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27

Pinnipeds, Porpoises, and Parsimony: Animal Language Research Viewed from a Bottom-up Perspective

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Animal Language Research (ALR) includes a variety of experimental studies of complex learning and cognition by nonhumans in which human language serves as a model for experimental design and data interpretation. For example, dolphins, who learned to react either to human sign language or to computer-generated sounds, were said to "give evidence of both semantic and syntactic processing. . . . The responses of the dolphins were consistent with the meaning of the words in a sequence and with the constraints imposed by word-order, and also appeared to take account of the state of the world" (Herman & Morrel-Samuels, 1990, p. 297). Without further analysis the above account may be more complicated and anthropomorphic than is necessary. The principle of parsimony states that simple explanations are usually better than complicated ones. Therefore some aspects of language comprehension by dolphins (and humans as well) might be

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described and explained more effectively by straightforward variants of discrimination learning principles (Catania, 1992).

The human linguistic model in ALR has indeed generated new ideas about nonhuman cognitive abilities as well as produced experimental demonstrations which were quite unexpected. However, a strong use of the human linguistic model in ALR has sometimes led to a reification of constructs, concepts, and terminology without further questioning and analysis of such linguistic concepts as "word," "meaning," "syntax," and "sentence." Thus, the top-down approach of adapting terminology from the study of a very complex set of learned skills (linguistics) to considerably less complex performances (ALR) has not been successful in (a) defining the learning abilities required for normal human language performance and (b) defining the quantitative or qualitative differences (if any) between learning abilities of different animals, including humans.

We have instead adopted a bottom-up approach: starting with operantly conditioned motor acts and moving up through an increasingly complex network of conditional relations emerging from and consistent with earlier discrimination learning. This gives us an operational model, or "how-to" guide, for investigating the role of reinforcement-based learning skills in complex cognitive performances, including human language. We describe the learning abilities required for appropriate responses to a simple artificial language taught to bottle-nosed dolphins (Herman, Richards, & Wolz, 1984) and a pinniped species—California sea lions (Schusterman & Krieger, 1984). These include the ability to learn (frequently by "exclusion") one-way sign-referent (conditional) relations, the ability to classify or categorize signs into functional categories, and the ability to learn generalized "rules" for the integration of multiple signs into an appropriate response (Gisiner & Schusterman, 1992; Schusterman & Gisiner, 1988, 1989; Schusterman & Krieger, 1984, 1986; Schusterman, Gisiner, Grimm, & Hanggi, 1993). To the degree that these processes and equivalence class formation are related to nonverbal behavior, they may give us a clue to the origins and evolution of human language (Catania, 1992; Sidman, 1990)

TRAINING STAGES AND LEARNING SKILLS IN SEA LIONS' ALR

Training Stages

Since 1981 three California sea lions (*Zalophus californianus*)—Rocky, Bucky, and Gertie—have been trained in two artificial language comprehension formats (Schusterman & Krieger, 1984; Schusterman &

Gisiner, 1988). The ALR with sea lions was designed to parallel a similar program on dolphins (Herman et al., 1984). This chapter is mostly concerned with Rocky, since this female sea lion has undergone the longest and most intensive analysis of all our sea lions in the ALR program.

The basic signaling repertoire and initial training procedures for nonrelational (single object) instructions are described in Schusterman and Krieger (1984). Training procedures for the relational (two object) instructional form are described in Schusterman and Gisiner (1988). The training stages between 1982 and 1988 are listed in Table 27-1. In Stages I and II paired relations between gestural cues and actions (stimulus-response relation) and gestural cues and objects (stimulus-stimulus relation) were established using standard operant conditioning techniques with food reinforcement. In Stage III a cue designating an object and a cue designating an action were combined, the required response being the performance of the specified action on the specified object only (out of two or more available objects). In Stage IV signs designating object brightness (white, black) and size (large, small) were added to the object-action combinations, requiring the subject to integrate the information from multiple cues when selecting a response object. Finally, in Stage V the sea lion was trained to conditionally modify its "fetch" response (bringing the designated object back to the signaler) to a "rela-

TABLE 27-1
Training stages in the artificial language taught to Rocky

Stage	*Training procedure*
I. Actions (A)	Shape response and place under control of a gestural sign.
II. Objects (O)	Pointing orientation to an object shape under control of a gestural sign.
III. Integration (O+A)	Combine separate behavioral repertoires from I and II.
IV. Modifiers (M)	A. Add conditional cues for brightness. B. Add conditional cues for relative size. C. Combine brightness and size modifiers in either order.
V. Relational (O-p)	A. Shape response (take Object A to Object B). B. Put response under control of gestural signs by adding an object sign designating Object B to the combination Object A + FETCH.

tional fetch" response (bringing the object to another object) by placing a sign designating a destination object before the OBJECT + FETCH combination. The instruction was called a relational instruction because the sequential relationship between the two object signs determined which was fetched (the second) and which was the destination (the first).

These training procedures resulted in the formation of over 7,000 different instructions composed of 2 to 7 members out of a repertoire of 23 members (13 object shape signs, 4 modifier signs, and 6 action signs). The types of standard combinations and an example of each are shown in Figure 27-1. The standard sign combinations given to Rocky all followed conventions for the sequential arrangement of signs as shown in the figure. Table 27-2 expresses these sequential ordering conventions as pairwise sequential relations between two events. These conditional rules for sequential pairing of signs produced all standard combinatorial forms taught to Rocky.

Learning Skills: Sign-Referent Relations

In a procedure similar to arbitrary match-to-sample, conditional discrimination training was first used to direct a pointing response to one of two or more choice stimuli in the presence of an arbitrary gestural sign (stimulus-stimulus pairings): This procedure generated the "objects" and "modifiers" of the subsequent sign combinations (see Table 27-1). As training proceeded, sea lions would respond to an undefined or "unnamed" object immediately and persistently if it had been paired with a novel sign and if the other available comparison objects each had already been established or experimentally defined by a previous relation (Schusterman, Gisiner, Grimm, & Hanggi, 1993). Our training of the sea lions in this errorless manner was quite similar to the way dolphins had been trained to relate novel signs to unnamed objects

TABLE 27-2
Sequential pairings of signs in Rocky's standard combinations
(refer to Figure 27-1)

	Sign A	→	*Sign B*	*(Sequence segment)*
I.	Start	→	MODIFIER, OBJECT	(M-, O-)
II.	MODIFIER	→	MODIFIER, OBJECT	(M-M, M-O)
III.	OBJECT	→	Pause, ACTION	(O-p, O-A)
IV.	Pause	→	MODIFIER, OBJECT	(p-M, p-O)
V.	ACTION	→	Release	(-A)

FIGURE 27-1

Path diagram for development of repertoire of standard combinatorial forms

Training Stage (refer to Table 27-1) *IV*	*V*	*IV*	*III*	*Complete Combination*	*Number*	*Example*
			O-A →	O-A	76	PIPE OVER
		M →	O-A →	M-O-A	528	SMALL BALL FLIPPER
		M-M →	O-A →	M-M-O-A	240	BLACK LARGE BALL TAIL-TOUCH
	O-p →		O-A →	O-p-O-A	130	BAT, DISC FETCH
M →	O-p →		O-A →	M-O-p-O-A	313	WHITE RING, CUBE FETCH
M-M →	O-p →		O-A →	M-M-O-p-O-A	384	WHITE SMALL CUBE, CAR FETCH
	O-p →	M →	O-A →	O-p-M-O-A	376	PERSON, BLACK RING FETCH
M →	O-p →	M →	O-A →	M-O-p-M-O-A	956	LARGE CONE, BLACK CLOROX FETCH
M-M →	O-p →	M →	O-A →	M-M-O-p-M-O-A	1,192	BLACK SMALL CONE, SMALL CLOROX FETCH
	O-p →	M-M →	O-A →	O-p-M-M-O-A	464	WATER, SMALL WHITE CONE FETCH
M →	O-p →	M-M →	O-A →	M-O-p-M-M-O-A	1,192	WHITE FOOTBALL, LARGE WHITE CUBE FETCH
M-M →	O-p →	M-M →	O-A →	M-M-O-p-M-M-O-A	1,216	WHITE LARGE CUBE, SMALL BLACK BALL FETCH
					7,067	

Note. The path diagram on the left shows how the complete repertoire of standard combinatorial forms was produced by the training stages listed in Table 27.1. M = modifier signs, O = object (shape) signs, A = action signs, p = pause. The total number of instructions of each form and an example are listed to the right of each completed combination.

(Herman et al., 1984). However, without further analysis, Herman et al. took this errorless training technique to be the process by which the signs acquired meaning for these marine mammals and concluded that "It was sometimes sufficient to pair a new signal with an unnamed object for the dolphin to associate the two immediately. Successful association was indicated by the dolphin continuing to respond appropriately to the previously unnamed object in the presence of the new signal and to other objects . . ." (p. 157). Herman et al. go on to summarize their results on reference as follows: "The concept that signs stand for referents seems to come easily to the dolphins" (p. 207). Indeed, without questioning, analyzing, or experimenting further we would have arrived at the same conclusion about our sea lions. For example, following 716 trials, Rocky had learned to relate the signs A_1 and A_2 to the objects "pipe" (B_1) and "ball" (B_2) respectively. Afterward, Rocky, like the dolphins, would select a new object like a "ring" (B_3) in the presence of a novel signal A_3 rather than choosing one of the already defined comparison objects—pipe or ball. Had Rocky, like the dolphins, also come easily to the concept that signs stand for referents, or is there a simpler explanation for Rocky's behavior? Could the sea lion Rocky or, as a matter of fact, could the dolphins, prior to learning the relation "if sign A_3 then object B_3," simply have selected the novel object (B_3) by using a "rule of thumb"? That is, could they have excluded the defined or so-called named comparisons (B_1 and B_2) in the presence of the new sign (A_3)? The answer appears to be yes.

From the viewpoint of experimental psychology, signs and their referents can be seen as stimulus-stimulus relations that are established by conditional discrimination training or "if . . . then" rules, particularly in match-to-sample formats. In order to illustrate how a subject might *seemingly* associate a new signal with an unnamed object immediately, consider the following experiment—the subject in this case is taught to match geometric shapes to the number of fingers being held up by the trainer, and, after a period of arduous training, has indeed learned the following conditional discriminations: if the sample is one finger, then the correct comparison shape is square; if the sample is two fingers, then triangle is correct. Note that there are two relations being taught simultaneously. In contrast to two relations being taught simultaneously, a transfer test might be set up in the following manner: the novel sample is three fingers and the novel shape is circle, and the incorrect comparison is either square or triangle—the already defined comparisons. The subject is likely to respond correctly the first time to the circle-shaped comparison; however, it is not clear that the sample three fingers is the controlling factor in this instance. The subject is probably responding to "not square" or "not triangle" when presented with a sample (three fingers) which is likewise unrelated to a triangle or a square. The only way a cogent transfer test can be arranged is to train two novel relations simultaneously. Under these conditions, only if a subject learns the two sample/comparison relations immediately—or following a single information trial—can the investigator validly conclude that the concept that signs stand for referents come easily to the subject.

Laboratory demonstrations of exclusion are quite common with human subjects, some with severe and prolonged mental retardation, who have not as yet, for example, learned to relate Greek symbols with their printed names or numerals with their printed names (see e.g., McIlvane & Stoddard, 1985). Recently we have conducted experiments with sea lions showing that they also use exclusion during the initial phase of learning to relate a signal to an object or in arbitrary match-to-sample procedures, a sample to a comparison stimulus (Schusterman et al., 1993). Thus, selection of a particular comparison in the presence of a particular sample or signal does not necessarily indicate a controlling relation between the two (Dube, McIlvane, & Green, 1992; Kastak & Schusterman, 1992). In the experiments on sea lions, test trials were used in which novel signals like A_3 or A_4 were presented along with novel alternatives B_3 and B_4. Such test trials afford no basis for exclusion, and learning of the $A_3 \rightarrow B_3$ and $A_4 \rightarrow B_4$ relations by California sea lions took about 100 to 200 reinforced pairings using an errorless "exclusion" training technique (see Schusterman et al., 1993). These results cast considerable doubt on the ability of dolphins to readily acquire a concept that signs stand for referents (Herman et al., 1984). More likely dolphins do what some humans and sea lions do in similar situations—they respond "not B_1" or "not B_2" in the presence of the new A_3 signal and thus select object B_3. It is only later in the learning process, in contexts where the basis for exclusion is no longer available, that a novel conditional performance occurs. This is indeed the most parsimonious explanation of how dolphins learned sign-referent relations.

Functional Classes and Ordinal Relations

Novel sign sequences were introduced in a variety of ways and included new combinatorial structures (see the path diagram on the left of Figure 27-1). After a limited number of available signs were used in training and a sea lion achieved a high percentage of correct responses to the training set, the signs that had been held out of training were introduced to produce novel instructions. All three sea lions, including Rocky, were able to respond correctly to these new instructions on the very first exposure to them. This demonstrates that a sea lion is capable of learning something about signal class membership, allowing the animal to extend what it has learned with the training set to all other signs within the appropriate class. Three examples listed below show how Rocky was able to respond perfectly to novel sign sequences based on her previous reinforcement history.

1. After Rocky was trained by shaping procedures to jump over any object floating in a pool and the behavior was placed under the control of a gestural cue, she was able to perform perfectly the first time she was given the sign sequences BALL OVER and CUBE OVER.
2. Prior to training Rocky to relate a gestural sign to a cone-shaped object, she had been trained by our manipulation of reinforcement contingencies to respond appropriately to brightness and size cues as they were added to or conjoined with cues she had already learned to relate to different shaped objects (see Table 27-2). After Rocky learned to relate a gestural cue (CONE) to a floating cone-shaped object, she performed perfectly the first time she was given the sign sequences WHITE CONE MOUTH and BLACK CONE MOUTH.
3. Relational instructions ("take Object A to Object B") were formed by the addition of a second object sign (with optional modifiers) to a FETCH object-action pairing sequence. Again, this was done by manipulating reinforcement contingencies. Thus, we conditionally changed a single-object (O-A), nonrelational instruction like RING FETCH ("fetch the ring" to the signaler) to a relational instruction (O-O-A) like PIPE, RING FETCH ("take the ring to the pipe") or RING, PIPE, FETCH ("take the pipe to the ring"). The instruction was identified as a relational one because the ordinal relations between the two object signs determined which was the transported item (the second) and which was the goal item (the first). Another way of stating this is that in a relational instruction, depending on their ordinal positions, first or second, the same object signs (with optional modifiers) may serve as conditional cues for entirely different sea lion or dolphin performances. Thus, even such novel reversed, five-sign instructions like WHITE WATER-WING (a float), SMALL WHITE BALL FETCH and SMALL WHITE BALL, WHITE WATER-WING FETCH were performed perfectly by Rocky the very first time she was exposed to them.

In the artificial language taught to sea lions and dolphins, the fact that all signs in a given class (e.g., object signs) could be freely substituted in the appropriate place constitutes evidence of the formation of *functional* classes. Goldiamond (1966) has defined a functional stimulus class as a set of discriminative stimuli controlling the same behavior. Vaughn (1988) showed that pigeons were capable of forming what he called *functional equivalence sets* to photographic slides of trees divided into arbitrary sets of 20 slides each. After several reversals in the reinforcement contingencies for responses to stimuli in one or the other of the two sets, the pigeons began shifting their pecks from one set to the other after being exposed to only a few stimuli of a given set. Basically, the ability to extend relationships learned from one member of the set to other members of the set permits the subject to extend relationships learned from one member of the set to all other members of the set without additional differentially reinforced experience. The principle of functional equivalence may be the most parsimonious explanation of immediately correct responses by pinnipeds and porpoises to novel sign combinations.

Equivalence Relations

The concept of *equivalence relations* was derived from a study on reading and auditory-visual equivalences (Sidman, 1971). In this research, Murray Sidman applied a match-to-sample format to train conditional discriminations in a mentally retarded boy. The subject matched pictures of objects, like a cat, to spoken words as well as matching printed words to the corresponding spoken words. Subsequently, the subject showed that he could spontaneously relate the printed word cat to the picture of a cat and vice versa, even though the printed word and picture had not previously been explicitly paired but had only been related to the spoken word.

Experimental demonstration of equivalence involves testing for the properties of reflexivity, symmetry, and transitivity in the associations formed between three or more stimuli, in the context of a match-to-sample procedure. If these three properties can be demonstrated, the stimuli comprising the conditional relations are referred to as equivalent members or elements of a class.

Reflexivity, or identity matching, is demonstrated when an animal that has been trained to relate various identical stimuli can do so immediately and accurately when presented with completely novel stimuli (Kastak & Schusterman, 1992). Symmetry is demonstrated when an association between nonidentical stimuli is shown to be reversible (i.e., when trained to match A_1 [sample] with B_1 [comparison], the subject is able to match B_1 [sample] with A_1 [comparison]). Finally, transitivity can be exhibited by the ability of the subject to relate stimuli which share an intermediate stimulus, yet have never been presented together in the match-to-sample context (i.e., when trained to match A_1 to B_1 and B_1 to C_1, the subject immediately perceives a relationship between A_1 and C_1). If the subject of this experiment can immediately match C stimuli with the appropriate A stimuli (a combination of symmetry and transitivity) then a combined test for equivalence has been passed.

Recently, Sidman (1990) has distinguished between functional classes or sets and equivalence relations, stating that they are "closely related" but not the same. Sidman and his colleagues (Sidman & Tailby, 1982; Sidman, Wynne, Maguire, & Barnes, 1989) have shown that it is possible for differentially reinforced training of one-way sign-referent relationships (A→B, B→C) to produce in human subjects additional reflexive (A→A, B→B, C→C), symmetric (B→A, C→B), and transitive (A→C) relationships which together form a set of stimulus equivalence relations (C→A) between the various signs and referents. They have pointed out the obvious significance of these learning abilities for language: "Stimulus classes formed by a network of equivalence relations establish a basis for referential meaning" (Sidman & Tailby, 1982, p. 20), and note for the equivalence relations (as we do for the conditional relations between functional classes—see below) that "It is not correct to assume that the new . . . performances emerged without a reinforcement history" (p. 20).

Stimulus equivalence learning abilities have recently been demonstrated with a single California sea lion (Schusterman & Kastak, 1993). Such a demonstration has considerable importance for the topics of interest to ALR: (a) defining the learning abilities required for language and (b) defining the differences in learning abilities of different animal taxa, including humans. Sidman et al. (1989) have made a similar point: "A continued search with nonhuman subjects may yet provide the key to the problem of what is primary, equivalence or language" (p. 273). Our recent finding suggests that equivalence relations are not mediated by language but may be a prerequisite for linguistic competence.

Sequential Conditional Relations

Gisiner and Schusterman (1992) presented Rocky with *anomalous* (unfamiliar combinations of) signs created by reordering (e.g., A-O instead of O-A), deleting (e.g., M-A instead of M-O-A) or adding signs (e.g., O-A-A instead of O-A). The results of this study provide perhaps the most compelling data in a nonhuman demonstrating the formation of functional equivalence relations within a variety of complex contexts. The sea lion Rocky had learned relations which were consistent with reinforcement contingencies established during her experience with the arbitrarily structured artificial language shown in Figure 27-1. For example, of 70 anomalous sign sequence probes embedded into a standard balanced series given over a period of 18 months, Rocky gave 62 orienting responses (prior to her release from station) which did *not* correspond to the class of sign actually given, but instead corresponded to a class of sign that would normally appear in a familiar, standard combination (see Table 27-2). For example, the anomalous combination of an action sign followed by an object sign (A-O) contains two sequence differences from the standard object-action (O-A) combination: first, the sequence begins with an action sign, whereas standard, familiar combinations always began with either a modifier or object sign; second, the action sign is followed by an object sign when normally it would be followed by a release from station (refer to Table 27-2). Rocky was given 9 different A-O anomalous combinations and either made an object orientation to the action sign (three times) or made an action orientation when given the object sign (six times). Such results show that Rocky had learned to use one class of signs to predict the class or classes of signs that would appear next in sequence. Another way of stating this is that each class of signs acted as a conditional cue for a subsequent class. We called this set of conditional relations between classes *sequential conditional relations* (Schusterman & Gisiner, 1988, 1989; Gisiner & Schusterman, 1992).

Although Rocky demonstrated sensitivity to fixed sequential relationships and learned to rely on them strongly during her processing of sign combinations, she was also able to learn to integrate elements that did not stand in fixed sequential relationship to each other. Double modifiers were trained and maintained in free sequential order; both brightness-size and size-brightness modifier pairs were used with equal frequency (e.g., both LARGE BLACK and BLACK LARGE were used equally often to indicate the larger and darker of four objects of the same shape). As a result modifier sign order did not affect Rocky's ability to select the appropriate response object (see Gisiner & Schusterman, 1992).

Similarly, another sea lion (Gertie) trained in a different artificial language format was exposed to a relational instructional form ("take Object A to Object B") that provided both sequence cues (first object sign, second object sign) and position cues (left object sign, right object sign) to indicate the destination (B) and transported (A) objects, respectively. Tests with anomalous trials showed that she had learned to use the position relationships rather than the sequential relationships to indicate the relative roles of the two object signs (Gisiner & Schusterman, unpublished data). Thus it would appear that the sequential relationships which Rocky learned were not absolutely necessary for processing multiple signs into a response, nor were sequential relationships necessarily the only type of relationship between combined elements that a sea lion might learn.

Hierarchical Conditional Relations

Gisiner and Schusterman (1992) also showed that Rocky had learned another set of relations for integrating information from individual signs into a final response, which they termed *hierarchical conditional relations.*

The relationships were hierarchical in the sense that a previously trained part of the combination had to be present before subsequently trained additional signs were secondarily incorporated into the response (see Table 27-1 and Figure 27-1 for the sequence of training stages). The first trained and hierarchically primary combination was the object-action (O-A) sign pair: Rocky's responses showed that she would not form a response unless an object sign and action sign were paired in that order (O-A) somewhere in the combination. Next trained, modifier signs secondarily modified selection of an object, but only if followed by an object sign. Modifier information was not incorporated into an object search until an object sign was given, and if no object sign was given Rocky did not use the modifier information alone to select a response object. By comparison, she *did* respond to O-A combinations in contexts that normally required modifier signs (more than one object of the same shape), thus illustrating the secondary and optional role of modifier in response formation. The last trained step in response formation was the addition of a second object sign to the beginning of an O-A sequence containing a FETCH action sign (Training Stage V, Table 27-1). The presence of the second object sign conditionally altered a fetch response into a relational response (fetching one object to another). When the action sign was not FETCH then the hierarchically secondary object sign was not integrated into the response and only the hierarchically primary step (O-A) was carried out (Schusterman & Gisiner, 1988; Gisiner & Schusterman, 1992).

CONCLUSION

Some investigators started into ALR in a relatively cautious manner and talked, for example, about a gesture *as if* it were analogous to a word or about a sequence of gestures *as if* it were analogous to a sentence. However, a strong use of the linguistic model in ALR led these investigators to lose their caution, take a top-down approach and begin to assume rather than to question, analyze, and demonstrate symbolism, meaning, syntactics, et cetera, in the animals under study. In contrast, our bottom-up approach attempts to define symbolism and syntax operationally in terms of equivalence relations (see Sidman, 1990) and demonstrates that straightforward discrimination procedures with California sea lions and dolphins can produce complex cognitive performances with relevance to both syntactic and semantic learning in human language (Schusterman & Krieger, 1984, 1986; Schusterman & Gisiner, 1988, 1989; Gisiner & Schusterman, 1992; Schusterman & Kastak, 1993, 1995; Schusterman et al., 1993).

In a search for the origins and evolution of language, the discovery of learned relationships emergent from and consistent with reinforcement contingencies, such as functional equivalence and stimulus equivalence, provides ALR with powerful new techniques for the investigation of the relationship between language and cognition.