (he already knew bigger/smaller and "none" for object pairs; see earlier). Thus he deduced that an Arabic symbol had the same numerical value as its *vocal label*, compared *representations* of quantity for which the labels stood, inferred rank ordering based on these representations, then stated the result *orally*. Controls ensured that the task tested number concepts exclusively (Pepperberg 2006b). Alex replied "none" for trials on identical, same-sized numerals of different colors (e.g., 6:6). For queries on differently colored and sized numerals of the same value (e.g., 2:2) he initially responded on a physical basis, but halfway through trials switched to a numerical basis. Mixing Arabic symbols and physical items showed he understood that, for example, one numeral (an Arabic 6) was bigger than four items (or Arabic 2 the same as two items), and cleanly separated mass and number (see Pepperberg 2006b).

Overall, Alex's understanding of symbolic number seemed far closer to that of children than to chimpanzees taught number labels (e.g., Biro and Matsuzawa 2001; Boysen and Hallberg 2000; Boysen et al. 1993; Le Corre et al. 2006; Matsuzawa 2009; Matsuzawa et al. 1991): He understood equivalence relations and inferred ordinality, despite being trained on numbers without respect to their ordinal value, unlike children and even other nonhumans.

3.8.7 Exact Integer System?

Despite all Alex's accomplishments, he, like nonhuman primates and unlike humans, had demonstrated no savings in his previous learning of larger numerals in our early training. Why? Might his issue be difficulty in learning to produce the English labels? To produce any given English utterance, he had to learn to coordinate his syrinx, tracheal muscles, glottis, larynx, tongue height and protrusion, beak opening, and even his esophagus (Patterson and Pepperberg 1994, 1998). Could vocal and conceptual learning be dissociated to test this possibility?

The plan was as follows (Pepperberg and Carey 2012): Alex was taught to identify vocally the Arabic numerals 7 and 8 in the absence of their respective quantities, then was trained that $6<7<8$; tests showed he inferred the relationships among 7 and 8 and his other Arabic labels. Could he then, like children (≥4 years old), *spontaneously* understand that "seven" represented one more physical object than "six," and that "eight" represented two more than "six" and one more than "seven," by labeling appropriate physical sets on first trials? That is, could he induce the cardinal meaning of the labels "seven" and "eight" from their ordinal positions on an implicit count list?

Interestingly, pretraining baseline trials suggested that Alex had some concept of quantity greater than six. When presented with sets of seven, eight, or nine items, he refused to answer on four of six trials. Only when forced to respond (badgered until he finally produced some utterance), did he use the available label ("six") that represented the largest currently trained quantity (Pepperberg and Carey 2012). His behavior suggested that he knew that a standard number answer would not be correct. Furthermore, when asked to provide the color of the (absent) set of six items on trays that held various numbers of differently colored items, including sets of seven and eight, Alex responded “none” on all four trials, but when subsequently asked on two of these trials for colors of smaller sets that were present, to ensure he was attending to the stimuli, he gave the appropriate labels. Thus, he demonstrated an understanding of the exact nature of the representation of his label “six” (Pepperberg and Carey 2012); it did not simply mean “the largest set present.”

Alex did label appropriately, on first trials, novel sets of seven and eight physical items. He, like children, created a representational structure that allowed him to encode the cardinal value expressed by any numeral in his count list (Carey 2004). Acquisition of symbolic communication, therefore, enabled a parrot, a nonhuman whose ancestors separated from the mammalian line ~280 million years ago, to demonstrate numerical competency comparable to children who understand cardinal principles, and in a manner not yet demonstrated by the phylogenetically closer chimpanzee.

3.9 Optical Illusions

The avian brain is anatomically distinct from that of mammals but, at least for birds such as parrots, differs at most quantitatively rather than qualitatively from mammals when processing certain cognitive tasks (see earlier); for tasks that primarily involve visual processing, however, differences may be more striking, as the avian and mammalian visual systems differ in many ways (reviewed in Pepperberg et al. 2008). Various experiments suggested that chickens (e.g., Regolin et al. 2004; Winslow 1933), ring doves (Warden and Baar 1929), pigeons (e.g., Aust and Huber 2006; Fujita et al. 1993; Nakamura et al. 2006), and both starlings and finches (Dücker 1966) perceive various optical illusions; some of these studies, however, involved training subjects to identify stimuli closely related to the eventual target and results often depended on, for example, on statistical averaging of pecking/touching behavior to a limited set of choices (e.g., for amodal completion, between a whole and closely-related partial figure). Results were often highly variable and dependent upon the details of the experimental design (review in Pepperberg et al. 2008; Pepperberg and Nakayama 2012, in prep). Symbolic communication, however enabled testing both Alex and our younger parrot, Griffin, on exactly how they saw the world, and testing them in ways more comparable to those used with humans—by simply asking them what they saw.

3.9.1 Müller-Lyer Illusion

Alex was presented with two-dimensional Müller-Lyer figures (Brentano form) in which the central lines were of contrasting colors. His responses to “What color bigger/smaller?" demonstrated that he saw the standard length illusion in the Müller-Lyer figures in 32 of 50 tests where human observers would also see the illusion and reported the reverse direction only twice. He did not report the illusion when (a) arrows on the shafts were perpendicular to the shafts or closely approached perpendicularity, (b) shafts were six times thicker than the arrows, or (c) after being tested with multiple exposures to conditions that also lessen or eliminate the illusion for human observers (Pepperberg et al. 2008). These data suggest that parrot and human visual systems process the Müller-Lyer figure in analogous ways despite a 175-fold difference in the respective sizes of their brain volumes and visual systems that are markedly different from each other. Because responses to the Müller-Lyer illusion may be a consequence of experience with significant examples of right-angled, parallel-perpendicular intersections (note Segall et al. 1966), something to which a captive born and bred parrot would be subject, we were also interested in a parrot's responses to types of illusions that might be less dependent upon experience in a laboratory.

3.9.2 Subjective Contours: Modal and Amodal Completion

Subjective contours involve ecologically relevant stimuli. Humans often fill in missing parts to facilitate the perception of objects in their environment. Early Gestalt psychologists (e.g., Kanizsa 1955, 1979) described two of the most common forms of this behavior: *amodal completion*, when the object of interest is occluded by some other item (Fig. 12.1a) and *modal completion*, when the object is actually illusory but nevertheless appears to exist (Fig. 12.1b). Many other creatures must experience this problem in their daily lives—'filling in the blanks' (perceptual completion) as a fundamental visual process. For example, processing partial clues about a potential predator and reacting is safer than not, even if some false alarms incur costs. As noted above, however, for most studies on nonhumans, subjects are not merely questioned about what they see, but undergo significant training prior to testing. Our parrot Griffin, however, because he, like Alex before him, knew labels for various colors and shapes based on three-dimensional objects, could simply be asked appropriate questions. Occluded objects were regular polygons (of one- to six-corners) of various colors, occluded mainly by black circles (which Griffin could not label either with respect to color or shape); occasionally occluders were other black polygons. Controls were colored polygons missing appropriate pieces

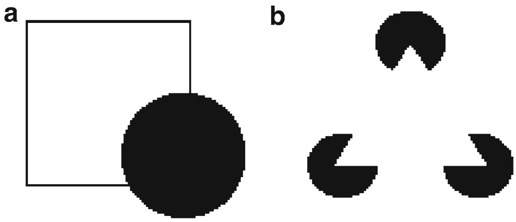

Fig. 12.1 (**a**) Occluded and (**b**) illusory objects

and black occluders appropriately displaced. In order to form illusory objects (again regular polygons of one- to six-corners), we used black ‘pacmen’ drawn on colored paper. Controls involved placing additional circles or ‘pac-men’ near the Kanizsa figure so Griffin could not simply quantify black objects. In both cases, Griffin was queried, “What shape X?”, where X was the appropriate color of the targeted object. All test stimuli, notably, were two-dimensional. For both sets of objects, Griffin responded correctly with about 80 % accuracy (Pepperberg and Nakayama 2012). Interestingly, he inferred the need to “count” corners only when presented with nonregular polygons that were controls in the occlusion task (i.e., regular polygons with missing pieces). Thus he transferred, without any training, from three-dimensional to two-dimensional stimuli, and performed in a manner that eliminated issues of stimulus generalization or local processing (e.g., basing responses on the familiarity of angular parts of stimuli), which may have occurred for nonhuman subjects having received significant training in previous studies. He was not asked to choose by pecking at a limited number of options, but actually had to state vocally what he observed, based on a repertoire of *all* of his shape labels.

4 Conclusions

Whether acquisition of symbolic representation simply enables a nonhuman to express abilities that are already part of its cognitive “tool kit”, or if such training actually alters the ways in which a nonhuman processes information, the results are, on the surface, the same: Data presented in this chapter demonstrate that the use of interspecies communication potentiates the discovery of cognitive abilities in avian subjects—cognitive abilities once thought to be the province of humans or, at most, nonhuman primates (Premack 1978).

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