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This paper presents a sea lion's responses to an array of novel, or anomalous, combinatorial structures. These responses are used to construct a more complete definition of the types of learning abilities a sea lion used to attain the observed level of performance on a complex language-like task. Finally, we discuss the possible relationship of these learning skills to human language performance.

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COMBINATORIAL RELATIONSHIPS LEARNED BY A LANGUAGE-TRAINED SEA LION

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INTRODUCTION

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 see Gardner and Gardner, 1975; Herman et al 1984; Pepperberg 1981; Premack, 1972; Savage-Rumbaugh et al. 1978; Schusterman and Krieger 1984; Terrace, 1979). However, 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 (i) defining the learning abilities required for normal human language performance and (ii) defining the quantitative or qualitative differences (if any) between learning abilities of different animals, including humans (for example, see Thomas, 1980; Macphail, 1987).

We have instead adopted a "bottom-up" approach: starting with directly trained, differentially reinforced paired associate relationships and moving up through increasingly complex relationships emerging from and consistent with earlier 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.

Previously Demonstrated Learning Abilities in Sea Lion ALR

Schusterman and Gisiner (1988) described the learning abilities required for appropriate response to a simple artificial language taught to sea lions and dolphins. These included the ability to learn one-way sign-referent relationships, 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.

Sign-Referent Pairing. In the first stages of training, several behaviors were shaped using standard operant conditioning procedures and then placed under control of a gestural cue (stimulus-response pairing): this procedure generated the "actions" of the subsequent sign combinations. Conditional discrimination training was used to direct a pointing response to one of two or more choice stimuli in the presence of a gestural cue (stimulus-stimulus pairing): this procedure generated the "objects" and "modifiers" of the subsequent sign combinations. As training proceeded the subject developed an "exclusion" rule, immediately pairing nonfamiliar sample and comparison stimuli, regardless of their identities, thus giving the appearance of immediate, errorless learning of new paired associates well before actual paired associates had formed (Schusterman et al., in press). Paired associate relationships based on physical properties of the new sample and comparison stimuli formed only after tens or hundreds of differentially reinforced pairings of the two stimuli had been given in conjunction with the other, familiar pairs (Schusterman et al, in press).

Formation of Functional Equivalence Sets. When a new combinatorial structure was introduced (e.g. Modifier + Object + Action, introduced after Object + Action) a limited number of the available signs were used in training (e.g. only four of the eleven object signs and three of the six action signs). Once the subject 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. The subject (Rocky, an adult female sea lion) was able to respond correctly to these new instructions on her first exposure to them, indicating that she had learned a generalized rule or relationship between the elements that allowed her to extend what she had learned with the training set to all other signs within the appropriate class or category (Schusterman and Krieger 1984, Schusterman and Gisiner, 1988).

The fact that all signs in a given class (e.g. all object signs) could be freely substituted for each other, following training with only one or a few members, constitutes evidence of the formation of a functional equivalence set. This learning ability was first formally defined by Vaughan (1988) in terms of a spontaneous extension of a reversal of response contingencies for one stimulus to all members of a set of stimuli that had shared the same reinforcement contingencies prior to the reversal. The definition has since been expanded to include spontanous extension of relationships learned for just one or a few members of a set of stimuli to all members that share the same reinforcer (Dube et al., 1987) or the same sequential position in a combination of stimuli (Sigurdardottir et al, 1990). Sidman et al (1989) were the first to refer to this type of equivalence relationship as functional equivalence, to distinguish it from another type of equivalence relationship previously defined by Sidman and Tailby (1982). Basically, the ability to form functional equivalence relations permits the subject to extend relationships learned for one member of the set to all other members of the set, without additional differentially reinforced experience.

Generalized Rules for the Combination of Elements. Schusterman and Gisiner (1988) speculated that sequential relationships between sign classes played an important role in the subject's ability to integrate multiple signs into a unitary response. However, it also was clear that sequential relationships alone could not account for the nonsequential way the subject processed some sets of signs. For example, modifier signs which preceded object signs did not elicit an examination of the choice items until an object sign was given, at which time both modifier sign and object sign information were used to select a response item. Similarly, the terminal action sign determined how the preceding object signs were processed. For example, in relational instructions (two object signs) if the action sign was FETCH Rocky would produce a response involving two objects (relational), but if the action sign was not FETCH she would ignore the first of the two object signs she had received (Schusterman and Gisiner, 1988).

This paper presents a sea lion's responses to an array of novel, or anomalous, combinatorial structures. These responses are used to construct a more complete definition of the types of learning abilities a sea lion used to attain the observed level of performance on a complex language-like task. Finally, we discuss the possible relationship of these learning skills to human language performance.

METHODS

The subject of this study was Rocky, an adult female California sea lion (Zalophus californianus). She was housed at Long Marine Laboratory, Santa Cruz, California in a 7.6 m diameter by 1.8 m deep pool surrounded by wooden decking. The pool was supplied with 10-15°C filtered seawater via a flow-through pumping system drawing water directly from the ocean. Rocky was fed approximately 4-5 kg of thawed market-grade fish (capelin, smelt, herring, mackerel, squid) per day. She received between half and all of her daily ration as reinforcement for correct responding during daily training and testing sessions. Rocky's test and training sessions incorporated a double-blind procedure to control for inadvertent cueing (see Schusterman and Krieger, 1984; Schusterman and Gisiner, 1988).

Training with the artificial language used in this study began in 1982. The basic signaling repertoire and initial training procedures for non-relational (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 1986 (when this study began) are listed in Table 1. In Stages I and II, paired relationships between gestural cues and actions (stimulus-response pairing) and gestural cues and objects (stimulus-stimulus pairing) 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

Table 1. Training stages in the artificial language taught to Rocky.

Stage	Training procedure
I. <u>Actions (A)</u>	shape response and place under control of a gestural sign.
II. <u>Objects (O)</u>	pointing orientation to an object shape under control of a gestural sign.
III. <u>Integration (O+A)</u>	combine behavioral repertoires I & II.
IV. <u>Modifiers (M)</u>	A. add conditional cues for brightness. B. add conditional cues for size. C. combine modifiers in either order.
V. <u>Relational (O-p)</u>	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.

selecting a response object. Finally, in Stage V the subject was trained to conditionally modify its "fetch" response (bringing the designated object back to the signaler) to a "relational fetch" response (bringing the object to another object) by placing a sign designating a destination object before the object + fetch combination (see Figure 1). 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 two to seven elements from a repertoire of 23 elements (13 object shapes, 4 modifiers, and 6 actions). The types of standard combinations and an example of each are shown in Figure 1. If we are to claim that Rocky learned her generalized structural relationships between signs from exposure to the standard combinations then those learned relationships should be consistent with the relationships illustrated in Figure 1.

TRAINING STAGE (refer to Table 1) IV	V	IV	III	COMPLETED 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 W'WING, 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 SM. CONE, SM. 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	WH. FOOTBALL, LG. WH. CUBE FETCH
M-M →	O-p →	M-M →	O-A →	M-M-O-p-M-M-O-A	1,216	WH. LG. CUBE, SM. BLK. BALL FETCH
					7,067	

Fig. 1. The path diagram on the left shows how the complete repertoire of standard combinatorial forms was produced by the training stages listed in Table 1. M = modifer 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.

To test Rocky for learning about the relationships between signs, we presented her with nonstandard or "anomalous" combinations of familiar signs by adding, deleting, or rearranging signs (Table 2). These anomalous combinations were presented as isolated probe trials with no more than two probe trials per 70 trial baseline session. The baseline sessions consisted of familiar and novel standard combinations (Figure 1). Responses that corresponded to all the signs in a combination were reinforced. We did not reinforce responses to anomalous trials, regardless of outcome. This experimental design maximized the likelihood that the subject would apply relationships learned from the standard sequences and not develop a nonstandard response strategy applied only when anomalous combinations appeared (see Gisiner and Schusterman, 1992).

We distinguished two forms of response behavior. Orienting behavior occurred immediately after each sign was given and differed for each class of signs (Object, Modifier, or Action). Object signs elicited a complete head turn and searching movements until a particular object was singled out, which usually took one or two seconds, but might last as long as ten seconds. After locating an object Rocky would return to station and await the next sign. Modifier signs elicited a quick (approximately 0.5 second) stereotypic head turn to the left. Action signs elicited no discernable orienting movement. Thus each class of sign was followed by a distinctively different type of orienting response behavior. Performance behavior occurred after a sign sequence was completed and the subject was released by withdrawal of the signaler's foot, on which rocky stationed during signaling. If Rocky performed the signed action to the signed object(s) the response was scored as correct and reinforced. If any part of the response did not correspond to the signs given then no reinforcement was given. Occasionally Rocky would balk, that is she would not perform an action on an object but would instead remain in front of the signaler following release. A balk usually occurred when Rocky had been unable to locate an object during orientation, had missed a signal due to inattention, or when a signaler performed a signal incorrectly. Although they were not reinforced, balks remained in Rocky's repertoire apparently because balking reduced time and energy expended on a response when she had a low expectancy of being reinforced.

RESULTS

Sequential Relationships

Schusterman and Gisiner (1988) noted that some anomalous combinations caused Rocky to produce orienting responses inappropriate to the sign being given, for example, if an object sign was given in a place normally occupied by a modifier sign then the subject would make a modifier orienting response. This effect only occurred in anomalous combinations that contained one or more sequential pairings of sign classes not found in standard combinations (see Table 3a). When we expanded the number of "sequentially anomalous" combinations to a total of 70 trials of six different types the tendency of these combinations to produce orienting errors was confirmed.

Table 2. Anomalous sign sequences given to Rocky (12/16/86 to 6/30/88).

TRIAL TYPE	EXAMPLE	NO. OF TRIALS
I. TRANSPOSED SIGNS		
	Transposed Modifier/Object	
O-M-A	CUBE SMALL MOUTH	7
O-M-M-A	BALL BLACK LARGE FLIPPER	6
M-O-M-A	WHITE CUBE SMALL UNDER	6
	Transposed Object/Action	
A-O	TAIL CAR	10
O-A-O	RING FETCH BAT	12
A-O-p-O	FETCH WATERWING (pause) CAR	7
II. OMITTED SIGNS		
	Omitted Object	
M-A	WHITE OVER	6
M-M-A	LARGE BLACK FETCH	4
	Omitted Action	
O	PIPE	4
O-p-O	PERSON (pause) BAT	4
	Omitted Modifier	
O-A	BALL OVER	6
III. ADDED SIGNS		
	Added Modifier	
	(nonbelonging)	
M-M-O-A	BLACK LARGE WATERWING FETCH	6
	(conflicting)	
M-M-O-A	BLACK WHITE PIPE TAIL	6
	(triple modifier)	
M-M-M-O-A	BLACK LARGE SMALL CONE OVER	18
	Added Action	
O-A-A	CAR OVER MOUTH	16
IV. RELATIONAL WITH NONFETCH ACTION		
O-p-O-A	BALL (pause) CUBE FLIPPER	12
V. NONTRANSPORTABLE TRANSPORTED ITEM		
O-p-O-A	CLOROX, PERSON FETCH	3
VI. PAUSE ANOMALY		
O-p-A	BAT (pause) UNDER	6
	TOTAL:	149

Table 3a. Sequential pairings of signs in Rocky's standard combinations (refer to Figure 1).

	SIGN A	→ SIGN B	(Sequence Segment)
I.	(start)[1]	→ 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)[1]	(-A)

[1] - 'start' and 'release' were not signs, but positional cues exchanged between signaler and sea lion to indicate mutual readiness to begin a sign sequence or that a sequence had been completed.

Table 3b. Orienting errors to sequentially anomalous sign sequences. Erroneous component of response is identified by the underlined letter.

SEQUENCE ANOMALY	STD. SEQ. (see 3a)	ORIENTING RESPONSE	ERRORS/ TOTAL
A-O	I	o-a	3/9
	V	a-a	6/9
O-A-O	V	o-a-a	11/12
A-O-p-O	I	o-o-p-o	5/7
	V	a-a-p-a	2/7
O-p-A	IV	o-p-o	5/6
(M)-M-A	II	(m)-m-o	9/10
M-p-O-A	II	m-o-a-a	8/8
O-M-(M)-A	II	o-m-(m)-o	5/13
	III	o-a-a-a	3/13
M-O-M-A	III	m-o-a-a	5/5
		TOTAL:	62/70

Table 3b shows that Rocky almost always produced an orienting response that 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 (62 of 70 or 89%). 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 3a). Rocky was given nine 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).

These data show that Rocky had learned to use a sign to predict the class or classes of signs that would appear next in sequence. Presumably this helped her process combinations more accurately and/or rapidly. However, the anomalous combinations also illustrate another consequence of using sequential regularities from the standard combinations: inability to successfully integrate the signs in nonstandard sequential arrangements, even though they all contained sufficient information to designate a single unambiguous response. Rocky balked on 55 of the 70 sequentially anomalous trials (79%) and produced a response corresponding to only one of the signs in the remaining 15 (21%) trials: none of her responses corresponded completely to the signs given.

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 and 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 and Schusterman, unpubl.). Thus, it appears 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.

Table 4a. Rocky's responses to anomalies without a standard O-A sign pair.

ANOMALOUS SEQUENCE	RESPONSE Balk	Match	Other
Omitted Object			
M-A	6	0	0
M-M-A	4	0	0
A	4	0	0
Omitted Action			
O	4	0	0
O-p-O	4	0	0
Transposed Modifier/Object			
O-M-A	7	0	0
O-M-M-A	5	0	1
M-O-M-A	6	0	0
Transposed Object/Action			
A-O	9	0	1
TOTAL:	49	0	2
PERCENT:	(96)	(0)	(4)

Table 4b. Rocky's responses to anomalies with an O-A sign pair.

ANOMALOUS SEQUENCE	RESPONSE Balk	Match	Other
Omitted Modifier			
O-A	0	6	0
Added Modifier			
(nonbelonging)			
M-M-O-A	0	6	0
(conflicting)			
M-M-O-A	0	6	0
(triple modifier)			
M-M-M-O-A	4	12	2
Added Action			
O-A-A	4	6	6
Nonfetch Relational			
O-p-O-A(A $\neq$ fetch)	0	11	1
Nontransportable Object			
O-p-O-A	0	3	0
TOTALS:	8	50	9
PERCENT:	(12)	(75)	(13)

Hierarchical Relationships

We also presented Rocky with novel combinatorial structures that maintained the standard sequential relationships listed in Table 3a. Novel combinatorial forms like M-M-M-O-A or O-p-O-A(A≠fetch) were anomalous either because they contained added signs (the extra M in M-M-M-O-A) or because they contained a sign not used in the familiar, standard combinations (the non-fetch action sign in an O-p-O-A combination). These combinations retained the pairwise relationships between successive sign classes found in standard combinations and therefore did not elicit orienting errors which might disrupt attention to the remainder of the sign sequence, as was the case with the sequentially anomalous combinations (Table 3b).

Rocky's responses to these sequentially "normal" anomalous combinations have been organized in the order of the training stages listed in Table 1. These anomalous combinations show that if conditions of an earlier training stage were not met then signs satisfying conditions of a later training stage were not incorporated into the response, regardless of their sequential position in the combination.

Object-Action Pairing (Stage III training). The first step in Rocky's training with multiple sign integration was the combination of an object sign and an action sign: the incorporation of information from other signs was therefore hierarchically secondary to the initiation of response formation by an O-A sign pair. Anomalous combinations lacking an O-A sign pair did not elicit responses, while anomalous combinations containing an O-A sign pair anywhere within the combination usually elicited responses consistent with both the object and action sign (compare Tables 4a and 4b). Rocky balked on 49 of 51 (96%) anomalous trials that did not contain a standard O-A sign pair (Table 4a). Neither of her two non-balk responses corresponded to both the action and object signs given. In contrast Rocky produced significantly more responses matching the object and action signs when there was a standard O-A pair somewhere in the anomalous combination (50/58 versus 0/51; $\chi^2 = 89.1$, $\alpha << 0.001$, d.f. = 2).

Modifiers (Stage IV Training). Modifiers were signs which had the effect of imposing additional criteria for the selection of a response object beyond the shape criterion established by the object sign. Paired relationships between modifier signs and object properties were trained in the context of a multi-element combination (M-O-A). A modifier sign's relationship with a specific object property was established first by oddity, e.g. the sign BLACK would be introduced with only one black object among several white objects (see Schusterman and Krieger, 1984; Schusterman et al., in press). Rocky's experience with modifier signs was therefore limited to contexts in which an object sign was also present.

Rocky's responses to anomalous combinations were consistent with this training history: she did not form a response corresponding to the signs given when logically unnecessary object sign information was missing, but did form a response corresponding to the signs when logically necessary modifier information was missing. Rocky balked on all ten presentations of M-A and M-M-A anomalies even though the objects were the same shape, differing only in their modifier properties (a sign indicating object shape was therefore unnecessary for the selection of a single appropriate response object). For example, when given the combination LARGE BLACK OVER in the presence of four cubes differing only in size and brightness Rocky had sufficient information to select a single cube to jump over, but she instead balked. However, when Rocky was given six replicates of the combination O-A in the presence of more than one object of the specified shape (plus various other objects) she responded with the specified action to the nearest object of the specified shape, without providing any indication that the missing modifier information made object choice difficult. For example, when given the combination BALL OVER in the presence of both a black and a white ball (plus other objects) Rocky responded by jumping over the nearer ball, without any indication of difficulty in choosing an object such as hesitation or prolonged inspection of multiple objects.

Rocky's orienting behavior also supported the hypothesis that she processed the modifier sign information secondarily to, and dependent on, an object sign. As described in the Methods section, Rocky's orienting response to a modifier sign was a rapid head flick to the left, unlike the slower and more varied movements following an object sign. Rocky therefore had to wait until she received an object sign to apply both modifier and object sign information to the task of searching for the appropriate response object. For example, when given the signs LARGE BLACK BALL Rocky did not fix her gaze on one or more large objects after the LARGE sign, then on large black objects after the BLACK sign, and finally the large black ball after the BALL sign. Instead she looked at no objects after either the LARGE or BLACK signs, and then upon receiving the BALL sign she located the large black ball.

Since Rocky retained modifier sign information until she received an object sign, it is not surprising that multiple modifier anomalies revealed the effects of interference on memory for modifier information. For example when given a "conflicting modifier" anomaly (e.g. BLACK WHITE CONE TAIL-TOUCH) Rocky's response always (n = 6) matched the second modifier (her response to the example given above was 'white cone tail-touch'). Schusterman and Gisiner (1988) also noted interference effects between the two object signs in standard relational instructions: Rocky was 95 to 100% successful in selecting the object designated by the second of two object signs, but was barely above chance (<50%) in selecting the object designated by the first of the two object signs.

In standard double-modifier combinations the modifiers were of different types (size and brightness) and, as we noted earlier, both modifiers were incorporated into an object choice as accurately as combinations containing one or no modifier (also see Schusterman and Gisiner, 1988). There were several objects that came in only one size and therefore size modifiers had never been combined with these object signs and a brightness modifier in standard sequences; in other words size modifiers did not "belong" with certain object signs (pipe, ring, waterwing, car, bat), with or without an added brightness modifier. This allowed us to create anomalous combinations containing familiar signs in a familiar order, but containing a "nonbelonging" size modifier that could not affect the response except by interfering with the integration into Rocky's response of the other belonging signs. Surprisingly, nonbelonging size modifiers did not affect response formation negatively, regardless of their position relative to other belonging signs in the combination. Rocky received three trials in which the nonbelonging modifier preceded the belonging modifier and three trials in which the nonbelonging modifier came after the belonging modifier. In all six trials Rocky's response corresponded to the signs for object, action and belonging modifier, with no interference from the nonbelonging modifier. For example, the sign SMALL was nonbelonging when it was used in the sequence WHITE SMALL RING FETCH because rings only came in one size, with no large or small ring to choose from (only balls, cubes, footballs and cones came in two sizes). The SMALL sign did not interfere with memory for the preceding WHITE modifier sign, since Rocky was able to select the white ring (and not the black ring or one of several other objects in the pool) and fetch it back to the signaler.

These data from combinations containing two modifiers of the same class (conflicting modifier anomaly) or two modifiers of two different classes (whether the second modifier was "belonging" and required for object selection or "nonbelonging" and irrelevant to object selection) suggest that Rocky was able to reduce interference effects between signs by assigning them to different categories, in this case two categories of modifiers, one of size (LARGE and SMALL) and one of brightness (WHITE and BLACK).

The effects of interference and categorization were further examined using another type of multiple modifier anomaly. Triple-modifier anomalies (M-M-M-O-A) created differences in the separation from the object sign of two conflicting modifiers and a single modifier of the other category (see Table 5a). Table 5b shows that when two conflicting modifiers occupied the first and second or first and third positions, interference between the two conflicting modifiers resulted in the elimination of the first modifier sign (9 of 12) and the successful incorporation of the last two modifier signs (one of each category) into an object choice in 9 of 12 trials. However, when the second and third modifiers conflicted Rocky was required to retain information from the first modifier if she was to successfully incorporate a modifier of each type into her object choice. She clearly had more difficulty doing this; her object choice agreed with two of the three modifier signs in only one of six trials and she balked on four trials (she made no balks to the other triple modifier arrangements).

Although the sample size is not large enough to be statistically significant it is clear that when two modifiers intervened between a modifier of the other type and an object sign there was a reduction in Rocky's ability to select a response object. This did not occur when only a single modifier intervened between a modifier of another type and the object sign (whether the single intervening modifier occurred in a standard double modifier combination, a nonbelonging modifier anomaly or the modifier 1-3 conflict version of the

Table 5a. Examples of triple-modifier anomalies. Conflicting modifiers are underlined.

Modifier 1-2 Conflict

BLACK WHITE LARGE FOOTBALL FLIPPER
LARGE SMALL BLACK CONE OVER

Modifier 1-3 Conflict

SMALL BLACK LARGE CONE MOUTH
WHITE LARGE BLACK BALL FETCH

Modifier 2-3 Conflict

LARGE BLACK WHITE BALL TAIL-TOUCH
WHITE LARGE SMALL CLOROX UNDER

Table 5b. Effects of sequence and modifer class in triple modifier anomalies. Numbers indicate how many object choices (out of six trials per category) corresponded to the first, second, or third modifiers.

CONFLICTING PAIR	RESPONSE			
	Mod.1	Mod.2	Mod.3	Balk
Modifier 1-2	2	4	5	0
Modifier 1-3	1	5	5	0
Modifier 2-3	1	2	0	4

triple modifer anomaly). Since Rocky usually balked when she wasunsure of signs her tendency to balk on this anomaly suggests to us that she had retained some information about the first modifier sign, but not enough to select a response object with assurance. If the information from the first sign had been completely eliminated we would have expected Rocky to select a response object without hesitation, and we would have expected the object selected to consistently correspond only to the third modifier sign and object sign; the second modifier sign having been eliminated by interference with the third modifier sign as in the conflicting modifier anomalies and the first modifier sign having also been eliminated by the interference effects of the two intervening modifiers. This never occured, however.

In summary, nonbelonging modifier anomalies showed us that Rocky's labelling or categorization of modifiers into two different categories reduced interference effects between successive modifiers of different subclasses, compared to the interference effects between two modifiers of the same type in the conflicting modifier anomalies. However, when two conflicting modifiers were placed between a modifier sign of the other type and the object sign, Rocky's difficulty in selecting a response object suggested that the reduction of interference achieved by classifying the modifiers was limited. Due to limitations in the variety of potential categorization/ interference relationships available within Rocky's simple artificial language and to limitations in the number of trials that could be run before an anomalous combination became "non-novel" we consider our interpretation preliminary and tentative, pending further study of the effects of categorization on interference.

Relational Combinations (Stage V Training). In this training stage an object sign (with optional modifiers) together with a FETCH action sign fulfilled the primary condition of an O-A pair: the hierarchically secondary step was the introduction of an added object sign (with optional modifiers) at the start of the sequence. The added object sign modified a fetch to the signaler (standard single object fetch) into a fetch to another object (relational fetch). An anomalous combination that failed to meet the criteria of the hierarchically primary step (O-A), for example O-p-O, did not elicit a response (see Table 4a) even though the O-p-O combination of two object signs was sufficient to unambiguously indicate a relational response (FETCH was the only action sign used in standard relational combinations).

The anomalous combination O-p-O-A (A ≠ fetch) illustrates the hierarchical and nonsequential process by which Rocky combined signs into a response. On 11 of 12 replicates of this

Table 6. Rocky's responses to O_1-p-O_2-A combinations in which A ≠ FETCH. Correspondence between signs and response are underlined.

SIGN SEQUENCE GIVEN O_1	O_2	A	RESPONSE O_1	O_2	A
CUBE	BALL	TAIL	--	ball	tail
CLOROX	FOOTBALL	UNDER	--	f'tball	under
CAR	BAT	MOUTH	--	bat	mouth
BALL	BAT	UNDER	--	bat	under
DISC	BALL	OVER	--	ball	over
F'TBALL	W'WING	TAIL	--	w'wing	tail
PERSON	DISC	MOUTH	--	disc	mouth
W'WING	PIPE	MOUTH	--	pipe	mouth
WATER	BAT	UNDER	--	bat	under
W'WING	CAR	PEC	ring	car	fetch
RING	W'WING	OVER	--	w'wing	over
BALL	CUBE	PEC	--	cube	pec

combination Rocky's response conformed to the conditions set by the hierarchically primary but sequentially terminal O-A sign pair, and excluded the information from the first object sign (Table 6).

SUMMARY

Rocky's responses to the anomalous combinations showed that she had indeed learned generalized relationships or "rules" governing the integration of multiple elements into a unified instruction.

One set of generalized relationships were the sequential conditional relationships in which each sign acted as a conditional cue for the class or classes of signs that would follow (see Table 3). However, we also noted that these relationships were not a necessary or inevitable part of being able to process multiple signs into a unitary response: Rocky was able to process modifiers that did not occur in fixed sequential relationships, and another sea lion (Gertie), trained in a different way, learned to use positional rather than sequential relationships. We speculate that Rocky's use of learned sequential relationships between signs improved her processing of the signs by generating expectancies that focused her attention on a limited set of probable outcomes. We propose two likely benefits to such a strategy: (i) reducing the probability of mistaking a given sign for a sign of an inappropriate class and/or (ii) reducing the processing time for each sign, consequently reducing the load on short-term memory during integration of multiple signs into a response. The presence of considerable interference effects between multiple object signs (Schusterman and Gisiner, 1988) and multiple modifier signs (this paper) suggest that strategies which speed processing of the signs might be of considerable value.

The second set of learned relationships were hierarchical conditional relationships for integrating information from the individual signs into a response. 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 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 a response 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 modifiers in response formation. Multiple modifier anomalies showed that interference between multiple modifiers was reduced by subclassification of modifiers into size and brightness subclasses. These are referred to as subclasses because in their interactions with other sign classes all modifiers were freely substitutable and thus constituted a unitary class, but when modifiers interacted with each other their effect on object selection depended on whether they were of the same or different subclasses. 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 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 added object sign was not integrated into the response and only the hierarchically primary step (O-A) was carried out (see Table 6).

CONCLUSIONS

Essential Cognitive Abilities

We have shown that the organizational relationships between signs did not necessarily have to be sequential, but could be based on positional cues (sea lion Gertie) or free sign order (Rocky's modifiers). Similarly, we suspect that the relationships between signs and response behavior could be based on other aspects of the subject's reinforcement history than the order of training stages. To give a hypothetical example; if Rocky had been given more food for a relational fetch than for a single object fetch, or if she was given relational instructions more frequently than single object instructions she might have been more likely to respond relationally to an anomalous combination that contained both relational and nonrelational cues (e.g. the O-p-O-A anomalous form shown in Table 6). (See Gisiner and Schusterman, 1992 for another example of how training history might affect responses to ambigous anomalous combinations). For these reasons our operational definition of the learning abilities required to produce a performance comparable to Rocky's de-emphasizes the specific features to which the subject may have attended and instead emphasizes the general abilities to (i) form functional equivalence classes of elements and (ii) form conditional relationships between the classes.

Consequences of Demonstrated Cognitive Abilities

The learning abilities described above produced a considerable savings in the time and effort required to learn a repertoire of behaviors when compared to more familiar learning processes, such as paired associate learning and conditional discrimination learning, in which each response possibility must be paired with a unique cue many times in the presence of reinforcement before the relationship is learned. Rocky's ability to learn consistent relationships between classes of elements allowed her to respond appropriately to hundreds of new sign combinations after trial-and-error experience with just a few examples.

Another consequence of the relationships that Rocky learned, revealed by the anomalous combinations, was the reduction of combinations potentially able to elicit responses from the entire set of logically equivalent combinations to that limited subset which conformed to the learned relationships. For example, the sign combinations BLACK BALL FETCH, BALL BLACK FETCH, FETCH BALL BLACK, BLACK FETCH BALL, BALL FETCH BLACK and FETCH BLACK BALL all convey the same information, but, due to her application of learned sequence relationships, Rocky would only produce a response corresponding to the signs when she was given the combination BLACK BALL FETCH.

A further consequence of Rocky's having learned relationships in addition to the directly taught unidirectional pairing of sign and referent was that individual signs acquired multiple relationships: serving as cues for the class or classes of signs to follow (sequential conditional relationships), setting up contingencies for the integration of other signs (hierarchical conditional relationships), and serving as cues about the properties of the response object and response action (one-way conditional discriminations and paired associates).

This expansion of relationships for individual signs raises the question of whether the semantic meaning or symbolic equivalence between sign and referent was also necessarily expanded beyond the originally trained one-way relationships between signs and their direct referents. Put another way; does the ability to form the relationships between elements described in this paper necessarily entail the learning of expanded relationships between sign and referent beyond the initial directly taught one-way relationship between sign and referent? The answer is <u>no</u>, since none of the emergent relationships between elements described in this paper required any additional relationship between sign and referent beyond the originally trained one-way relationships. However, expanded sign-referent relationships <u>are</u> necessary for signs to function as symbolic equivalents for referents (as words do in human language) and in another paper we have described a procedure for demonstrating emergent sign-referent relationships which would be necessary for semantic or symbolic equivalence between sign and referent (Schusterman and Gisiner, in press). The procedure is based on the stimulus equivalence learning procedure developed by Sidman and his colleagues (Sidman and Tailby, 1982; Sidman et al., 1982; 1989).

<u>The Significance of Stimulus Equivalence</u>

Sidman and his colleagues (Sidman and Tailby, 1982; Sidman et al., 1982; 1989) have shown that it is possible for differentially reinforced training of one-way sign-referent relationships (A→B, A→C) to produce in human subjects emergent, untrained reflexive (A→A, B→B, C→C), symmetric (B→A, C→A), and transitive (B→C) relationships which together form a set of stimulus equivalence relations between the various signs and referents. They have pointed out the significance of these learning abilities to the issues of symbolic equivalence and semantic meaning: "Stimulus classes formed by a network of equivalence relations establish a basis for referential meaning." (Sidman and Tailby, 1982; p.20) and note for the stimulus equivalence relationships, as we did for the conditional relationships between stimulus classes, that "It is not correct to assume that the new ... performances emerged without a reinforcement history." (ibid.). Stimulus equivalence learning abilities have not yet been demonstrated with nonhuman subjects, although such a demonstration has considerable importance for the topics of interest to ALR: 1) defining the learning abilities required for language and 2) defining the differences in learning abilities of different animal taxa, including humans. Sidman et al. (1989, p.273) 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."

The Future of ALR

The time seems ripe for a new approach to Animal Language Research. Following the exchange between Skinner (1957) and Chomsky (1959), analysis of reinforcement contingencies has been considered largely irrelevant to those learning processes that separate language learning from other kinds of learning. The results of this study, together with Sidman's formulation of stimulus equivalence learning, demonstrate that reinforcement-based procedures can produce complex cognitive performances with obvious relevance to both syntactic and semantic learning in human 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 those questions about language and cognition which first inspired us to "talk to the animals".

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