STIMULUS EQUIVALENCE AND CROSS-MODAL PERCEPTION: A TESTABLE MODEL FOR DEMONSTRATING SYMBOLIC REPRESENTATIONS IN BOTTLENOSE DOLPHINS

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INTRODUCTION

Dolphins make a variety of decisions while swimming in schools. These decisions determine the way they navigate, avoid predation, forage, reproduce, care for young and otherwise engage in social interactions. These decisions are based on the ability of dolphins to process information from a variety of sensory avenues, including the active process of investigating objects via echolocation. Information from all sensory systems is most probably used in an integrated fashion. However, whether information from the various sensory modalities is also stored and retrieved, as well as used in an integrated way, i.e., whether dolphins are capable of intermodal stimulus equivalence or cross-modal perception, currently remains a hypothesis (Schusterman, 1988a).

Studies on the psychophysics of echolocation, hearing, vision, skin senses and taste suggest that dolphins have rather rich and detailed representations of the external world. (For detailed critical reviews on the psychophysics of dolphin sensory perception, see the following: Dawson, 1980; Fobes and Smock, 1981; Johnson, 1986; Madsen and Herman, 1980; Murchison, 1980; Nachtigall, 1980; 1986; Popper, 1980; Ridgway, 1986; Schusterman, 1980; Watkins and Wartzok, 1985). Research on rule learning and concept formation suggest that, like some primates, dolphins may be able to represent abstract relations, as well as perceptual relations in both the auditory and visual modalities (for reviews see Herman, 1980; 1986; Schusterman, 1988a; Seyfarth, 1986). Indeed, an important source of evidence for determining symbolic representation involves intermodal stimulus equivalence. This cognitive ability, which has been demonstrated bidirectionally in some anthropoid apes and monkeys using cues from visual and tactile modalities (Cowey and Weiskrantz, 1975; Davenport and Rogers, 1970; Davenport, Rogers and Cross, 1973), is thought by some to be essential for the emergence of language (Geschwind, 1965; Lancaster, 1968). It has also been suggested that cross-modal perception requires a "modality-free representation" of a stimulus pattern (Rumbaugh, et. al., 1982). Are dolphins capable of intermodal equivalence of sonar cues and reflected light cues emanating from common objects, or are they capable of intermodal equivalence of tactile cues and visual cues emanating from common objects? A dolphin's use of symbols within such intermodal tasks would be a good demonstration of the ability of these large-brained marine mammals to use modality-free or symbolic representations of stimulus patterns. In this

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paper, I present a simple model based on Sidman's notion of stimulus equivalence (1986) to test these ideas. However, before presenting the model as applied to cross-modal perception in dolphins, allow me to illustrate stimulus class equivalencies as applied to one of the most well-known and well-documented examples of semantic communication in animals--vervet monkey alarm calls (Seyfarth, 1986).

VERVET MONKEY ALARM CALLS AND STIMULUS EQUIVALENCES

In a conditional discrimination, the most commonly used procedure is called matching-to-sample (MTS) in which an animal's choice between two or more comparison stimuli is contingent on sample or conditional stimuli. For example, in the presence of A_1, B_1 is correct and reinforced, but not B_2 or B_3, etc., and in the presence of A_2, B_2 is correct and reinforced, but not B_1 or B_3, etc. In a concrete but totally hypothetical illustration, a naive vervet monkey may be shown two pictures simultaneously or played two different recordings of vervet monkey alarm calls in rapid succession; perhaps pictures of a leopard vs. a martial eagle in the first instance or a "loud bark" vs. "chuckle" in the second case. The monkey must use a third stimulus, the sample or instructional cue, that determines which picture or which alarm call should be responded to. In identity matching, the instructional cue and the appropriate comparison stimulus are physically the same, so the monkey would match a leopard comparison to a leopard sample and a martial eagle comparison to a martial eagle sample, etc. A different MTS procedure called arbitrary or "symbolic" matching, specifies a relation in which the sample and its matching comparison stimulus bear no physical resemblance to each other, and for that reason, the symbolic matching task has been of interest as a task that illustrates simple semantic relations (Catania, 1970). For example, a naive vervet monkey might learn to match animal pictures (comparisons) to vervet monkey call samples; with leopard a paired associate of the sample "loud bark" and martial eagle the paired associate of the sample "chuckle."

Note that several characteristics of the MTS procedure make it a suitable method for experimental studies of animal cognition including short-term memory, perceptual categorization, abstraction and various aspects of language, especially semantic comprehension (see Carter and Werner, 1978; Schusterman, 1988b; Schusterman and Gisiner, 1989; Sidman and Tailby, 1982 for reviews of various MTS paradigms in the study of animal cognition as it relates to semantic comprehension). Sidman and Tailby (1982) and others have pointed out that the term "MTS" sometimes refers to a procedure and sometimes it refers to the results of a procedure. These two different meanings of MTS have frequently been muddled in the interpreting of results which bear on fundamental issues in animal cognition [e.g. see the controversy between Herman (1988; 1989) and Schusterman and Gisiner (1988; 1989)]. For example, if a vervet monkey performs appropriately on a matching task and its opposite, a mismatching or oddity task, the behavior does not necessarily mean that the monkey has a "sameness" or "oddity" concept. The critical test of concept formation comes when the monkey must match <u>novel</u> stimuli solely on the basis of their identity relationship. As in identity MTS, symbolic MTS also tacitly assumes that each paired associate of sample and comparison stimulus is related not merely by an "if ... then ..." relationship, but by equivalence. Thus, in the vervet monkey illustration, it is easy to assume that each alarm call sample and each animal picture comparison stands in an equivalence relation to one another (e.g. the monkey makes both of these relationships: "if 'loud bark' then leopard", <u>and</u> "if leopard, then 'loud bark' "). However, as Sidman and Tailby (1982) have shown, like identity, the arbitrary relationship between so-called symbols and their referents remains in a unidirectional "if ... then ..." relation and can not be considered to form an equivalence class relationship unless there are explicit and independent tests. Simple behavioral variables may be mistakenly identified as evidence of complex cognitive processes, such as symbol manipulation, if the assumption of stimulus equivalence is in fact invalid (Mackay and Sidman, 1984).

If the training of a series of conditional discriminations with MTS paradigms (if A_1 then B_1; if A_2 then B_2; etc., or if "loud bark" then leopard; if "chuckle," then martial eagle, etc.), results in the emergence of untrained relationships between dissimilar stimulus patterns, then the equivalence of stimulus classes exists. Stimulus equivalence has three defining characteristics: reflexivity, symmetry and transitivity.

1. Reflexivity. Reflexivity emerges from generalized identity matching of the type: If A_1, then A_1; if A_2, then A_2; and if B_1, then B_1; if B_2, then B_2, etc. Thus, if it takes several trials before a naive vervet monkey can consistently match a "loud bark" call to itself, but then the monkey matches a "chuckle" to itself on the first trial and a "chittering" call to itself on the first trial, and if the monkey overcomes the difficulty in matching a picture of a leopard to itself, and immediately can match a picture of a martial eagle to itself and a picture of a python to itself, etc., then we can conclude that this vervet monkey who was taught a set of sample-comparison relations (vervet monkey alarm calls and pictures of animals) has demonstrated that these relations were reflexive by showing that it was capable of matching the two kinds of stimuli to themselves. Moreover, ideally, to develop additional critical tests of class equivalency, another set of sample-comparison relations are needed. These could consist of vervet monkey alarm calls and printed lexigrams. Reflexivity would also be demônstrated if the subject could match each lexigram to itself.

2. Symmetry. Symmetric relations are shown when two or more dissimilar stimuli are related bidirectionally or reciprocally (e.g., if A_1, then B_1; if B_1 then A_1). Figure 1 illustrates a basic equivalence paradigm. The vervet monkey who has learned to match comparison stimulus B_1 (e.g. leopard) to sample stimulus A_1 (e.g. "loud bark") or comparison stimulus C_2 [e.g. a lexigram consisting of a square shape with a dot in the middle (⊡)] to sample stimulus A_2 (e.g. "chuckle"), must then, without additional training, be able to match A_1 (comparison) to B_1 (sample) and A_2 (comparison) to C_2 (sample). Symmetry requires sample and comparison stimuli to be functionally interchangeable. Stated another way, within the context of semantics, symmetry occurs when "conditional cues have become more than conventional discriminative stimuli ... [i.e.], when signs and their referents are shown to be immediately interchangeable ..." (Schusterman and Gisiner, 1989). In this hypothetical experiment, symmetry could be tested indirectly with a vervet monkey by determining whether the test subject vocalizes appropriately to pictures of a leopard or to the printed lexigram ⊕ (see Fig. 1).

3. Transitivity. The emergence of transitive stimulus relations from conditional discriminations requires three stimulus types as illustrated in Fig. 1. Once "if A_1, then B_1" and "if A_1, then C_1" have been established, transitivity requires "if B_1, then C_1" to emerge without explicit training. Suppose, for example, our vervet monkey subject, having learned to select a picture of a martial eagle when it hears a "chuckle" alarm call, and having learned to select the lexigram ⊡ when it hears a "chuckle" alarm call, now without explicit training, chooses a picture of a martial eagle when presented with the lexigram ⊡ , and chooses the same lexigram when shown a picture of a martial eagle. We may conclude that for the vervet monkey, the "chuckle" call, the martial eagle and the lexigram ⊡ form a single equivalent class despite no physical similarity. The monkey's emergent ability to perform new types of matching tasks, BC and CB, will have con-

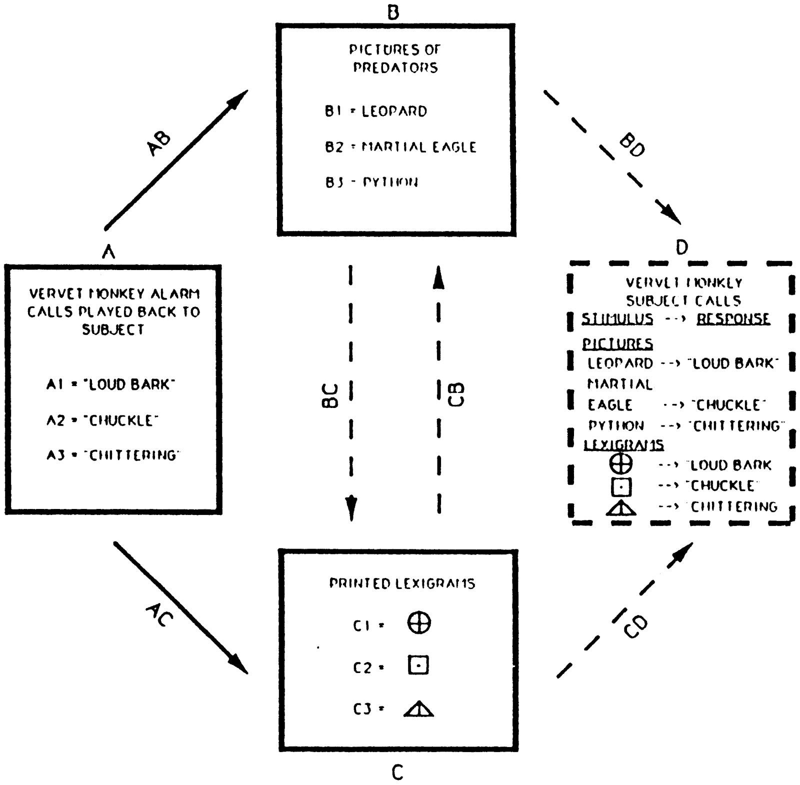

Fig. 1. An equivalence paradigm for teaching a "naive" vervet monkey subject semantic relations. Each of the three enclosed boxes A, B and C represent a set of three stimuli. Arrows AB, AC, BC and CB, each representing a set of conditional relations, point from sample to comparison stimuli. Solid arrows (AB and AC) represent relations that are explicitly taught to the monkey and broken arrows represent conditional relations that are expected to emerge subsequently. For a given sample stimulus, the appropriate comparison is designated by the same number. Broken box D represents calls by the monkey which name or label stimulus sets B and C. Broken arrows from these stimulus sets to vocal responses represent picture naming (BD) and printed lexigram naming (CD).

firmed the development of three novel, three-member classes of equivalent stimuli: $A_1B_1C_1$, $A_2B_2C_2$, and $A_3B_3C_3$, (see Fig. 1). Moreover, one could conclude that by passing the stimulus equivalence test, this monkey shows that the conditional relations between monkey calls and their referents as well as lexigrams and their referents involve semantic relations.

CROSS-MODAL PERCEPTION IN DOLPHINS AND STIMULUS EQUIVALENCIES

Figure 2 illustrates a model for testing stimulus equivalencies in bottlenose dolphins which includes a cross-modal perception task. As in the vervet monkey example, evidence of stimulus class equivalence requires three different types of stimuli. The stimuli in this paradigm consist of (A) acoustic signals, (B) a variety of shapes which can be inspected visually but are opaque to a dolphin's sonar signals, and (C) the same shapes which can be interrogated by a dolphin's sonar under water but are visually opaque. We are relatively safe in assuming that dolphins can do generalized MTS (see Herman and Gordon, 1974; Herman, Gory, Hovancik and Bradshaw, 1989) and thereby meet the reflexivity criterion.

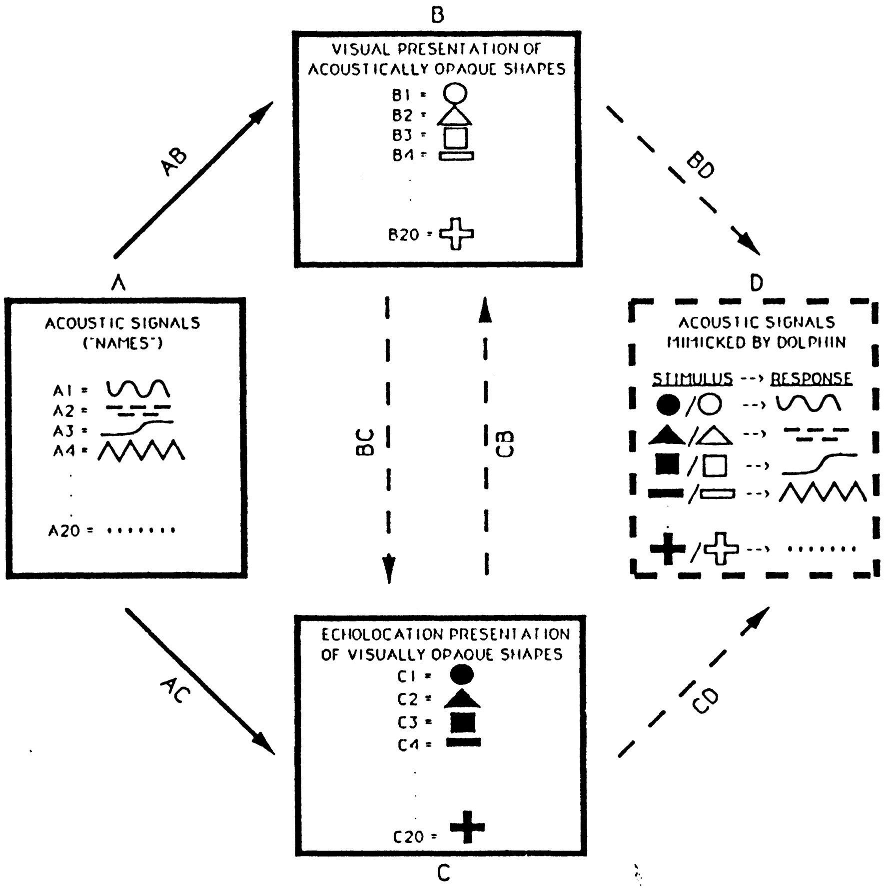

Fig. 2. An equivalence paradigm for teaching a dolphin subject bi-directional cross-modal transfer. Each of the three enclosed boxes A, B and C represent a set of twenty stimuli. Arrows AB, AC, BC and CB, a set of conditional relations, point from sample to comparison stimuli. Solid arrows (AB and AC) represent relations that are explicitly taught to the dolphin and broken arrows represent conditional relations ---- the bi-directional cross-modal perception ---- that are expected to emerge subsequently. For a given sample stimulus, the appropriate comparison is designated by the same number. Broken box D represents mimicked sounds by the dolphin which "name" or "label" stimulus sets B and C. Broken arrows from these stimulus sets to vocal mimicry of acoustic names or labels represent object shape naming in the visual mode (BD) and the echolocation mode (CD).

The dolphin first has to learn to select visually presented shapes (comparison stimuli) conditionally upon any of, for example, twenty acoustic signals (sample stimuli); AB in Fig. 2 represents 20 conditional relations (A_1B_1, A_2B_2 . . . $A_{20}B_{20}$). Next, the dolphin has to learn to select a stimulus shape interrogated by its sonar (comparison stimuli) conditionally upon the same twenty acoustic signals (sample stimuli); AC in Fig. 2 represents 20 new conditional relations (A_1C_1, A_2C_2 . . . $A_{20}C_{20}$). At the conclusion of AB and AC training, the dolphin should select any of 20 shapes inspected visually or by sonar conditionally upon a broadcasted signal.

It will then be feasible to determine whether AB and AC are equivalence relations by giving a combined test for symmetry and transitivity using cross-modal perception. Proof of equivalence and evidence for "modality-free" or "symbolic" representation requires a dolphin to select an appropriate shape inspected by echolocation (comparison stimulus) conditionally upon that same shape being investigated visually (sample stimulus) -- the BC relation, and to select an appropriate shape inspected visually (comparison stimulus) conditional upon that same shape being interrogated by the dolphins' sonar (sample stimulus) -- the CB relation. The above described cross-modal tasks have to be accomplished by the dolphin without explicit training; however, the dolphin will need some training in the mechanics of working in a cross-modal task of echolocation and vision using different stimulus objects. Furthermore, if we want to make inferences about dolphins having symbolic representations, a "control" animal should be given the cross-modal tasks (BC and CB) without having "names" or "tags" related to the shapes (AB and AC). Finally, based on previous research on vocal mimicry of computer-generated sounds and the vocal "labeling" of objects by a dolphin (Richards, 1986), it may be plausible for the dolphin to mimic the acoustic signals and "name" the shapes both visually (BD) and by echolocation (CD). The dolphins' emergent cognitive ability to do two new sets of matching tasks, BC and CB, will have confirmed the creation of 20 three-member classes of equivalent stimuli: $A_1B_1C_1$, $A_2B_2C_2$, . . . $A_{20}B_{20}C_{20}$. Indeed, if the dolphin can mimic the names of the shapes presented to it for visual inspection (BD) or for echolocation (CD), then the original teaching of 40 conditional relations to the dolphin will have resulted in the creation of 40 novel conditional relations and 40 naming relations or a total of 80 novel performances.

SUMMARY AND CONCLUSION

Although the ability of dolphins, apes, monkeys and several other vertebrate taxa to respond to complex classes of stimuli are not in doubt, their ability to "refer" to objects, events and relations and, in general, to manipulate symbols is very controversial. The origin and nature of symbolic activity, which invariably involves the logical properties of reflexivity, symmetry and transitivity may be rooted in the way animals acquire rules to deal with social and nonsocial stimulus objects, events and relationships. Sidman (1986) has shown that in humans conditional discriminations can lead to a semantic correspondence between each sample and its matching comparison stimulus, i.e. a stimulus class equivalency within an MTS paradigm. I have attempted to show that cross-modal perception in dolphins and perhaps even semantic comprehension in vervet monkeys may be trained to reveal symbol manipulation in these mammals.

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