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Comprehension of sentences by bottlenosed dolphins

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Abstract

The ability of two bottlenosed dolphins (Tursiops truncatus) *to understand imperative sentences expressed in artificial languages was studied. One dolphin (Phoenix) was tutored in an acoustic language whose words were computer-generated sounds presented through an underwater speaker. The second dolphin (Akeakamai) was tutored in a visually-based language whose words were gestures of a trainer's arms and hands. The words represented agents, objects, object modifiers, and actions and were recombinable, according to a set of syntactic rules, into hundreds of uniquely meaningful sentences from two to five words in length. The sentences instructed the dolphins to carry out named actions relative to named objects and named modifiers; comprehension was measured by the accuracy of response to the instructions and was tested within a format that controlled for context cues, for other nonlinguistic cues, and for observer bias. Comprehension, at levels far above chance, was shown for all of the sentence forms and sentence meanings that could be generated by the lexicon and the set of syntactic rules, and included the understanding of: (a) lexically novel sentences; (b) structurally novel sentences; (c) semantically re-*

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versible sentences that expressed relationships between objects; (d) sentences in which changes in modifier position changed sentence meaning; and (e) conjoined sentences (Phoenix). Additional abilities demonstrated included a broad and immediate generalization of the lexical items to different exemplars of objects; an ability to modulate the form of response to given action words, in order to apply the action appropriately to new objects, to different object attributes, or to different object locations; an ability to carry out instructions correctly despite changes in the context or location in which a sentence was given, or in the trainer providing the instructions; an ability to distinguish between different relational concepts; an ability to respond correctly to sentences given with no objects present in the tank until 30 seconds after the instruction was given (displacement tests); and an ability to report correctly that the particular object designated in a sentence was in fact not present in the tank, although all other objects were (Akeakamai). These various abilities evidenced that the words of the languages had come to represent symbolically the objects and events referred to in the sentences. The successful processing of either a left-to-right grammar (Phoenix) or of an inverse grammar (Akeakamai) indicated that wholly arbitrary syntactic rules could be understood and that an understanding of the function of words occurring early in a sentence could be carried out by the dolphin on the basis of succeeding words, including in at least one case, nonadjacent words. The comprehension approach used was a radical departure from the emphasis on language production in studies of the linguistic abilities of apes; the result obtained offer the first convincing evidence of the ability of animals to process both semantic and syntactic features of sentences. The ability of the dolphins to utilize both their visual and acoustic modalities in these tasks underscored the amodal dependency of the sentence understanding skill. Some comparisons were given of the dolphins' performances with those of language-trained apes and of young children on related or relevant language tasks.

Introduction

A central issue in the assessment of animal linguistic competency is sentence processing ability. Sentences have both semantic and syntactic components; together, semantics and syntax have been described as the "indispensable core attributes of any human language" (Paivio and Begg, 1981, p. 25). A key human linguistic skill is the tacit use of the grammatical features of a language, consisting of the lexical component and syntactic rules, to produce and comprehend sentences, including ones that are novel to the user (Chomsky, 1957). Chomsky (1972, p. 100) described this "mysterious ability" of human language users: "Having mastered a language, one is able to understand an indefinite number of expressions that are new to one's experience; and one is able, with greater or less facility, to produce such expressions on an appropriate occasion ..."

Sentence processing ability has been explicitly or implicitly claimed for apes tutored in languages (e.g., R. Gardner and Gardner, 1969; B. Gardner and Gardner, 1971, 1975; Patterson, 1978*a*, 1978*b*; Premack, 1971, 1976; Rumbaugh *et al.*, 1973; Rumbaugh, 1977). However, challenges from others (Bronowski and Bellugi, 1970; Fodor *et al.*, 1974; Petitto and Seidenberg, 1979; Ristau and Robbins, 1982; Savage-Rumbaugh *et al.*, 1980; Seidenberg and Petitto, 1979, 1981; Terrace, 1979; Terrace *et al.*, 1979, 1981) have pointed to flaws in experimental design, to insufficiencies and deficiencies in data reporting and analyses, to shortcomings in contextual controls or other controls against nonlinguistic cues, and to overly 'rich' interpretations of results that, in their sum, vitiated the claims for sentence processing abilities of apes. As a result, many have judged the apes by an all-or-none criterion as incapable of processing sentences, and therefore without linguistic competency.

It seems unwise for science to take a strictly adversarial stance on this issue, such that the jury of scientific peers is asked to decide once and for all on sentence processing abilities of apes and, by implication, of other animals as well. There is a good deal of evidence that some animals can process, remember, and utilize variable sequences of nonlexical items in order to organize appropriate responses (e.g., Devine and Jones, 1975; Sands and Wright, 1980; Straub *et al.*, 1979; Thompson and Herman, 1977). At the very least, these findings urge caution before concluding that animals cannot similarly utilize structured sequences of lexical items, i.e., sentences.

To demonstrate sentence processing ability it is imperative to show that in the absence of nonlinguistic cues the animal can use the grammatical features of the language to generate or understand sentences. From their detailed, comprehensive review of language work with apes, and of the criticisms of that work, Ristau and Robbins (1982) concluded that there was "... no convincing evidence that apes' utterances are grammatical" (p. 247). In particular, there was little or no evidence for any knowledge or use of syntactic rules. Typically, multiple signs were strung together without structure and, apparently, often were prompted by similar signs produced earlier by the trainers (Seidenberg and Petitto, 1979; Terrace *et al.*, 1979). Subsets of signs appropriate to a desired reward might be repeated in various orders, until the ape received the reward (Seidenberg and Petitto, 1981; Terrace *et al.*, 1981). Novel combinations of signs, when they occurred, seemed to be largely restricted to naming new objects, and not to producing sentences. The novel combinations were reported anecdotally by the researchers and may have been overinterpreted (Petitto and Seidenberg, 1979; Ristau and Robbins, 1982; Savage-Rumbaugh *et al.*, 1980; Terrace *et al.*, 1979). Highly constraining context cues, and the use of a limited set of "stock" sentences, resulted in responses having the appearance of sentence processing ability (e.g., Premack, 1976; Rumbaugh, 1977). However, closer scrutiny (Savage-Rumbaugh *et al*, 1980; Terrace, 1979; Thompson and Church, 1980) suggested that simpler, nonlinguistic interpretations could be given to the data. Nevertheless, we must agree with Rumbaugh (1981) in his response to criticisms of the ape language work that "... at this point in time ... it is anticipatory and counterproductive for anyone to presume that 'the data are in' for a valid assessment of what is to be offered from this area of research" (p. 30). Also, despite their extensive criticisms of the ape language work, Seidenberg and Petitto (1981) concluded that "It would be unfortunate if the inadequacies of the existing research—and widespread publicity concerning this controversy—were to inhibit further work ..." (p. 127).

What is needed, it seems, are different, more systematic, and better controlled approaches than those used to date for studying sentence processing abilities of animals. The goals of these improved approaches would be to describe the specializations, capabilities, and limitations of animal subjects for processing sentences, to include their capability for using or understanding lexical, syntactic, and semantic information. In this paper we report on the results of an innovative comprehension approach for studying sentence processing abilities of bottlenosed dolphins (*Tursiops truncatus*).

The use of comprehension as a critical measure of sentence processing ability has particular merit for work with animals but has not been fully exploited previously. The bulk of the work with apes has emphasized the production of language, rather than its comprehension (Savage-Rumbaugh *et al.*, 1980). Typically, researchers have assumed that production implied comprehension, but have not provided valid objective tests for this assertion (Savage-Rumbaugh *et al.*, 1980; Seidenberg and Petitto, 1981; Terrace, 1979). In the few cases reporting valid tests (e.g., Savage-Rumbaugh and Rumbaugh, 1978), comprehension did not in fact flow automatically from production. The production of language by apes can be difficult to assess quantitatively or to interpret objectively. The same is true of the production of language by humans, especially children (e.g., Anderson, 1980, p. 401; McNeil, 1970). Gaining experimental control of the user's generation of language is very difficult. Also, production may be easily prompted by nonlinguistic cues, a common and often useful occurrence in human communication, but one which makes the interpretation of animal productions difficult. In contrast, comprehension can be tested under rigid controls, the tests can be devised to relate to specific linguistic issues, and the results of the tests can usually be expressed quantitatively, and evaluated statistically.

Comprehension tests need not be limiting in their application nor in the inferences that may be drawn from their results. In human work, comprehension tests have demonstrated language competency in preverbal or nonverbal children (Curtiss, 1977; Itard, 1932) and have been used to examine the ways in which children and adults learn new languages (e.g., Moeser, 1977; Schlesinger, 1977). Comprehension approaches that emphasize the carrying out of instructions given as imperative statements by the teacher have been found to be useful in the analysis of the grammatical competence of children (Bever, 1970; Chapman and Miller, 1975; Churchill, 1978; Hoban, 1983; McNeill *et al.*, 1971; Shipley *et al.*, 1969; Strohner and Nelson, 1974) and to be highly effective for teaching second languages to adults (see readings in Winitz, 1981). The use of the imperative statement as a tool for language instruction parallels in many ways the approach taken in the present study.

In this study, we examined the ability of two bottlenosed dolphins to understand sentences constructed within artificial languages. We report on the findings during the first four years of study. The understanding of familiar and of novel sentences was studied, as was the understanding of novel syntactic forms and of semantically reversible sentences. All of the sentences were in the imperative mood and instructed the dolphins to carry out named actions relative to named objects and named modifiers. Comprehension was defined as the ability of the dolphins to utilize the semantic and syntactic information in the sentences in order to carry out the instructions, and was measured by the accuracy or appropriateness of their responses to those instructions.

Earlier attempts to study language learning abilities of dolphins or to detect extant language were summarized in detail by Herman (1980). These included the unsuccessful efforts by Lilly (1961, 1967) to demonstrate the existence of a natural language in dolphins or to teach dolphins English; the work of Batteau (Batteau and Markey, 1968) with an artificial language; and the preliminary language comprehension work of Herman (summarized in Herman (1980)) that provided the model for the extended approach reported in this paper.

Lilly's work was poorly documented, of questionable validity, and is not useful scientifically (for particularly strong criticisms of this work see, e.g., Wilson, 1975; Wood, 1973). Batteau and Markey (1968) tested the ability of two bottlenosed dolphins to respond to simple commands given via artificially generated whistle "words". Because of the death of Batteau, the project remains incomplete and its results, often weak on behavioral detail, appear only in the cited unpublished government report. Batteau and Markey appeared to have had a comprehension approach in mind, but their concept of language was seriously flawed. Individual whistles did not refer to individual semantic entities, i.e., to unique words, but instead merely set the occasion for a chain of responses. For example, a single, particular whistle sound instructed the dolphin to "hit the ball with your pectoral fin". There were no separate words for "hit" or "ball" or "pectoral fin". Another single whistle sound instructed the dolphin to "swim through the hoop". Since there were no unique words for independent semantic entities there was no way to recombine elements to create new instructions, for example, "hit the hoop (rather than the ball) with your pectoral fin". Batteau and Markey's system thus lacked the linguistic features of openness (Hockett, 1960) and reconstitution (Bronowski and Bellugi, 1970) that allow for the addition of words to the vocabulary and for the recombining of words, according to the syntactic structure of the language, into new sentences with new meaning. Their approach, in effect, was not different from the procedures used to train dolphins to perform rote chains of behaviors in oceanarium shows.

The language comprehension work reported by Herman (1980) was begun in January 1977 using the dolphin Keakiko (Kea). Sounds generated by a computer-controlled system were projected underwater into Kea's tank. Kea was taught that there were specific sounds ('names') for each of three objects (a ball, a life ring, and a styrofoam cylinder) and for each of three actions (to fetch, to touch, and to mouth). Each action was clearly defined and different from the others, as were the objects. The first stage of training emphasized object names, the second action names, and the third 2-word sentences. Kea was able to respond immediately and correctly to new objects that were instances of a class of old object, e.g., to new balls of different sizes or textures. She also generalized her action responses immediately to new (unnamed) objects introduced into the tank.

The syntactic rule adopted for 2-word sentences was Object + Action, e.g., BALL FETCH, meaning "go to the ball and bring it back to the trainer".[1] The Object + Action rule was found to be easier to train than was an Action + Object rule, since in the first instance an intention response (orienting response) to the object named could serve as a bridge on which delivery of the following action signal was contingent. This bridging method was successfully used during the initial stages of training. During later training an automatic half-second interval was used between the two words without waiting for any intermediate response. Under these conditions Kea quickly came to respond nearly flawlessly to each of the nine possible 2-word sen-

[1]Throughout this paper the words or sentences given to the dolphins are shown in all capital letters. The English glosses for the instructions are provided only as an aid to the reader. They are not intended to suggest that the dolphin understood the sentence in the sense of the gloss.

tences generated by the six vocabulary items (e.g., CYLINDER MOUTH, RING TOUCH, etc.). The study ended abruptly in May of 1977 with the abduction of Kea from the laboratory.[2]

For our current work, begun in 1979 with two new dolphins, both an artifical acoustic language and an artificial gestural language were developed. One dolphin was specialized in the acoustic language and the other in the gestural language. If both the acoustic and the visual mediums could be used successfully it would greatly strengthen the case for a general capability of dolphins for understanding instructions specified by a sentence. At the same time, the use of two mediums guarded against artifacts governing responses that might be peculiar to one language medium but not the other. Also, the degree to which competency in sentence comprehension could be demonstrated within each medium would provide more information about the cognitive specializations, capabilities, and constraints of the bottlenosed dolphin than would the use of only a single medium.

'Language', as used here, refers to the lexical component and the set of syntactic rules that governed the construction and interpretation of sentences in the acoustic and gestural formats. There were many similarities in the vocabulary and syntactic rules across the two languages, but there were also some major differences.

Within each language, a sentence was defined as a sequence of words that expressed a unique semantic proposition (cf. Terrace *et al.*, 1979). The sentences ranged in length from two to five words. In English, and in many other languages, altering word order may drastically change the meaning of a sentence. Similarly, in both of the dolphin artificial languages, the meaning of some sentences depended upon word order as well as on the particular words used.

A word was defined as a unique, independent semantic entity; entities were agents, objects, actions, or modifiers of place or direction. The words of the acoustic language were short, discrete, whistle-like sounds produced by computer-controlled waveform generators, while the words of the gestural language were unique movements of a trainer's arms and hands. The words chosen for inclusion in the dolphins' vocabularies were those that could be readily combined with other words into meaningful sentences, allowing for the creation of hundreds of different sentences through a relatively small

[2]Kea was abducted from the University of Hawaii laboratory together with the dolphin Puka, who had been specialized in visual tasks and was one of the two dolphins used in the Batteau and Markey (1968) study. The pair was transported in a small van to a remote location about 50 miles from their home tank and abandoned in the open ocean. The sudden demands of open-ocean living combined with the stress of removal from familiar surroundings posed a cruel survival test for these long-time domesticated dolphins that surely could not be met.

vocabulary. Some sentences were used for training purposes; others were reserved for testing for the immediate understanding of novel sentences or of novel syntactic forms. A lexically novel sentence is one whose syntactic structure is patterned after familiar sentence forms but where at least one lexical item occurs for the first time in that form. A syntactically (structurally) novel sentence is one where a new sentence form is represented for the first time.

Some of the syntactic categories expressed a relationship between two named objects, with one object designated for transport and the other as the destination. If both objects could be transported, semantically reversible sentences could be created, e.g., 'take A to B' *versus* 'take B to A'. Thus, reversing the order of A and B results in a reversal of meaning. To carry out the instructions of a semantically reversible sentence correctly, a dolphin must utilize both semantic and syntactic information. The acoustic language employed a straightforward 'left-to-right' grammar for the transport relationship ('A take to B'), while the gestural language used an inverse grammar ('to B, A take'). These different syntactic rules allowed us to explore more fully whether there might be constraints in the ability of the dolphins to utilize word-order information. Additionally, the placement of modifier words in the sentence determined which object word was modified. This enabled the further exploration of a dolphin's ability to use word-order information. Also, in the most recent work on relational terms reported here, the transport relationship was contrasted with a new relational term which required one object to be placed in or on another. Here, we were able to study whether the syntactic similarities and semantic differences between the two relational words could be understood.

A major goal of this project, in addition to examining for sentence processing abilities in a nonhuman animal, was to open new avenues into the study of the cognitive characteristics of the bottlenosed dolphin (Herman, 1980). The semantic and syntactic complexity that can be created through sentences, and the requirement that information in the serially-unfolding sentence be integrated over time, can place great demands on information-processing resources. By calling for the fuller use of processing resources we may be able to arrive at a better understanding of the limits and characteristics of dolphin cognition and, possibly, their relationship to the limits and characteristics of cognition in other animals, including the human (e.g., Griffin, 1981, 1982). A philosophy underlying our project was that complex information processing is in part a skill that can be honed through education. The realization of human potential is largely dependent on long-term special education. Knowledge structures are greatly enriched through education and expand the ability to recognize and solve problems. Strategies for allocating processing resources and techniques for integrating, reducing, or manipulating information are in part acquired skills. The implication is that the extent and limitations of animal cognition may be best revealed through long-term studies that build on the growing knowledge structures, cognitive skills, and sophistication of the animal.

Method

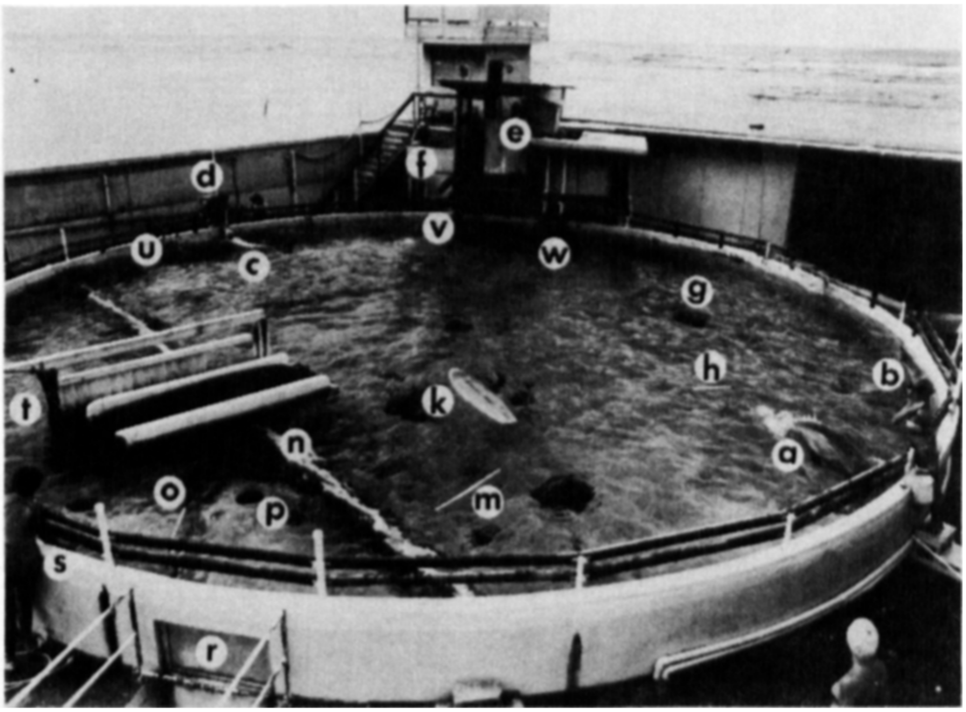
The dolphins and pre-language training

Figure 1 shows the two female bottlenosed dolphins that were studied, Phoenix and Akeakamai.[3] The pair is in their home tank, a concrete sea-water enclosure of diameter 15.2 m and having a depth of 1.7 m. The two were collected from the wild on the same date in June of 1978 in the shallow coastal waters near Gulfport, Mississippi and were brought to the University of Hawaii Kewalo Basin Marine Mammal Laboratory one month later. The capture locations were within approximately 2 km of each other so that it is likely that the two were part of the same seasonally resident school. At the time of collection each was approximately 2.0 m in length and 94 kg in weight, which categorized them as juveniles of approximately two to three years of age. Two years later the pair had grown in synchrony to approximately 2.2 m in length and 128 kg in weight. After an additional two years the lengths had increased slightly to 2.3 m and the weights to approximately 144 kg. Caldwell and Caldwell (1977) give 2.4 m as a minimum length for a reproductive female. Estimates of age at sexual maturity of female bottlenosed dolphins range from 6 to 12 years. Physical growth of bottlenosed dolphins may continue to age 15 or later and longevity of captive animals can be 30 years or more.

During their first 30 days after capture, spent at Gulfport, Phoenix and Akeakamai were acclimated to tank living and to eating freshly thawed fish from the hand of a trainer. During their next seven months at Hawaii preparations were made for language comprehension training. Attention was given to socializing the pair toward humans, and to initial familiarization training with sounds and gestures. To promote an affiliative response towards humans, the authors and others of the staff swam daily with the pair, hand fed them, stroked them, and engaged them in games such as 'tag' (attempting to touch the dolphins with a short length of plastic pipe while they dodged

[3]The name Phoenix symbolized the rebirth of the laboratory after the tragic loss of Kea and Puka. Akeakamai ('Ake') is a Hawaiian word meaning 'lover of wisdom,' and symbolized the hopes for the future.

Figure 1. *The living and testing tank of the dolphins. Akeakamai (a) is at the right, responding in a formal trial to the gestural instruction OVER given by her trainer (b); Phoenix (c) is at the left engaged in 'local' trials by her trainer (d). The keyboard operator (e) and the recorder (f) are in the tower overlooking the tank. A blind observer, if used (see results of novel sentence testing), as well as a videotape operator, position themselves on the roof to the right of the keyboard operator. Named objects (see Table 1) visible include (g) LEFT BASKET, (h) LEFT HOOP, (k) SURFBOARD, (m) PIPE, (n) RIGHT BASKET, (o) RIGHT HOOP, (p) FRISBEE, (r) WINDOW (one of four in tank), (s) PERSON, (t) GATE, (u) SPEAKER, (v) WATER, and (w) PANEL.*



furiously, always returning for more) or 'retrieve' (throwing objects in the tank for the dolphins to return). Also, much time was spent at tankside or at the underwater windows soliciting the dolphins to approach and to attend to objects displayed. The tankside activities were intended in part to orient the pair toward human activities and the visual world outside of their tank, and to give them experience in manipulating objects within the tank.

Simple two-choice sound-discrimination training, using a variety of pairs of sounds, was instituted during this first seven-month period. This training acquainted the dolphins with some of the types of sounds that might appear in the subsequent language study, and with some pertinent discrimination and reinforcement procedures. Individual freshly thawed silver smelt (approximately 45 g in weight) were used as reward for correct responses to a limit of approximately 8.5 kg daily, a full ration for most bottlenosed dolphins. Our goal in these initial tasks was to develop a learning set or, more generally, a positive attitude toward learning that would not only encourage the dolphins to attempt to solve the problems at hand but would also give them a more generalized concept that problems could be solved. None of the research reported here provided direct tests for the success in meeting any of these general goals, but the overall success of the dolphins in the comprehension tasks and their ability to sustain their efforts daily and over years testifies, we believe, to the probable utility of these early procedures.

Some gestural training was also begun during this first seven-month period. A number of actions, e.g., touching objects, bringing them back to the trainer, and jumping over objects, were put under the control of gestures of the trainer's arms and hands. This gestural training was intended to acquaint the dolphins with the kinds of responses that might later be required as part of an acoustic instruction. At that early time, we did not intend to develop a gestural language format, but the ease of accomplishing control of actions with these gestures and the ready generalization of responses that we observed prompted us to specialize one dolphin (Akeakamai) in a gestural language while the second (Phoenix) was transferred to the preplanned acoustic format.

The languages

The strong auditory orientation of delphinid information processing (Herman, 1980; Herman and Tavolga, 1980) dictated our choice that one language format be acoustic. As was stated, because of the good success in obtaining gestural control of behaviors during the first seven-month period a visual (gestural) format was also used.

Physical characteristics of the acoustic language

The sounds used were mainly whistle-like in character. Whistles are one of the natural sounds produced by bottlenosed dolphins (Herman and Tavolga, 1980). Whistle sounds are relatively easy to generate electronically, making them a pragmatic choice for this study, and have previously been used successfully for controlling responses of dolphins (Batteau and Markey, 1968). In general, we avoided using whistle sounds that resembled the natural whistles of the dolphins, because these sounds might have had prior significance. An exception were the sounds assigned as dolphin names. Each dolphin had an individually characteristic 'signature' whistle that it used frequently (Richards *et al.*, 1984) and which, presumably, identified that dolphin to other dolphins (Caldwell and Caldwell, 1965). Hence, it seemed reasonable to use approximations to these signature whistles, as generated by a computer system, for the dolphins' names.

All sounds were produced by two Wavetek 154 waveform generators digitally controlled by a minicomputer. The computer, housed in a building remote from tankside, controlled the frequency and waveform type of the first (primary) generator. Where applicable, it also controlled the modulation rate and modulation range induced on the base frequency of the primary generator by the second (modulator) generator. The base frequencies ranged from 1 to 40 kHz, well within the hearing limits of the bottlenosed dolphin (Johnson, 1967). Modulation rates ranged from unmodulated to 50 Hz.

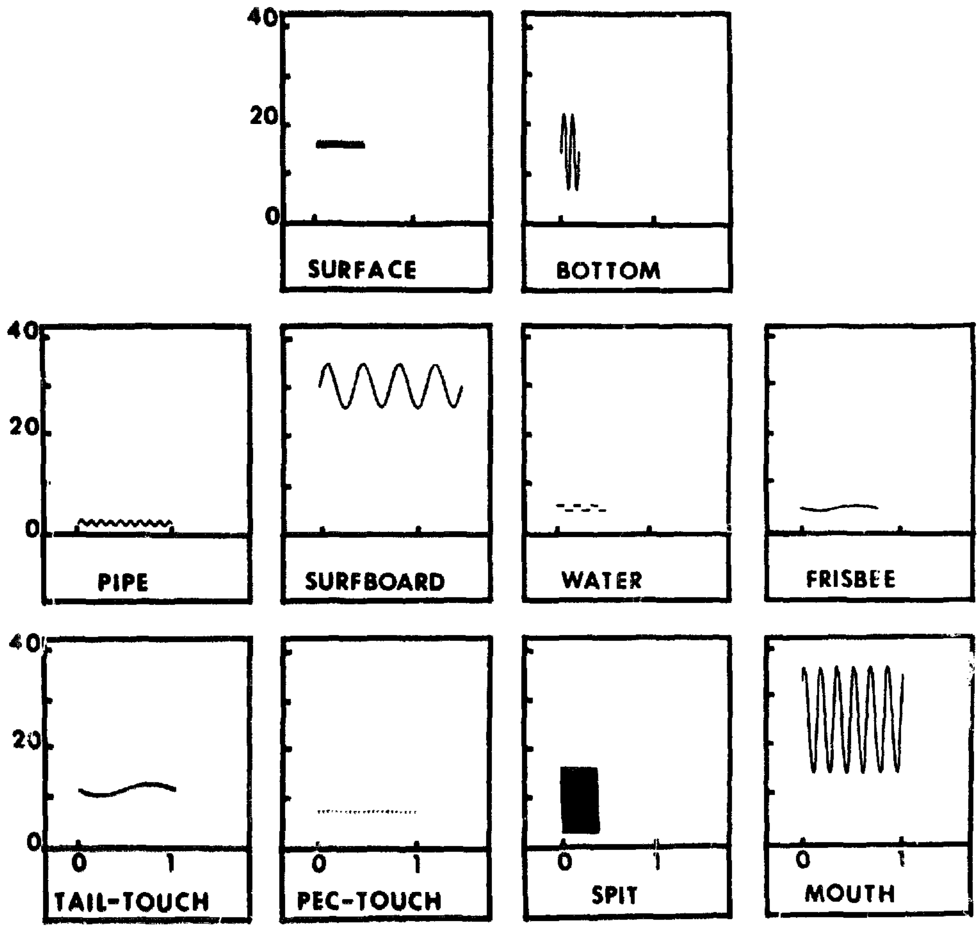
The waveform types produced were either the unmodulated sine or triangle wave output of the primary generator, or these same waves symmetrically modulated in frequency by a sine, square, or triangle wave from the modulator generator. Additionally, a few sounds were pulse modulated by switching them on and off under computer control. The final output waveform from the primary generator was routed through a Hewlett-Packard 467A power amplifier, and broadcast through a J9 underwater speaker obtained from the U.S. Naval Research Laboratory, Underwater Sound Reference Detachment. Figure 2 illustrates the frequency *versus* time spectrum of a few of the sounds used as names for modifiers, objects, and actions in the acoustic language.

The nominal limiting equipment factor on frequency range was the J9 speaker, which is flat in frequency response to 20 kHz, and has both variable frequency response and increasing directionality above that frequency. However, Curtis (1979) has shown that the useful frequency response of the J9 extends to well over 40 kHz in our tank. Most sounds were at least partially within the range of human hearing for ease in monitoring.

The computer maintained the library of sounds of the acoustic language and set the Wavetek parameters appropriately for producing any sound selected. An ASCII keyboard located at tankside enabled the computer to be addressed remotely. Words were assigned to specific keys. To construct an acoustic sentence the successive words were keyed in, as was the desired spacing between words (usually 0.25 second or occasionally 0.5 second). The constructed sentence was stored by the computer and projected underwater, when desired, by a press of the space bar by the keyboard operator.

The sounds of the language were developed so as to differ in at least two acoustic dimensions from other words in the same semantic category. In a few cases, a sound as initially constructed appeared to be hard for Phoenix

Figure 2. *The modulation waveform characteristics (frequency* versus *time plots) of selected sounds of the acoustic language. Frequency (0–40 kHz) is on the vertical axis and time (in seconds) on the horizontal axis. The sounds illustrated in the top row are the acoustic signals for the modifiers SURFACE and BOTTOM; the second row shows the sounds for the objects PIPE, SURFBOARD, WATER and FRISBEE; the final row illustrates sounds for the actions TAIL-TOUCH, PEC-TOUCH, SPIT and MOUTH.*



to discriminate from an already existing sound. Lengthening the new sound beyond the duration of other sounds was usually sufficient to overcome the initial discrimination difficulty. After performance stabilized, the new sound was shortened to the typical 0.5 to 1.5 second range of other sounds. If performance was not maintained, the new sound was changed in some acoustic parameter.

The hearing of the bottlenosed dolphin shows large decreases in sensitivity for frequencies below approximately 10 kHz (Johnson, 1967). Consequently, we applied higher voltage levels to the J9 speaker for these lower frequencies, but no attempt was made to equate sensation levels across the different sounds. Owing to the varied locations at which the speaker was placed, its changing directional characteristics with frequency, and the varied positions of the dolphin relative to the speaker when sounds were played, the perceived loudness of any given sound was undoubtedly quite variable. Hence, sound intensity was not useful for discriminating among sounds.

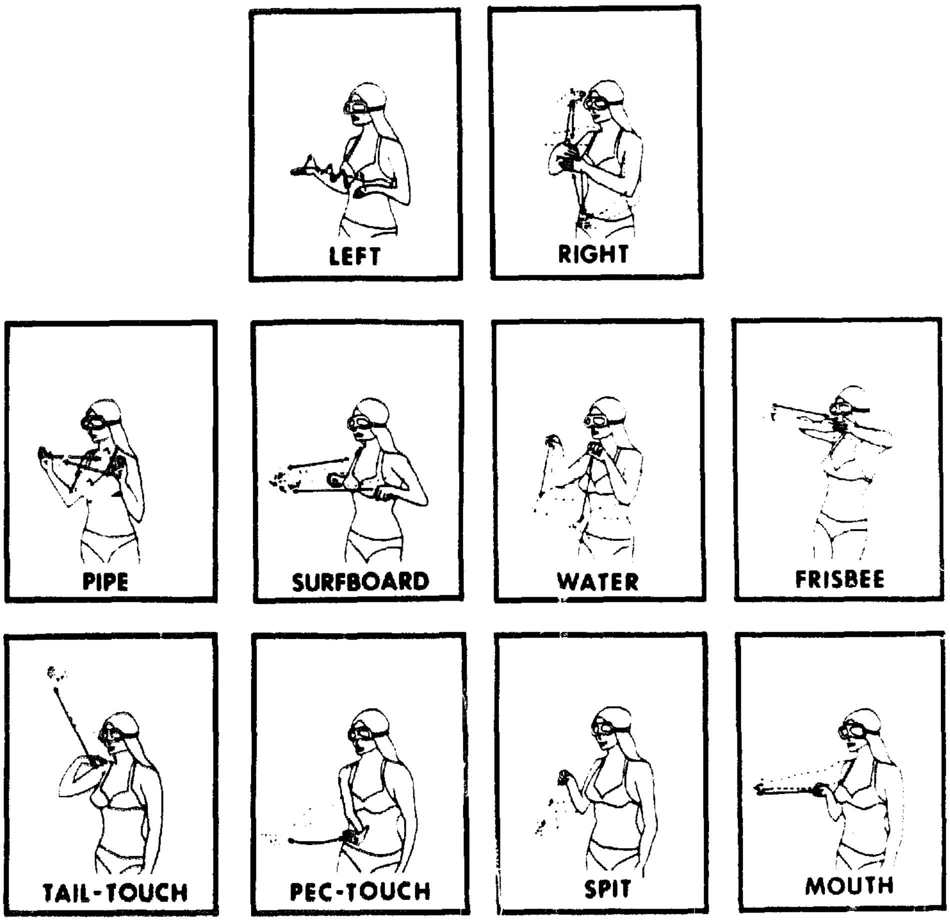
Physical characteristics of the gestural language

The gestural signs were moderate- to large-scale movements of the arms and hands of a trainer standing immediately adjacent to the tank wall. The wall rises approximately 1 m above the floor level surrounding the tank and hence only the upper half of the trainer's body is visible to the dolphin in the tank (Fig. 1).

Signs were chosen to be easily discriminable by human observers and to be substantially different from other signs, as judged by the consensus of authors of this paper. As with the acoustic signals, gestures were modified in the event of apparent confusions by the dolphin. Some gestures, e.g., those for PERSON and SPEAKER, were modified versions of signs taken from American Sign Language. However, most of the gestures are not related to American Sign Language. By convention, all signs denoting actions are made with one arm, while signs denoting objects or object modifiers are made with symmetrical or alternating movements of both arms. Figure 3 illustrates the signs for a few of the words of the gestural language–including modifiers, objects and actions.

Signs are made rapidly although with considerable variation in rate across trainers. Experienced signers average close to 1 second per complete gesture, and approximately 0.25 second in transition between successive gestures. Novice trainers usually take longer to complete each gesture, and include a full pause, returning their hands briefly to a neutral position in front of their bodies, between successive gestures. Many different signers have been used during the course of our project. A study at our laboratory by M. Shyan appears to show that the idiosyncratic signing differences among trainers has led Akeakamai to focus on certain key distinguishing elements across signs, particularly arm movement and hand position. At the present time it is possible to instruct a novice trainer in an arbitrary subset of the signs in a few minutes and these will almost always be immediately understood by Akeakamai.

Figure 3. *Examples of some of the signals used in the gestural language, as obtained from tracings of videotape records of gestures. The trainer is wearing opaque goggles to guard against social cueing by eye movements. The top row illustrates the gestural signals for the modifiers LEFT and RIGHT; the second row gives the gestural signals for the objects PIPE, SURFBOARD, WATER, and FRISBEE; the bottom row illustrates the gestures for the actions TAIL-TOUCH, PEC-TOUCH, SPIT, and MOUTH (see lexicon in Table 1).*



Creation of the lexicon

Table 1 gives the current vocabulary of the dolphins. The letter P for Phoenix or A for Akeakamai signifies that that word is in the vocabulary of only the one dolphin; otherwise, both dolphins understand the word. Since alle sentences, thus far, are in the imperative mood, the dolphins are always the agents; each sentence begins with a dolphin's acoustic name. Note in Table 1 that dolphin names appear not only as agents but also as objects.

Table 1. *Comprehension vocabulary of Phoenix (P) and Akeakamai (A); if only one dolphin understands a listed word it is followed by the initial of that dolphin*

OBJECTS

Tank fixtures	*Relocatable objects*[a]	*Transferable objects*[b]
GATE (divides portion of tank; can be opened or shut) (P)	SPEAKER (underwater)	BALL
WINDOW (any of four underwater windows)[c]	WATER (jetted from hose)	HOOP
PANEL (metal panel attached underwater to side of tank) (P)	PHOENIX (dolphin as object) (A)	PIPE (length of rigid plastic pipe)
	AKEAKAMAI (dolphin as object) (P)	FISH (used as object or reward)
	NET[c,d]	PERSON (any body part or whole person in or out of water)
		FRISBEE
		SURFBOARD
		BASKET

ACTIONS

Take direct object only	*Take direct and indirect object*
TAIL-TOUCH (touch with flukes)	FETCH (take one named object to another named object)
PECTORAL-TOUCH (touch with pectoral fin)	IN[c,d] (place one named object in or on another named object)
MOUTH (grasp with mouth)	
(GO) OVER	
(GO) UNDER	
(GO) THRU	
TOSS (throw object using rostrum movement)	
SPIT (squirt water from mouth at object)	

AGENTS

PHOENIX or AKEAKAMAI (prefix for each sentence; calls dolphin named to her station; indicates to dolphins which is to receive fish reward)

MODIFIERS

RIGHT or LEFT (used before object name to refer to object at that position) (A)
SURFACE or BOTTOM (used before object name to refer to object at that location) (P)

OTHER

ERASE (used in place of action word to cancel the preceding words—requires the dolphin to remain at station or to return immediately)
YES (used after correctly executed instruction)
NO (sometimes used after incorrectly executed instruction—can cause emotional behavior)

[a]Objects whose locations may be changed by trainers.
[b]Objects that may be moved by dolphins—all names represent classes of objects with multiple exemplars.
[c]Added to Akeakamai's vocabulary after completion of the majority of testing reported in data tables.
[d]Added to Phoenix's vocabulary after completion of the majority of testing reported in data tables.

Thus, the acoustic sentence PHOENIX AKEAKAMAI OVER instructs Phoenix to swim to Akeakamai and leap over her. Similarly, note that FISH is both the name of a reward and the name of an object to which an action (other than eating it) may be performed.

Object words are divided into those represented by single exemplars, such as GATE, the single wooden gate in the tank (Fig. 1, t), and classes of objects, such as BALL, which refers to any of a number of balls of various sizes and materials. Words referring to object classes allow the use of modifiers to specify a particular exemplar when several members of the class are present. For example, when pipes are present at both the bottom and the surface of the tank, the modifier SURFACE or BOTTOM may be given to indicate the specific pipe to which a response is to be made. Similarly, if there are paired frisbees, one at each side of the dolphin, the modifier RIGHT or LEFT indicates the particular frisbee to be acted on. Note that RIGHT and LEFT are in only Akeakamai's vocabulary and that SURFACE and BOTTOM are restricted to Phoenix's vocabulary. The assignment of different modifiers to the two dolphins allowed us to explore the ability of dolphins to understand different types of modifiers without duplicating training time in teaching both types of modifiers to each dolphin.

Both class and single exemplar objects are further divided into three categories: transportable by dolphins, relocatable by trainers, or fixed in place (tank fixtures). Transportable objects can be taken ('fetched') to other transportable objects, to relocatable objects, or to fixed objects. The first case, involving two transportable objects, allows for the generation of semantically reversible sentences.

Referents for several of the object words in Table 1 can be seen in Fig. 1. These include the tank fixtures (GATE, WINDOW, PANEL); objects relocatable by trainers (SPEAKER, WATER, PERSON); and several objects transportable by the dolphins (SURFBOARD, PIPE, FRISBEE, and RIGHT and LEFT BASKETS and HOOPS).

Actions are divided into two categories, those which take only a direct object and those which take both direct and indirect objects. The latter category allows the expression of a relationship between objects. For most of the results given in this paper, FETCH was the only action in the second category. However, training of the action IN, to place a transportable object inside of or on top of another object was instituted recently. A brief summary of findings comparing responses to FETCH and IN is provided in the results section.

YES and NO are acoustic words used with both dolphins. YES appears in the strings YES PHOENIX FISH or YES AKEAKAMAI FISH. A string follows a correct response to an instruction and indicates to the dolphins which dolphin is being referred to and that a fish reward will be given to that dolphin. The named dolphin responds to the sentence by returning to the trainer for a fish reward; the one not named continues in whatever behavior it was engaged in at the time of the string. NO is an acoustic word used to interrupt an ongoing behavior of either dolphin. It is used rarely, however, since it tends to produce emotional behavior, such as flinging an object or jaw snapping.

Finally, ERASE takes the place of any action word and is used to cancel a sentence. For example, the sequence BALL ERASE or RIGHT BALL ERASE cancels the sentence that has been begun. The proper response is for the dolphin to remain at her instruction station or to return to it promptly if in the act of leaving.

The syntax

Table 2 gives the syntactic rules for construction of 2-, 3-, 4-, and 5-word sentences in each language. Five-word sentences have so far been given extensively only to Phoenix. The basic rules are that object words always precede action words, and modifiers always precede the object word modified. Thus, the instruction WINDOW TAIL-TOUCH is glossed as "Go to any of the underwater windows in the tank and touch it with your tail flukes". HOOP UNDER means "Go to the hoop and swim under it". SURFACE PIPE SPIT instructs Phoenix to "Go to the pipe floating at the surface (and not the one lying at the bottom) and spit at it." LEFT BALL MOUTH is an instruction to Akeakamai to "Go to the ball to your left (and not the one to your right) and place your mouth about it." LEFT and RIGHT are always referenced to Akeakamai's location at the time that the instruction is given. Figure 4 illustrates typical responses of the dolphins to a few of the many 2-word Object + Action sentences in their languages. It can be seen that the responses to action words are distinct from one another and easily classifiable by an observer.

The syntactic rules for 2-word sentences and for 3-word modifier sentences are the same for the two languages. All of the other types of sentences utilize the relational words FETCH or IN, and are radically different for the two dolphins. For Phoenix, the 3-word sentence SURFBOARD FETCH SPEAKER is glossed as "Go to the surfboard (direct object) and take it to the speaker (indirect object)."[4] When dealing with transportable indirect ob-

[4]We recognize that the terms 'indirect object' and 'direct object' are grammatical terms describing the function of nouns in the sentence and not, normally, the referents of those nouns. However, since it is cumbersome to specify in every case in this paper the 'physical object referred to by the direct object' or the 'physical object referred to by the indirect object' in the sentences, we use the terms to refer both to the words in the sentences and to their referents. This usage is qualified only when the meaning is not made clear by

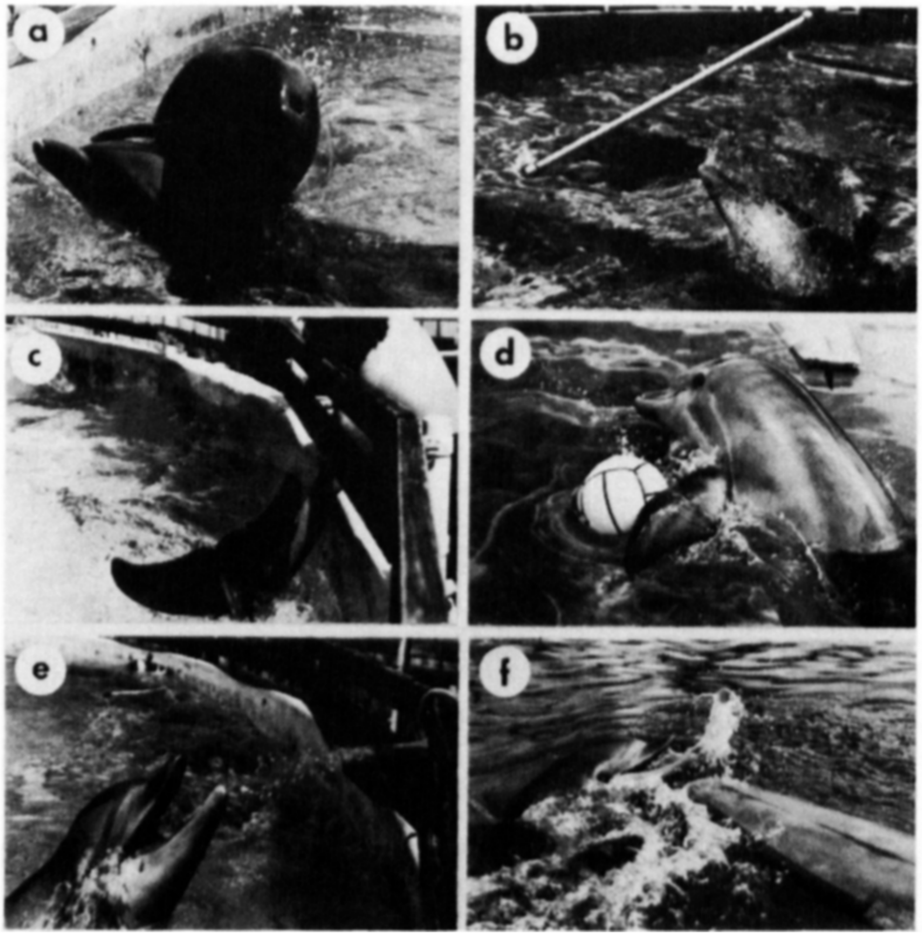
Table 2. *Syntactic rules for acoustical language for Phoenix (P) and gestural language for Akeakamai (A)*

Rule	Examples
2-word	
Object + Action (P, A)	WINDOW TAIL-TOUCH; BASKET TOSS PHOENIX OVER (An instruction to Akeakamai) AKEAKAMAI UNDER (An instruction to Phoenix)
3-word	
Modifier + Object + Action (P, A)	LEFT PERSON MOUTH; RIGHT FISH PEC-TOUCH SURFACE PIPE SPIT; BOTTOM HOOP THRU;
DO + Action + IO (P)	SURFBOARD FETCH SPEAKER [a] HOOP FETCH PIPE [a] PIPE FETCH HOOP
IO + DO + Action (A)	SPEAKER SURFBOARD FETCH [a] PIPE HOOP FETCH [a] HOOP PIPE FETCH
4-word	
Modifier + DO + Action + IO (P)	BOTTOM HOOP FETCH PANEL [a] SURFACE FRISBEE FETCH BASKET
DO + Action + Modifier + IO (P)	[a] PIPE FETCH BOTTOM BASKET [a] BASKET FETCH SURFACE PIPE
IO + Modifier + DO + Action (A)	SPEAKER LEFT HOOP FETCH [a] BALL RIGHT FRISBEE FETCH
Modifier + IO + DO + Action (A)	[a] RIGHT BASKET PIPE FETCH LEFT WATER SURFBOARD FETCH
5-word	
Modifier+ DO + Action + + Modifier + IO (P)	[a] SURFACE PIPE FETCH BOTTOM HOOP [a] BOTTOM HOOP FETCH SURFACE PIPE [a] BOTTOM BASKET FETCH BOTTOM HOOP

Note. DO = Direct Object; IO = Indirect Object.
[a]Reversal of order of direct and indirect objects reverses meaning.

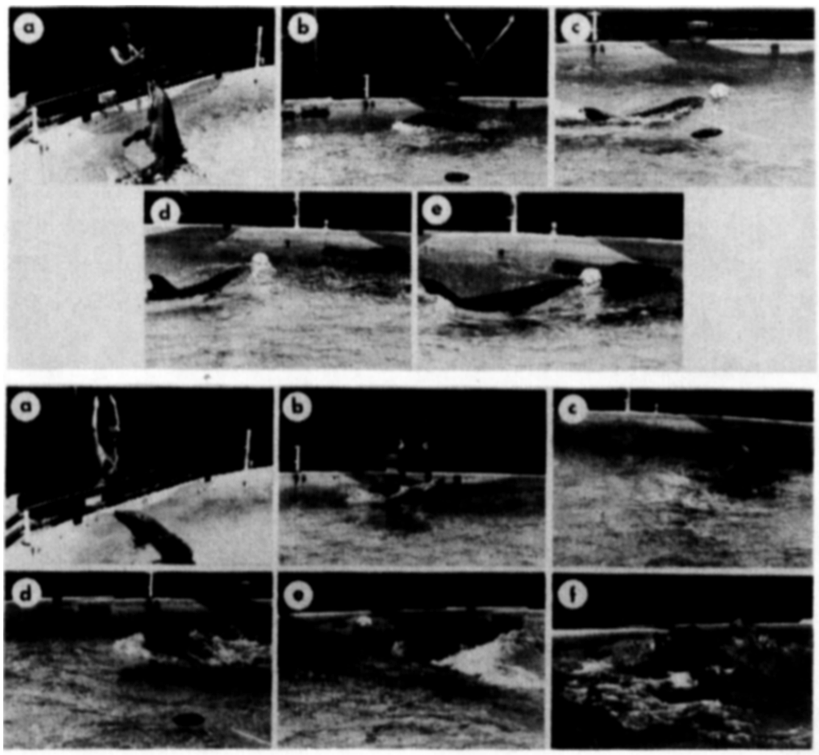
the context. Our glosses for sentences including both indirect and direct objects use, for clarity, a directional prepositional phrase to specify the indirect object. Thus, SURFBOARD FETCH SPEAKER is glossed for the reader as "go to the surfboard and take it to the speaker." However, in parallel to the English sentence "Fetch Lou a pencil," a more precise gloss, properly showing the indirect object function of SPEAKER in the sentence, would be "Fetch the speaker the surfboard."

Figure 4. *Typical responses to selected 2-word sentences: (a) Phoenix responding to AKEAKAMAI OVER; (b) Phoenix responding to PIPE TOSS; (c) Phoenix responding to PERSON TAIL-TOUCH (PERSON is individual leaning against fence with arm in water); (d) Akeakamai responding to BALL PEC-TOUCH; (e) Akeakamai responding to WATER MOUTH; (f) AKEAKAMAI responding to SURFBOARD SPIT. The forms of the responses illustrated are highly reliable and distinct from one another, permitting observers to label action responses easily.*



jects, FETCH sentences are semantically reversible. Thus, HOOP FETCH PIPE is glossed as "Go to the hoop and take it to the pipe," while PIPE FETCH HOOP means "Go to the pipe and take it to the hoop." In Akeakamai's gestural language, the indirect object is specified first, then the direct object, and finally the action. Thus, SPEAKER SURFBOARD FETCH is interpreted as "To the speaker (indirect object), surfboard (direct

Figure 5. *Example of Akeakamai responding to semantically reversible 3-word sentences.* Top: *The sentence is BASKET BALL FETCH ("go to the ball and take it to the basket") (a) gesture for BASKET given—Akeakamai watches trainer; (b) gesture for BALL given—Akeakamai is moving to her left toward the ball and not waiting for the terminal FETCH gesture (given but not shown)—FRISBEE and PIPE are visible in picture and are being bypassed; (c) having retrieved the ball, Akeakamai pushes it back to the right toward the basket—the basket was to her right at the start of the instruction; (d)–(e) Akeakamai approaches the basket and touches the ball to it to complete the instruction correctly.* Bottom: *The sentence is BALL BASKET FETCH ("go to the basket and take it to the ball"), the semantic reversal of the prior sentence. The ball and basket are in the same positions relative to Akeakamai as in the prior sequence. (a) gesture for BALL given—Akeakamai leaning to left toward ball; (b) gesture for BASKET given—Akeakamai starts to right toward basket, again not waiting for terminal FETCH gesture; (c) basket is retrieved and Akeakamai starts back toward her left; (d) carrying basket on head while swimming toward ball—FRISBEE and PIPE, visible in photograph, are being bypassed; (e)–(f) continuing towards ball and arriving at ball with basket to complete instruction correctly. The duration of the top sequence was approximately 9 seconds and of the bottom 11 seconds. Timing was from initiation of the first gesture to the completion of the response by Akeakamai.*



object) take," or in better English, "Take the surfboard to the speaker." SPEAKER SURFBOARD FETCH in the gestural language is thus the semantic equivalent of SURFBOARD FETCH SPEAKER in the acoustic language. Similarly, PIPE HOOP FETCH and HOOP PIPE FETCH in the gestural language are the semantic equivalents, respectively, of HOOP FETCH PIPE and PIPE FETCH HOOP in the acoustic language. Figure 5 illustrates Akeakamai responding to the semantically reversible sentences BASKET BALL FETCH ("To the basket, ball take") *versus* BALL BASKET FETCH ("To the ball, basket take").

The rules for the use of IN within each language correspond to the rules for FETCH. For Phoenix's acoustic language, the sentence HOOP IN BASKET requires that a hoop be placed inside of a basket. The equivalent instruction in Akeakamai's gestural language would be BASKET HOOP IN ("In the basket, hoop put").

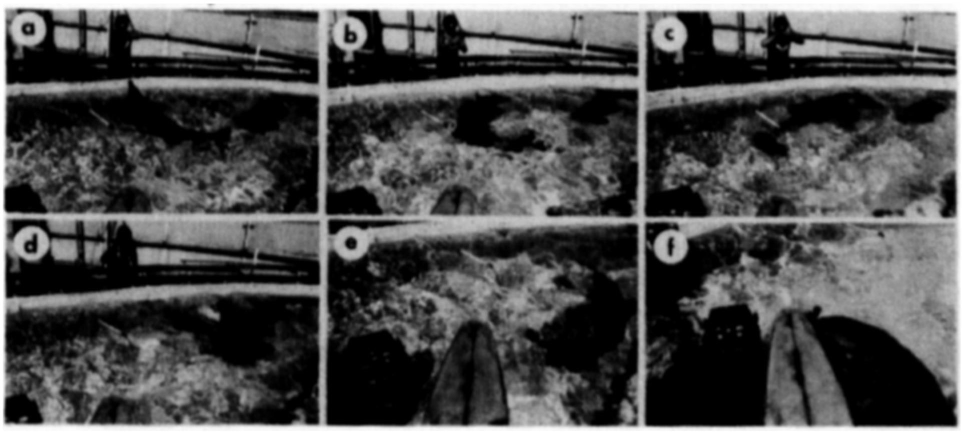
The divergent syntactic rules across the two languages for sentences involving direct and indirect objects were chosen for two reasons. First, successful training of dolphins to respond to sentences having different rules for structure but the same meaning would demonstrate that wholly arbitrary rules can be learned, as is the case for the diversity of rules to be found across human languages (Hockett, 1960). Second, the word order for Akeakamai's FETCH or IN sentences precludes her from carrying out the instruction as a simple chain of responses in which successive actions have a one-to-one temporal correspondence with the word order of the presented instruction. Phoenix's syntax is like a left-to-right grammar; a correct response to the sentence BASKET FETCH WATER requires a sequence of responses that correspond in their performed order to the left to right sequence of words in the sentence, i.e., swimming to the basket and carrying it to the stream of water flowing from the suspended hose. For Akeakamai, the relationship is more indirect; the sequence of words does not correspond to the sequence in which the actions must be performed. For example, in response to the sentence WATER BASKET FETCH Akeakamai must first swim to the basket, retrieve it, and then carry it to the stream of water. Akeakamai's WATER BASKET FETCH is thus semantically equivalent to Phoenix's BASKET FETCH WATER, and requires the same sequence of responses as exercised by Phoenix. Eventually, it will be important to determine how the mapping of instruction onto action takes place cognitively for each dolphin.

For most of the 3-word FETCH or IN sentences, the direct and indirect object represent different object classes, e.g., a ball is fetched to a hoop. However, the rules allow for an object to be fetched to another of the same class, as long as there are two exemplars present. Thus the sentence FRISBEE FETCH FRISBEE ("Take one frisbee to another frisbee") is legitimate.

Modifiers may be used in 4- and 5-word FETCH sentences to specify a particular exemplar. The modifier always refers to the object name it precedes. Thus, for Phoenix, BOTTOM HOOP FETCH PIPE instructs her to go to the hoop that is on the bottom of the tank (and, by implication, not the one that is at the surface) and take it to a pipe (any pipe present in the tank, either floating or on the bottom). In contrast, HOOP FETCH BOTTOM PIPE instructs Phoenix to take any hoop (either a floating hoop or one lying at the bottom) and transport it to the pipe at the bottom (and, by implication, not the one at the surface).

For the gestural language, the 4-word sentence WATER RIGHT BALL FETCH instructs Akeakamai to go to the ball to her right (and not the one to her left) and take it to the water streaming from the suspended hose. In contrast, RIGHT WATER BALL FETCH instructs Akeakamai to go to any ball and take it to the stream of water to her right (and not the stream to her left). Figure 6 illustrates Akeakamai responding to the 4-word sentence SURFBOARD RIGHT FRISBEE FETCH. The syntactic rules for 4-word or longer IN sentences parallel those described for FETCH sentences.

Figure 6. *Example of Akeakamai responding to the 4-word sentence SURFBOARD RIGHT FRISBEE FETCH ("go to the frisbee to your right and take it to the surfboard"). (a) gesture for SURFBOARD being given—immediately to Akeakamai's left is the LEFT HOOP with SURFBOARD and LEFT BASKET visible in bottom left corner of photo. To Akeakamai's right can be seen the RIGHT FRISBEE and the RIGHT BASKET; (b) gesture for RIGHT being given—Akeakamai is leaning right; (c) gesture for FRISBEE being given—Akeakamai moving toward RIGHT FRISBEE; (d) gesture for FETCH given—Akeakamai already at the frisbee to her right and beginning to transport it; (e)–(f) Akeakamai carries frisbee on her rostrum back to her left to surfboard and touches it to surfboard, successfully carrying out instruction—LEFT FRISBEE visible next to LEFT BASKET. Entire sequence was approximately 12 seconds in duration. Timing was as in Fig. 5.*



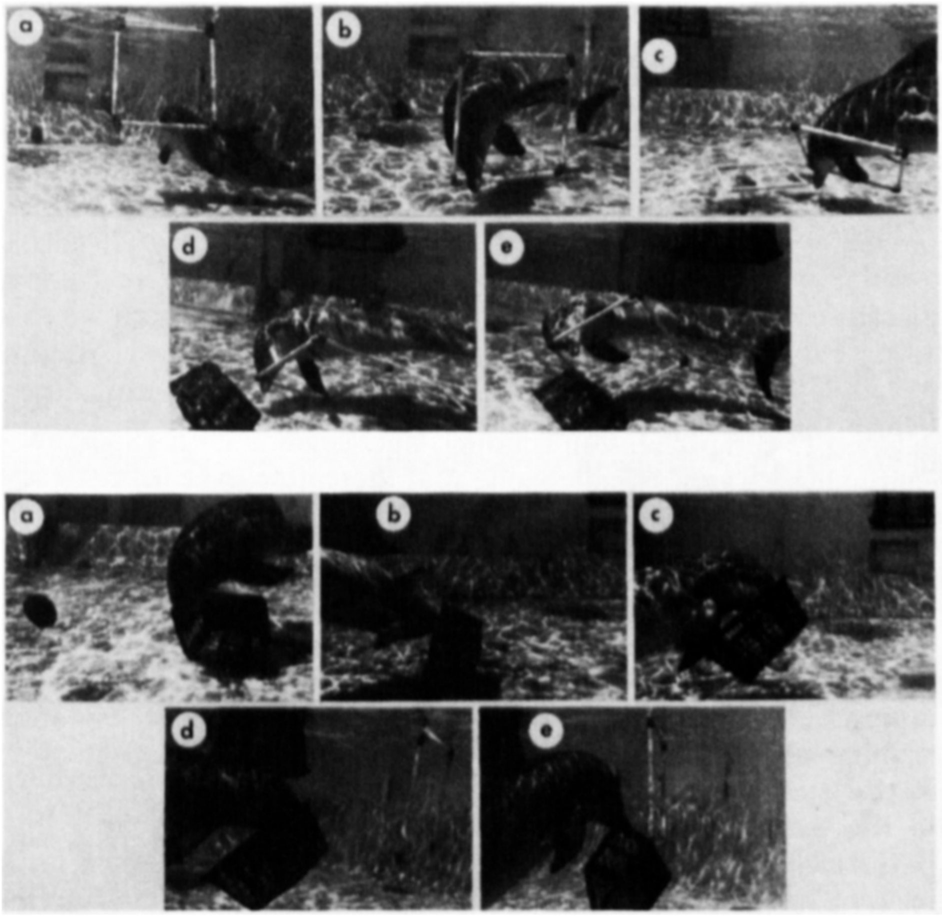
Many 5-word sentences have been given to Phoenix, but only a few probes have been given to Akeakamai thus far. All 5-word sentences in Phoenix's language are semantically reversible since they involve transportable direct objects and indirect objects. For example, BOTTOM FRISBEE FETCH SURFACE HOOP and SURFACE HOOP FETCH BOTTOM FRISBEE instruct, respectively, "Go to the frisbee at the bottom of the tank and take it to the hoop at the surface," and "Go to the hoop at the surface and take it to the frisbee at the bottom." Such sentences are given with both bottom (i.e., sunken) and surface (i.e., floating) exemplars of the named objects in the tank and, generally, with one or more other surface and bottom object pairs present as well. Note that there are several variations to the semantically reversible 5-word sentence. Thus, in addition to the two examples just given, two other sentences involving the same five words can be constructed, each with a unique semantic interpretation: BOTTOM HOOP FETCH SURFACE FRISBEE and SURFACE FRISBEE FETCH BOTTOM HOOP. Also, a change of a single modifier or a single object name creates many more sentences which are semantically related to the previous four but are still unique, e.g., BOTTOM FRISBEE FETCH BOTTOM HOOP, BOTTOM FRISBEE FETCH SURFACE FRISBEE, or BOTTOM PIPE FETCH SURFACE HOOP. Figure 7 illustrates Phoenix responding to the 5-word semantically reversible sentences SURFACE HOOP FETCH BOTTOM BASKET *versus* BOTTOM BASKET FETCH SURFACE HOOP.

General procedure

The dolphins were trained twice daily, five to six days per week. Each training session was from two to three hours in length. All of Phoenix's sessions were devoted to comprehension training, but, beginning on 15 October 1979 and continuing for approximately one year thereafter, Akeakamai's sessions were divided equally between comprehension training and vocal mimicry training. The results for mimicry training are reported elsewhere (Richards *et al.*, 1984). At each training session a keyboard operator located in a tower above

Figure 7. *Example of Phoenix responding to semantically reversible 5-word sentences.* Top: *The sentence is SURFACE HOOP FETCH BOTTOM BASKET ("Go to the hoop at the surface and take it to the basket at the bottom"). (a) Phoenix arrives at the surface hoop which floats vertically, and begins to push it down toward the tank bottom—BOTTOM FRISBEE visible in background beneath WINDOW; (b) Phoenix begins to transport hoop along bottom, pushing with the top of her head; (c)–(d) BOTTOM HOOP and SURFACE BASKET visible—Phoenix passes above BOTTOM*

HOOP and below SURFACE BASKET and continues toward BOTTOM BASKET; (e) Phoenix arrives at BOTTOM BASKET and touches SURFACE HOOP to it, successfully completing instruction. Bottom: *The sentence is BOTTOM BASKET FETCH SURFACE HOOP, one form of a semantic reversal of prior sentence. (a) Phoenix arrives at BOTTOM BASKET and begins to turn it so she can get into a transport position with her rostrum inside the basket—BOTTOM FRISBEE visible to left and BOTTOM HOOP is just behind BOTTOM BASKET; (b) Phoenix begins her turn in the opposite direction from which she arrived in order to begin transport of basket to the right in the direction of the SURFACE HOOP; (c)–(d) Phoenix carrying basket past BOTTOM HOOP and SURFACE BASKET (upper right corner) toward SURFACE HOOP—WINDOW visible in background; (e) Phoenix arrives at SURFACE HOOP and touches BOTTOM BASKET to it, successfully completing instruction. Each sequence was approximately 10 seconds from the start of the first acoustic word (PHOENIX) to the completion of the response by Phoenix.*



the tank operated the ASCII keyboard and additionally directed each dolphin's tankside trainer. An assistant ('recorder') in the tower maintained a log of instructions given the dolphins and of the dolphins' responses. Sessions were begun by calling each dolphin to its station by playing its name through the underwater speaker. Station locations were identified by the presence of a trainer at tankside. Station locations and trainers were generally changed from session to session.

During each session one dolphin was tested in 'formal' blocks of trials while the second was simultaneously given 'local' trials. Formal and local blocks of trials were alternated between dolphins within a session. During formal training multiple sentences were given to practice old words or concepts, to train new words or concepts, or to test for comprehension. These formal trials were under the continuous supervision and control of the keyboard operator. Local trials were conducted by the tankside trainer and consisted of activities such as 'play,' e.g., playing 'catch' with the dolphin using a ball; the giving of simple action commands that were not part of the formal language, e.g., giving gestures for leaping or slapping the tail flukes on the water; or, for Akeakamai, giving practice in some gesturally-controlled behaviors that were part of the formal language, as instructed in advance by the keyboard operator. Additionally, several new behaviors were trained during local trials, e.g., spitting at objects, an action which was later named SPIT and incorporated into the language. Local trials were always characterized by a great deal of social interaction between trainer and dolphin.

Prior to each block of formal trials, dolphin-transportable objects were placed in the tank. In the early phases of training, objects were tethered on strings adjacent to the dolphin, the number of objects was generally limited to two, and the objects were removed after each response and repositioned before the next instruction was given. As the competency of the dolphins improved, the number of objects available on a given presentation was increased, the objects were allowed to drift freely about the tank with only minor repositioning to separate objects that had drifted together, or that had drifted too far, or into inaccessible nooks, and the objects were no longer removed after each instruction. The particular objects used during a block of formal trials depended on whether any special training was in effect, and whether any modifiers were to be used. The selection of objects was changed during a block if training circumstances dictated a change, but after the initial training phase was completed (approximately nine months after language instruction began) there was almost always an exemplar of each named object in the tank throughout all trials. Objects to be described by modifiers (RIGHT/LEFT or SURFACE/BOTTOM) were represented by pairs of objects of the same name, positioned so that the modifier descriptions were appropriate.

To give a formal instruction to Phoenix, the keyboard operator called Phoenix to her station by playing her computer-generated acoustic name. The operator then loaded a sentence into the computer via the keyboard and, when Phoenix was in a neutral listening position, with head underwater, initiated presentation of the sentence by pressing the space bar on the keyboard. All sentences began with Phoenix's name as agent; the successive words of the acoustic instruction (modifiers, objects, actions) were then broadcast, separated from one another by the pre-selected 250 millisecond interval (or occasionally 500 millisecond intervals if training circumstances dictated a slower presentation rate). In order to control for unintentional cueing, the tankside trainer for Phoenix was not told the acoustic sentence given to Phoenix and was informed after Phoenix's response whether or not she was correct.

During formal training for Akeakamai, the keyboard operator called Akeakamai to station by her computer-generated acoustic name, directed the tankside trainer to don a pair of opaque goggles as a guard against visual cueing, then vocally informed the trainer of the next sentence to be given. Akeakamai's acoustic name was repeated, and when Akeakamai was stationed with head out of water, looking at the tankside trainer, the operator called out "Ready", directing the tankside trainer to begin the gestural sentence. As with Phoenix, the tankside trainer was informed of the outcome of Akeakamai's response after each trial was completed and at that time removed the goggles.

Whenever a dolphin responded correctly to an instruction, as judged by the keyboard operator (or by the 'blind observer' as described later), he or she entered and executed the acoustic sentences YES (PHOENIX or AKEAKAMAI) FISH and informed the tankside trainer that the response was correct. The tankside trainer then clapped his/her hands silently as a gestural conditioned-reinforcer signal, petted the dolphin upon its return to station, and fed it a fish. If the dolphin's response was incorrect, its acoustic name (or occasionally, NO) was played as a 'recall to station' and the tankside trainer made no response.

These procedures were modified slightly during comprehension testing using a blind-observer technique. In this technique, responses were judged by an observer having no prior knowledge of the sentences to be given. The observer, positioned on the tower overlooking the tank (see Fig. 1), was any one of the authors. All were familiar with the languages and with the forms of the responses of the dolphins to the various action words. When judging Phoenix's responses, the observer wore a headset into which white noise was inserted binaurally. This precluded any possibility of the observer hearing the acoustic signals, as was verified by all observers. When judging Akeakamai's responses, the observer was positioned with his back toward the tank in such a manner that he could see neither Akeakamai nor her trainer. When the tankside trainer completed the gestural sentence, the supervisor called out "Now" and the observer swiftly turned around to watch Akeakamai's response. For both the acoustic and the gestural case, the observer watched the dolphin's response and called out the sentence that represented the observed behavior. An unclear response or an ambiguous object choice was indicated by calling out the letter "M" in the position of the missing semantic element or elements. The dolphin's response was scored as correct only if the sentence named by the observer agreed wholly with the sentence actually given.

Additional controls during blind-observer procedures were that the tankside trainer interacting with Phoenix (acoustic language), or other tankside personnel acting as PERSON, had no advance knowledge of the instruction given Phoenix and were also uninformed about the nature of any error made. The trainer gesturing to Akeakamai necessarily had to be informed of the sentence to be given. To avoid cueing the observer, the supervisor transmitted the instruction to the trainer by gestures which could not be seen by the observer. Prior to transmitting the instruction to Akeakamai the tankside trainer put on his/her opaque goggles and was consequently unaware of the responses being made by the dolphin or of the changes in locations of floating objects. An independent record of all the sentences given and of the sentences named by the blind observer was kept by the recorder located in the tower together with the keyboard operator. Additionally, a videotape record was made of all sessions using a blind observer to provide a permanent historical record and to allow for the later detailed study of responses.

Training goals and general techniques

The dolphin training program involved a progression in which successively longer sentences and new syntactic forms were introduced as proficiency with shorter sentences or earlier syntactic forms developed. New vocabulary items and new semantic entities were introduced as necessary to accomplish this progression.

The initial training of Phoenix and Akeakamai for sentence comprehension generally followed the procedures developed earlier for the dolphin Kea by Herman (1980). The early goals were (*a*) to establish an acoustic conditioned-reinforcer sound ("YES") to be used in common with both dolphins, (*b*) to establish a unique acoustic name for each dolphin, and (*c*) to establish a small lexicon of object and action words that could be combined into a number of different 2-word Object + Action sentences.

After these training goals were achieved successfully, additional training efforts were directed toward some enlargement of each dolphin's vocabulary, with a consequent increase in the number of 2-word sentences that could be generated in the languages. Of more general importance, however, were the later efforts directed toward the expansion of the semantic and syntactic categories and toward increases in the complexity of the syntactic structure. Together, these efforts allowed for the creation of new types of sentences and of sentences of increased length and complexity.

The training methods used were selected to suit the particular goals and were modified as necessary depending on training outcomes. We have no way to judge whether the training methods were efficient since that would require extensive study of the effects of a variety of techniques on a large number of dolphins. The techniques used have been shown to be successful and efficient in training dolphins for other types of complex learning tasks, such as discrimination learning sets (Herman and Arbeit, 1973) or generalized delayed match-to-sample (Herman and Gordon, 1974). Generally, the techniques employed some type of auditory, visual, temporal, spatial, or context cue to prompt a correct response. Once the response stabilized under cueing, the cue was omitted on an increasing proportion of trials and finally deleted altogether. Context cues principally involved the use of blocks of trials of a fixed type to stabilize responding under a constant condition with conditions changed only when a performance criterion was met. Blocking of trials was used irregularly throughout the language training. Generally, the amount of cueing of any type required to teach a new object name decreased as the project progressed. In later training it was sometimes sufficient to pair a new signal (sound or gesture, as appropriate for the dolphin) 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 of other objects, during regular formal sessions having a variety of sentences.

Additional conventional training techniques were used. Shaping, the reinforcement of successively closer approximations to the desired response, was used extensively for the training of actions (e.g., see Herman, 1980). For improving Phoenix's performance on 4- and 5-word sentences, sentences were stepped through one word at a time; a succeeding word appeared only if the response to the prior word was correct. This technique gave immediate feedback to Phoenix if an error was made at any step, since the sentence was interrupted at the point of the error by the playing of her name. Phoenix then returned to her station. Application of the stepping technique was temporary and quickly led to improved performance on unstepped (continuous) sentences.

Perhaps the most important facet of our training procedures was the expansion of the generality of existing words or sentences beyond the restricted context in which they were first taught. The intent was to teach the dolphin that a concept had meaning in a wide variety of situations, and could be applied in completely novel situations as well. To this end we varied the context in which the instructions were given, and made the course of the training sessions unpredictable to the dolphins in the following ways:

(1) Except for the special training conditions in which blocks of trials of a particular sentence type were given, most of the training was characterized by the presentation of sentences in quasi-random order. This insured that it was not possible for the dolphins to predict the next sentence to be given during a training session and guarded against the formation of response expectations or biases.

(2) Where possible, multiple exemplars of objects were used, e.g., presentation of different balls, hoops, and persons allowed for the generalizations of a word from a specific exemplar to an object class.

(3) The location in the tank of dolphin-transportable objects was varied, at first according to a predetermined schedule and, later, by allowing them to drift freely about the tank or to remain wherever the dolphins left them after responding to them. Exceptions occurred during special object discrimination training sessions in which distance cues were used to guide response to particular objects. As training proceeded, searching behavior was explicitly encouraged by the placement of objects in distant locations or in 'hidden' locations (generally, on the side of the fence opposite to that of the dolphin; see Fig. 1). 'Displacement' training (see later) in which objects were not placed in the tank until after a sentence had been given was particularly useful in encouraging search behavior.

(4) The location of trainer-transportable objects (SPEAKER, WATER, PERSON) was changed frequently.

(5) The station locations of the dolphins were changed over sessions and occasionally during sessions, such that even fixed tank locations such as GATE did not always occur in the same position relative to the dolphin. Early problems in training demonstrated clearly that the dolphins were likely to encode objects, even floating ones, by their spatial locations unless explicitly trained otherwise.

(6) Emphasis was given to recombinations. Not only were words chosen to be recombinable meaningfully with a large number of other words, but in order to encourage the conceptual generalization of actions, we allowed the dolphins to change their response topographies in response to new objects or new situations.

(7) For both dolphins, the use of many different people as tankside trainers promoted generalization over trainers. Also, for Akeakamai, the variability in the signs across trainers appeared to promote her identification, for each sign, of the key components that were used in common by all trainers. As was noted earlier, Akeakamai will at present respond appropriately to novice trainers who have received only a few minute's tutelage in signing. Also, in many cases she will respond correctly even if the trainer stands a meter or so back from the tank or turns sideways while signing.

Results and discussion

This section reviews the methods used for testing comprehension and provides data on the responses of the dolphins to (*a*) lexically novel sentences; (*b*) novel syntactic forms (structural novelty); (*c*) semantically reversible sentences; and (*d*) the entire corpus of sentences that could be generated in the acoustic language (Phoenix) or a sample of 66% of the sentences that could be generated in the gestural language (Akeakamai). The responses under Item *d* were collected under procedures termed 'calibration' tests. Also provided are recent results with the dolphin Akeakamai comparing her responses to sentences using the relational words FETCH and IN. A further section gives examples of the generalization of responses to objects and to actions, the generalization of context, some results of 'displacement' tests, and results of tests of the dolphins' ability to report that a named object is not present in the tank. A final section reports on results of preliminary tests of Phoenix's ability to understand conjoined sentences and of tests of Akeakamai's responses to a particular type of anomalous sentence.

Generally, the performance levels attained on the various comprehension tests were evaluated for significance using the summed binomial distribution function, $\sum_{k=k'}^{n} C_k^n p^k(1-p)^{n-k}$, where n is the number of sentences given of a particular syntactic form, k' is the number of those sentences responded to wholly correctly, and p is the probability of a correct response by chance to a sentence of that syntactic form. The values for p were derived from the finite-state ('syntactic-form') model described in the Appendix, one of several models discussed for evaluating chance probabilities in responding to a sentence. Table A1 of the Appendix shows that the probability of a correct response to a sentence by chance alone was less than 0.04 for any of Phoenix's sentences and less than 0.02 for any of Akeakamai's.

Comprehension of novel sentences (lexical novelty)

A lexically novel sentence occurs when a new word, or a new combination of words, is inserted into one of the familiar sentence forms. Once that sentence has been given, it is classified thereafter as 'familiar'. Presentations of lexically novel sentences were categorized as Class A, B, or C, representing, in that order, high to lower levels of experimental control for the presence of nonlinguistic cues. Together, the three classes include all of the novel sentences tested throughout the period of the project covered by this report.

Class A presentations were preplanned and were tested within a set of strict procedures for the control of nonlinguistic cues and observer bias. The novel sentence to be tested was inserted into a predetermined list of 30 to 40 familiar sentences and the entire list was then given during a single testing session. The familiar sentences were selected quasi-randomly from the entire set of familiar sentences, under the constraint that all or most of the familiar syntactic forms be represented and that no sentence be repeated. The novel sentence was inserted into the list of familiar sentences such that no word used in the novel sentence appeared in the preceding five sentences. Generally, only one novel sentence, at most two, was tested during a session. During the calibration tests (see later) a slightly different set of rules was used for embedding novel sentences within a set of familiar sentences.

During Class A testing procedures, all of the objects that had names in the vocabulary of the dolphin were present in the tank. Floating objects were allowed to drift about the tank throughout the session and were repositioned only if they became located in inaccessible places or drifted very close together. The responses of the dolphins to both familiar and novel sentences were judged by the blind-observer technique described earlier.

Class B presentations were unplanned—given 'accidentally' during the course of the standard training format described earlier in the procedure section. There was no blind observer and no videotape record. The early standard training procedures allowed the keyboard operator to generate sentences *ad lib*, using his/her knowledge of the existing vocabulary and grammar and the particular training goals in effect at the time. During the course of such training, novel sentences might be given, but without awareness by the keyboard operator or tankside trainer that they were novel. Class B presentations, though unplanned, are useful for assessing comprehension because they were given without the presence of context cues that might guide the dolphin's response and without awareness by the keyboard operator that the sentences were novel. Generally, during these standard training procedures all of the objects named in the language were in the tank and available to the dolphin for response.

Class C presentations had moderate to extensive nonlinguistic cues available for guiding responses. Novel sentences of this class were given during the early stages of the language training program to extend the generality of some of the words or concepts being taught. During these early stages new words or new sentences were often presented in a context that might predispose responses of one type or another, including, in the beginning, actual shaping of responses. In somewhat later stages of training the number of alternative objects available for response was small, or the elements composing the new sentence received special emphasis during immediately preceding trials. Class C presentations are thus not useful for judging competency in understanding novel sentences but are noted here for completeness. Altogether, 191 sentences were presented under Class C conditions to Phoenix, and 143 to Akeakamai.

The results of Class A and of Class B novel sentence testing are shown in Table 3 (Phoenix) and Table 4 (Akeakamai). For each sentence type listed, the tables show the total number of novel sentences tested under Class A and B conditions ('Total novel sentences'). The succeeding columns show the number of sentences in which any error was made ('Sentence errors'), the percentage of sentences having wholly correct responses, and the number of errors on the individual semantic elements of the sentences not responded to wholly correctly. The final column gives the number of sentences on which errors occurred to two or more semantic elements. The results for Class A are of greatest relevance to the question of sentence understanding because of the strict controls applied and because all syntactic types were tested. Also, the sample size is relatively large as compared with Class B. The percentage of wholly correct responses to Class A novel sentences ranged from 57% to 69% for Phoenix, except for the unusally high performance level of 92% correct on the Modifier + Direct Object + Action sentences. However, the sample size is the smallest for this category. Akeakamai's performance level on her Class A sentences ranged from 50% to 77% correct. Using the conservative 'syntactic form' probability model discussed in the Appendix and applying the cumulative binomial distribution to test for departure from chance expectations, it was found that for each dolphin and for each syntactic category, the number of novel sentences responded to wholly correctly greatly exceeded chance expectations ($p < 0.0001$). The binomial test was also applied to the data for the Class B novel sentences. Again, all of the obtained numbers of wholly correct responses greatly exceeded chance expectations ($p < 0.0001$).

Table 3. *Results of novel sentence presentations: Phoenix*

Category A: Blind observer present, no context constraints

Sentence type	Total novel sentences	Sentence errors	Percent correct	Element error[a]					Mult. error[b]
				M	DO	A	M	IO	
DO + A	19	6	68.4	–	5	1	–	–	0
M + DO + A	12	1	91.7	0	0	1	–	–	0
DO + *A* + IO	32	10	68.8	–	3	0	–	7	0
DO + *A* + M + IO	28	10	64.3	–	1	1	9	5	5
M + DO + *A* + IO	42	14	66.7	6	5	3	–	7	4
M + DO + *A* + M + IO	28	12	57.1	2	2	1	8	5	6
All	161	53	67.1	9.8	9.9	4.3	30.4	18.5	15

Category B: Blind observer absent, no context constraints

Sentence type	Total novel sentences	Sentence errors	Percent correct	M	DO	A	M	IO	Mult. error
DO + A	27	6	77.8	–	4	3	–	–	1
M + DO + A	4	0	100.0	0	0	0	–	–	0
DO + *A* + IO	16	11	31.3	–	6	6	–	10	8
DO + *A* + M + IO	0	0	–	–	–	–	–	–	–
M + DO + *A* + IO	6	3	50.0	1	0	1	–	3	1
M + DO + *A* + M + IO	6	3	50.0	2	0	0	2	0	1
All	59	23	61.0	18.8	17.0	17.0	33.3	46.4	11

Note. M = Modifier; DO = Direct Object; A = Action (non-FETCH); *A* = FETCH action; IO = Indirect Object.

[a]Number of errors in each semantic category except for 'All' which gives the percentage of errors calculated by dividing the total of errors in that category by the number of sentences containing that category and multiplying by 100.

[b]Indicates the number of sentences on which errors occurred to more than one semantic element.

Considering the Class A data on individual elements ('element error'), both dolphins performed admirably in selecting the specified direct object (better than 90% correct selections) and the specified action (better than 95% correct selections). Indirect objects were more difficult for both dolphins. Phoenix responded correctly to slightly more than 81% of the specified indirect objects and Akeakamai to slightly more than 70%. Akeakamai's grammar, in which the indirect object precedes the direct object, likely places a substantial burden on her short-term memory and on her ability to allocate her attention effectively. That is, while selecting and manipulating the specified direct object she must continue to remember and search for the

Table 4. ***Results of novel sentence presentations: Akeakamai***

Sentence type	Total novel sentences	Sentence errors	Percent correct	Element error[a]					Mult. error[b]
				M	DO	A	M	IO	
Category A: Blind observer present, no context constraints									
DO + A	10	3	70.0	-	3	0	-	-	0
M + DO + A	48	13	72.9	11	4	4	-	-	4
IO + DO + *A*	24	12	50.0	-	1	0	-	11	0
M + IO + DO + *A*	31	7	77.4	-	1	2	5	6	2
IO + M + DO + *A*	40	18	55.0	14	2	1	-	11	4
All	153	53	65.4	28.4	7.2	4.6	16.1	29.5	10
Category B: Blind observer absent, no context constraints									
DO + A	20	4	80.0	-	4	0	-	-	0
M + DO + A	6	1	83.3	1	1	0	-	-	1
IO + DO + *A*	34	13	61.8	-	5	1	-	11	3
M + IO + DO + *A*	0	0	-	-	-	-	-	-	-
IO + M + DO + *A*	0	0	-	-	-	-	-	-	-
All	60	18	70.0	16.7	16.7	1.7	-	32.4	4

Note. M = Modifier; DO = Direct Object; A = Action (non-FETCH); *A* = FETCH action; IO = Indirect Object.

[a]Number of errors in each semantic category except for 'All' which gives the percentage of errors calculated by dividing the total of errors in that category by the number of sentences containing that category and multiplying by 100.

[b]Indicates the number of sentences on which errors occurred to more than one semantic element.

indirect object that had been specified earlier. Some evidence that an attention/memory problem may be involved in Akeakamai's lowered performance level on indirect objects is found in her improved performance with this syntactic element when it is modified. For the Class A novel sentences of Table 4, the error rate to modified indirect objects, in the sentence form Modifier + Indirect Object + Direct Object + FETCH was only 19.4%. In contrast, the error rate to indirect objects was 27.5% in the unmodified form Indirect Object + Modifier + Direct Object + FETCH and 45.8% in the unmodified form Indirect Object + Direct Object + FETCH. Apparently, the modifier (RIGHT or LEFT) helped to resolve some of the uncertainty about location of the indirect object, either by restricting the search area or by serving as a spatial mnemonic code. Either interpretation is strengthened by the finding seen in Table 4 that modifying the indirect object helped more than modifying the direct object. The direct object is responded to first and hence need not be held in short-term memory while performing a response to another object.

For Phoenix, in which the grammar was straightforwardly left to right, the sentence may be executed in part while it is still unfolding. That is, on hearing the direct object Phoenix can begin to orient toward it immediately. She may occasionally arrive at or near the direct object before the indirect object name has been completed. Hence, her memory demands would appear to be less and there would be less of a need to partition her attentional resources between direct and indirect objects. In keeping with this view, the data in Table 3 show that, unlike the case for Akeakamai, the error rate with modified and unmodified indirect objects was virtually the same. Also, there was no facilitation of Phoenix's performance on either type of 4-word FETCH sentence relative to performance with the 3-word FETCH sentence.

Error rates on the modifier elements themselves were relatively high for both dolphins. For Phoenix, on Class A presentations, there was 10% error on modifiers of direct objects and 30% error on modifiers of indirect objects. The corresponding error rates for Akeakamai were 28% and 16%. Hence both dolphins performed better on modifiers that occur earlier in the sentence (the modifier of direct object for Phoenix and the modifier of indirect object for Akeakamai). To some degree, the high error rate on modifiers of indirect objects for Phoenix may have offset any gain obtained from the resolution of spatial uncertainty provided by these modifiers. The modifier elements were the most recently taught semantic element for both dolphins and this may partly explain the relatively low performance levels with this semantic element. Nevertheless, the performance levels were all significantly above chance levels by the summed binomial distribution test ($p < 0.003$). For these tests, the probability of responding correctly to a modifier element by chance was set at 0.50 (it could actually be less if it is assumed that the dolphins can ignore the modifier element entirely by selecting an unmodified object).

There were very few occasions when either dolphin made a completely inappropriate (irrelevant) response to a novel sentence. In particular, in only 15 (9.3%) of the 161 Class A novel sentences given Phoenix, and ten (6.5%) of the 153 Class A novel sentences given Akeakamai, was an error made on more than one semantic element. This indicates that even for those sentences listed as errors in Tables 3 and 4, a good deal of correct syntactic, semantic and lexical processing was occurring.

Comprehension of novel syntactic forms (structural novelty)

Both dolphins were given new syntactic forms of 4-word sentences without specific training. Phoenix had received specific training in the syntactic form Modifier + Direct Object + FETCH + Indirect Object at a relatively early stage of her language program. However, she was later given the form Direct Object + FETCH + Modifier + Indirect Object without specific training. She responded wholly correctly to her first sentence of this type, FRISBEE FETCH BOTTOM HOOP, given as a Class A novel sentence, and thereafter to 17 (63.0%) of 27 additional sentences of this type given in the Class A format at irregular intervals over a several month period (Table 3). Akeakamai showed a similar ability to generalize her responses to a new syntactic form. Both types of 4-word sentence—Modifier + Indirect Object + Direct Object + FETCH and Indirect Object + Modifier + Direct Object + FETCH—were given without any specific training. She responded correctly to her first 4-word sentence involving a modified indirect object (RIGHT WATER BASKET FETCH) and to 23 (76.7%) of 30 additional sentences of this type given in the Class A format over a subsequent four-month interval (Table 4). She also responded correctly to her first 4-word sentence using a modified direct object (PERSON LEFT FRISBEE FETCH) and to 21 (53.8%) of an additional 39 sentences of this type given in the Class A format, mainly over the subsequent four-month period (Table 4). We noted previously that modifying the indirect object was more helpful than modifying the direct object. The stated performance levels all greatly exceeded chance expectations ($p < 0.0001$).

Semantically reversible sentences

Table 5, derived from a subset of the data used to generate Tables 3 and 4, summarizes performance of the dolphins on semantically reversible novel sentences, using pooled Class A and B testing data. Phoenix was given 85 3-, 4- and 5-word semantically reversible FETCH sentences and Akeakamai 48 novel 3- and 4-word semantically reversible FETCH sentences. Akeakamai began her FETCH training later than Phoenix and except for two 5-word probes given in a training context (and not performed correctly) has not yet been formally tested with 5-word FETCH sentences.

Overall, Phoenix's responses to her semantically reversible sentences were 65.9% correct and Akeakamai's were 54.2% correct. These levels are close to the overall performance level on all novel FETCH sentences, reversible plus nonreversible—60.1% for Phoenix (Table 3) and 61.2% for Akeakamai (Table 4), for Classes A and B combined. The lowest performance level in

Table 5. *Results of novel sentence testing: Semantically reversible sentences: Phoenix and Akeakamai*

Sentence type	Total novel sentences	Sentence errors	Percent correct	Element errors[a]					Mult. error[b]	Rev. error[c]
				M	DO	A	M	IO		
Phoenix										
DO + *A* + IO	11	3	72.7	–	1	0	–	2	0	0
DO + *A* + M + IO	28	10	64.3	–	1	1	9	5	5	0
M + DO + *A* + IO	18	5	72.2	2	2	1	–	2	0	0
M + DO + *A* + M + IO	28	11	60.7	2	2	0	7	8	0	1
All	85	29	65.9	8.7	7.1	2.4	28.6	20.0	5	1
Akeakamai										
IO + DO + *A*	8	6	25.0	–	0	0	–	6	0	0
M + IO + DO + *A*	20	6	70.0	–	1	2	4	6	4	0
IO + M + DO + *A*	20	10	50.0	7	1	0	–	6	0	0
All	48	22	54.2	35.0	4.2	4.2	20.0	37.5	4	0

Note. M = Modifier; DO = Direct Object; *A* = FETCH action; IO = Indirect Object.

[a]Number of errors in each semantic category except for 'All' which gives the percentage of errors calculated by dividing the total of errors in that category by the number of sentences containing that category and multiplying by 100.

[b]Indicates the number of sentences on which errors occurred to more than one semantic element.

[c]Indicates the number of sentences on which there was a reversal of response to the specified direct and indirect objects, such that the indirect object was transported to the direct object.

Table 5 was that for Akeakamai on her 3-word semantically reversible sentences. Although she was wholly correct on only two of the eight sentences of this type given, the expected number correct by the cumulative binomial distribution function is less than 0.2 and the obtained significance level p is less than 0.008. All of the remaining performance levels in Table 5 greatly exceeded chance expectations ($p < 0.0001$).

An important indicant of the dolphins' good level of understanding of the syntactic rules governing the assignment of direct object and indirect object within a semantically reversible sentence is the extremely low incidence of reversal error. A reversal error is taking the specified indirect object to the specified direct object. Table 5 shows only one such reversal for Phoenix in the total of 85 semantically reversible sentences given her and no reversal errors at all for Akeakamai throughout her total of 48 semantically reversible sentences. For Phoenix, errors were mainly selection of the wrong modifier of indirect object or the wrong indirect object. For Akeakamai, errors were mainly selection of the wrong modifier of direct object or the wrong indirect object. If the dolphins had no syntactic knowledge, but perfect semantic knowledge, one would expect the reversal error rate to be close to 50%. That is, there would be an equal probability that the specified direct object would be taken to the specified indirect object (a correct response) or that the specified indirect object would be transported to the specified direct object (a reversal error). The extreme rarity of reversal errors confirms the sensitivity of the dolphins to the word-order rules of their respective languages. That Akeakamai's performance on semantically reversible sentences was somewhat lower than Phoenix's most probably reflects the greater demands Akeakamai's syntactic rule placed on memory for and attention to the indirect object, as was discussed earlier. Akeakamai's performance on direct objects, 95.8% correct selections, slightly exceeded Phoenix's level of 92.9%, but her level of 62.5% correct responses to indirect objects was substantially lower than the 80.0% level achieved by Phoenix.

Performance on 'calibration' tests

The dolphins' comprehension of the entire corpus of sentences in their respective languages was measured or estimated at various stages of their language training using procedures termed 'calibration' tests. The calibration procedure involved the generation of the set of all possible sentences or of a representative sample of these, the arrangement of the selected sentences in a predetermined pseudorandom order, and the testing of responses to the set. The first calibration test was given in the period August–September 1979 when the total corpus consisted of 31 2-word Object + Action sentences for each dolphin. The overall performance results were 80.8% correct responses for Phoenix and 81.6% correct responses for Akeakamai. The second calibration was in October–December, 1980, when the corpus was 204 sentences for Phoenix and 170 sentences for Akeakamai. For Phoenix, the corpus included 67 2-word Object + Action sentences, 27 3-word sentences of the type Direct Object + FETCH + Indirect Object, 44 3-word sentences of the type Modifier + Object + Action, 36 4-word sentences of the type Modifier + Direct Object + FETCH + Indirect Object, and 30 5-word sentences of the type Modifier + Direct Object + FETCH + Modifier + Indirect Object. Phoenix responded wholly correctly to 78.9% of her 204 unique sentences, with each sentence tested at least twice.

Akeakamai's 170 sentences were limited to 64 2-word Object + Action sentences and 106 3-word sentences of the type Modifier + Object + Action.

At the time of this second calibration testing, Akeakamai had not yet been taught any sentence forms involving transporting one object to another. Akeakamai responded wholly correctly to 87.3% of her 170 sentences, with each unique sentence tested at least twice.

The most recent calibration testing was in April of 1982. At that time, Phoenix's corpus had grown to 368 sentences, including the new syntactic form Direct Object + FETCH + Modifier + Indirect Object. Akeakamai's corpus had increased dramatically to 464 unique sentences, owing largely to the addition of 3- and 4-word FETCH sentences to her language. For both dolphins, the testing included both familiar and novel sentences. The results of this April 1982 calibration offer a good evaluation of overall proficiency in the languages and also allow for some comparisons of performance on novel and familiar sentences, when both are tested in the same procedure. The remainder of this section is devoted to details of this most recent calibration test.

All of Phoenix's 368 sentences were tested. Akeakamai's testing included all of her 2-word sentences, all of her 3-word modifier sentences, and all of her 3-word FETCH sentences. Most of her many 4-word sentences were novel. Accordingly, we selected for testing a representative sample of 35% (29) 4-word sentences of the type Modifier + Indirect Object + Direct Object + FETCH and 28% (39) 4-word sentences of the type Indirect Object + Modifier + Direct Object + FETCH. Altogether, 308 (66.4%) of Akeakamai's total of 464 sentences were tested. Of the 308, 62 (20.1%) were novel sentences. Of Phoenix's 368 sentences, 90 (24.5%) were novel. Hence, the percentage of novel sentences was roughly equated across the two dolphins.

Testing schedules consisted of blocks of 20 sentences presented in pseudorandom order and were generated in the following way: For each syntactic category, all of the sentences that were to be used throughout the testing were randomly ordered by a computer program. From each randomized list, sentences were selected in the order generated and in numbers that were representative of the relative frequency of occurrence of the syntactic category in our regular training sessions. By this means, the calibration sessions, from the dolphins' perspective, were indistinguishable from the normal training sessions. The order of occurrence of the selected sentences within each 20-sentence block was random with the constraint that a given syntactic category could occur no more often than three times in a row. For both dolphins, the entire corpus of 2-word sentences, of which none was novel, was given more than once to decrease the density of longer sentences. Since both dolphins generally responded to familiar 2-word sentences at levels of 90% correct or better, a high proportion of 2-word sentence in the 20-sentence blocks guarded against a high error rate at any session. During regular training sessions errors often resulted in negative emotional responses, which in turn might lead to further error that was not indicative of true capability. For both dolphins, all 3-word and longer sentences that were selected were administered exactly once. For comparability with these longer sentences, only the data for the first presentation of each of the 2-word sentences is included in the results.

Table 6. *Results of April, 1982 calibration test: Phoenix*

Sentence type	Sentence status	Unique sentences	Sentence errors	Percent correct	Element error[a]					Mult. error[b]
					M	DO	A	M	IO	
DO + A[c]	Familiar	82	5	93.9	–	3	2	–	–	0
	Novel	0	–	–	–	–	–	–	–	–
	Both	82	5	93.9	–	3	2	–	–	0
M + DO + A	Familiar	45	4	91.1	2	3	1	–	–	2
	Novel	9	1	88.9	0	0	1	–	–	0
	Both	54	5	90.7	2	3	1	–	–	0
DO + *A* + IO	Familiar	56	6	89.3	–	2	1	–	4	1
	Novel	4	1	75.0	–	1	0	–	0	0
	Both	60	7	88.3	–	3	1	–	4	1
DO + *A* + M + IO	Familiar	4	0	100.0	–	0	0	0	0	0
	Novel	24	8	66.7	–	1	1	8	4	4
	Both	28	8	71.4	–	1	1	8	4	4
M + DO + *A* + IO	Familiar	60	8	86.7	5	3	2	–	4	2
	Novel	28	6	78.6	3	4	1	–	1	1
	Both	88	14	84.1	8	7	3	–	5	3
M + DO + *A* + M + IO	Familiar	31	6	80.6	2	0	0	5	1	2
	Novel	25	10	60.0	1	2	1	8	6	7
	Both	56	16	71.4	3	2	1	13	7	9
All	Familiar	278	29	89.6	6.6	4.0	2.2	14.3	6.0	7
	Novel	90	26	71.1	6.4	8.9	4.4	32.7	13.6	12
	Both	368	55	85.1	6.6	5.2	2.4	25.0	8.6	19

Note. M = Modifier; DO = Direct Object; A = Action (non-FETCH); *A* = FETCH action; IO = Indirect Object.

[a]Number of errors in each semantic category except for 'All' which gives the percentage of errors calculated by dividing the total of errors in that category by the number of sentences containing that category and multiplying by 100.

[b]Indicates the number of sentences on which errors occurred to more than one semantic element.

[c]Data are for the first occurrence of each unique 2-word sentence. A total of 303 2-word sentences were given over all replications yielding 93.7% correct responses.

Table 7. *Results of April, 1982 calibration test: Akeakamai*

Sentence type	Sentence status	Unique sentences	Sentence errors	Percent correct	Element error[a]					Mult. error[b]
					M	DO	A	*M*	IO	
DO + A[c]	Familiar	68	4	94.1	–	4	1	–	–	1
	Novel	0	–	–	–	–	–	–	–	–
	Both	68	4	94.1	–	4	1	–	–	1
M + DO + A	Familiar	111	4	96.4	1	1	1	–	–	0
	Novel	1	1	0.0	0	0	1	–	–	0
	Both	112	5	95.5	1	1	2	–	–	0
IO + DO + *A*	Familiar	53	18	66.0	–	2	0	–	17	1
	Novel	7	6	14.3	–	0	0	–	6	0
	Both	60	24	60.0	–	2	0	–	23	1
M + IO + DO + *A*	Familiar	5	0	100.0	–	0	0	0	0	0
	Novel	24	7	70.8	–	1	2	5	6	4
	Both	29 (84)	7	75.9	–	1	2	5	6	4
IO + M + DO + *A*	Familiar	9	1	88.9	1	0	0	–	0	0
	Novel	30	12	60.0	8	2	1	–	7	3
	Both	39 (140)	13	66.7	9	2	1	–	7	3
All	Familiar	246	27	89.0	1.7	2.8	0.8	0.0	25.4	2
	Novel	62	26	58.1	25.8	4.8	6.5	20.8	31.1	7
	Both	308 (464)	53	82.8	6.6	3.2	1.9	17.2	28.1	9

Note. M = Modifier; DO = Direct Object; A = Action (non-FETCH); *A* = FETCH action; IO = Indirect Object; All = All sentences combined. Numbers in parentheses are the total unique sentences available and are given only for those cases in which less than the total was tested.

[a]Number of errors in each semantic category except for 'All' which gives the percentage of errors calculated by dividing the total of errors in that category by the number of sentences containing that category and multiplying by 100.

[b]Indicates the number of sentences on which errors occurred to more than one semantic element.

[c]Data are for the first occurrence of each unique 2-word sentence. A total of 136 2-word sentences were given over all replications yielding 96.3% correct responses.

Tables 6 and 7 summarize the results of the April 1982 calibration tests for Phoenix and Akeakamai, respectively. The tests were conducted over a 15-day period without interruption except for the weekly tank cleaning. From two to four blocks of sentences were given each dolphin daily. As was the case for Class A novel-sentence testing, all of the objects in a dolphin's vocabulary were present in the tank when a sentence was given, the dolphin's responses were judged by the blind-observer technique, and all responses were recorded on videotape. All of the other procedures for guarding against nonlinguistic cueing discussed under Class A novel-sentence testing were in effect during this calibration testing.

For each sentence length and type, Tables 6 and 7 show the number of different ('unique') syntactically and semantically correct sentences that could be generated within each language at the time of testing. For Phoenix (Table 6) the total number of unique sentences actually given was equal to the number of unique sentences available. For Akeakamai (Table 7), as noted previously, not all possible sentences were given in each grammatical category. Shown in the tables are the number of sentences actually given, and the number of these that were familiar and the number that were novel. The successive columns then follow the same organization as did Tables 3 and 4.

The summed binomial distribution and the probability values of the Appendix were used to test whether the obtained numbers of correct responses significantly exceeded chance expectations, as in the previous cases described. For Phoenix, all values in Table 6 were highly significant ($p < 0.0001$). The same was true for Akeakamai (Table 7) with the exception that the one wholly correct response to the seven novel sentences in the syntactic category Indirect Object + Direct Object + FETCH was not a significant departure from chance ($p > 0.05$). Five of the six errors in this category were with sentences of the type A + A + FETCH (e.g., BALL BALL FETCH), requiring the transport of one object to another of the same name, with no modifiers indicated. In all cases, Akeakamai took the named object to an object with a different name, i.e., she substituted another object for the specified indirect object. Importantly, Akeakamai had only one exposure to a sentence of this type before the calibration test (FRISBEE FRISBEE FETCH) to which she responded incorrectly. In general, although she did respond correctly during calibration to one instance of this sentence type, SURFBOARD SURFBOARD FETCH, Akeakamai appeared to treat the sentence form as an anomaly. Semantic substitutions were found to be a common form of response to truly anomalous sentences by both Phoenix and Akeakamai (Herman *et al.*, Reference Note 1). Also, in Table 7, the result (an error) for the one novel sentence given in the category Modifier + Direct Object + FETCH was, of course, not a significant departure from chance.

The performance of both dolphins on whole sentences tended to decline slightly to moderately with increasing sentence complexity, reflecting the increased opportunity for error on the increased number of semantic elements present; however, performance on given sentence elements tended to remain stable regardless of sentence length or type. Generally, as was the case for the data on novel sentences in Tables 3 and 4, action errors were rare, direct object errors slightly less so. For Phoenix, the error rate for indirect objects (8.6%) was not much higher than the error rate for direct objects (5.2%). Phoenix's only difficult category was the modifier of indirect object (25% error overall). Likewise, Akeakamai's overall error rate on indirect objects remained relatively high (28.1% error, cf. Table 4). Once again there were very few multiple errors on sentences, indicating that although the response to a sentence may have been scored as incorrect, the response was in fact likely to have been largely correct.

As was the case in Table 4, which reported on the novel sentence testing of Akeakamai, there was a facilitative effect of modifiers in that 4-word FETCH sentences were responded to more reliably than were 3-word FETCH sentences. When error rates on modifiers are compared strictly within 4-word sentence forms, once again error rates were lower for modifiers of indirect objects (17.2% error) than for modifiers of direct objects (23.1% error). It was suggested earlier that the modifier appears to aid in the location of objects and was most helpful if it located the indirect object. The modifier effect was not obvious for Phoenix; facilitation can be seen in some comparisons in Table 6 but not in other comparisons. Generally, as can be seen by comparing performance of the two dolphins on 3-word Modifier + Object + Action sentences, Phoenix was somewhat less reliable in her responses to modifiers than was Akeakamai. Hence the use of the modifier as an aid to location of objects would be less valuable for Phoenix than for Akeakamai.

Tables 6 and 7 suggest a practice effect in that within each syntactic category performance on familiar sentences was consistently higher than was performance on novel sentences. However, none of the differences within a syntactic category reached significance for Phoenix (z-test, $p > 0.05$). For Akeakamai, the percentage of correct responses obtained with familiar sentences of the form Indirect Object + Direct Object + FETCH was significantly higher than the percentage obtained for novel sentences ($z = 2.06$, $p < 0.05$), but none of the remaining comparisons was significant. Overall, then, it cannot be concluded that within syntactic categories there was a significant enhancement of performance on familiar sentences relative to that obtained with novel sentences. For all syntactic categories combined, and for each dolphin, the percentage of correct responses to familiar sentences was significantly higher than the percentage of correct responses to novel sentences ($z \geq 4.09$, $p < 0.0001$). However, the totals are biased since the various syntactic categories are not equally represented across the familiar and novel sentences. The imbalance was due to the limited availability of either familiar or novel sentences within a syntactic category at the time of testing.

Table 8 summarizes the performance of the two dolphins on the subset of semantically reversible sentences given during the April 1982 calibration tests. The results for both familiar and novel sentences are shown. With the exception of the three cases in Table 8 in which the sample size was only one or two sentences, all of the obtained numbers of correct responses were

Table 8. *Results of April, 1982 calibration test: Semantically reversible sentences given Phoenix and Akeakamai*

Sentence type	Sentence status	Unique sentences	Sentence errors	Percent correct	Element error[a]					Mult. error[b]	Rev. error[c]
					M	DO	A	M	IO		
Phoenix											
DO + *A* + IO	Familiar	16	0	100.0	–	0	0	–	0	0	0
	Novel	4	1	75.0	–	1	0	–	0	0	0
	Both	20	1	95.0	–	1	0	–	0	0	0
DO + *A* + M + IO	Familiar	0	–	–	–	–	–	–	–	–	0
	Novel	24	8	66.7	–	1	1	8	4	4	0
	Both	24	8	66.7	–	1	1	8	4	4	0
M + DO + *A* + IO	Familiar	14	2	85.7	2	1	1	–	1	1	0
	Novel	14	3	78.6	1	2	0	–	0	0	0
	Both	28	5	82.1	3	3	1	–	1	1	0
M + DO + *A* + M + IO	Familiar	31	6	80.6	2	0	0	5	1	2	1
	Novel	25	10	60.0	1	2	1	8	6	7	0
	Both	56	16	71.4	3	2	1	13	7	9	1
All	Familiar	61	8	86.9	8.9	1.6	1.6	16.1	3.3	3	1
	Novel	67	22	67.2	5.1	9.0	3.0	32.7	14.9	11	0
	Both	128	30	76.6	7.1	5.5	2.3	26.3	9.4	14	1
Akeakamai											
IO + DO + *A*	Familiar	28	12	57.1	–	1	0	–	11	0	0
	Novel	2	2	0.0	–	0	0	–	2	0	0
	Both	30	14	53.3	–	1	0	–	13	0	0
M + IO + DO + *A*	Familiar	1	0	100.0	–	0	0	0	0	0	0
	Novel	19	6	68.4	–	1	2	4	6	4	0
	Both	20 (60)	6	70.0	–	1	2	4	6	4	0
IO + M + DO + *A*	Familiar	2	0	100.0	0	0	0	–	0	0	0
	Novel	17	8	52.9	5	1	0	–	6	3	0
	Both	[illegible] (60)	8	57.9	5	1	0	–	6	3	0
All	Familiar	31	12	61.3	0.0	3.2	0.0	0.0	35.5	0	0
	Novel	38	16	57.9	29.4	5.3	5.3	21.1	36.8	7	0
	Both	69 (150)	28	59.4	26.3	4.3	2.9	20.0	36.2	7	0

Note. M = Modifier; DO = Direct Object; *A* = FETCH action; IO = Indirect Object. Numbers in parentheses are the total unique sentences available and are given only for those cases in which less than the total was tested.

[a]Number of errors in each semantic category except for 'All' which gives the percentage of errors calculated by dividing the total of errors in that category by the number of sentences containing that category and multiplying by 100.

[b]Indicates the number of sentences on which errors occurred to more than one semantic element.

[c]Indicates the number of sentences on which there was a reversal of response to the specified direct and indirect objects, such that the indirect object was transported to the direct object.

highly significant ($p < 0.0001$). For the three cases noted of extremely small numbers of sentences, the percentage of correct responses was nevertheless significant in two cases ($p < 0.001$) and not significant, of course, for the remaining case in which both sentences given were responded to incorrectly.

As was true for Tables 6 and 7, performance on novel sentences was consistently below that for familiar sentences, although comparisons remain restricted in some cases by the small sample size. The only significant elevation of performance on familiar sentences relative to novel ones was for Phoenix, for all sentences combined ($z = 2.40, p < 0.05$). Overall, the results demonstrate significant levels of proficiency, relative to chance levels, in the execution of the novel (and familiar) semantically reversible sentences. It is important to stress once again that reversal errors—reversing the roles of direct and indirect object during transport—were extremely rare: only one such error for Phoenix in the total of 130 semantically reversible sentences given her and none for Akeakamai over her 69 semantically reversible sentences. These data add to those of Table 5 and evidence the dolphins' ability to use word order to determine meaning.

In summary, over the period of this study there have been substantial increases in the size of the corpus of sentences available to the dolphins and in the types of sentences generated. This has been accomplished with little or no reduction in overall performance levels. Not apparent from the numerical results is the greatly increased generalization that has taken place with respect to objects, actions, and context, and the increased difficulty of choices for the dolphins owing to the continuous availability of many more objects for response. Also not apparent from the results is the proficiency of the dolphins in carrying out instructions while searching for freely drifting objects, perhaps the most difficult non-language cognitive task in the present research, and one which finds no parallel in the chimpanzee language projects.

Alternatives to FETCH: ERASE and IN

FETCH and IN express relationships between objects; respectively, these words connote "take to" and "put in or on". Both dolphins had been exposed to the FETCH word throughout a major portion of their training. Their ability to utilize this word effectively has been documented extensively in the previous sections. To study the ability of the dolphins to understand an alternative relational form, the word IN was recently introduced into the vocabulary. Akeakamai received training first and was the subject of the study reported here. Phoenix's training is still underway.

In brief, the training for Akeakamai first introduced the word ERASE as a substitute for any action word, with the goal of it being an alternative to FETCH in Indirect Object + Direct Object + FETCH sentences. Since FETCH had been the only word appearing after an Indirect Object + Direct Object sequence, Akeakamai often did not attend to the terminal FETCH gesture, as if realizing its redundancy. Typically, she began her response immediately after seeing the gesture for the direct object. ERASE may be interpreted as meaning "Stop" or "Disregard the previous words." When ERASE appears, a correct response is to remain at station or, if in the act of leaving, to return immediately. ERASE was initially taught alone, then incorporated into 2-word sentences of the form Direct Object + ERASE, and finally used in 3-word sentences of the form Indirect Object + Direct Object + ERASE as well as in 4-word sentences of the form Modifier + Indirect Object + Direct Object + ERASE. During this training, Akeakamai was tested with several novel sentences employing ERASE, including one 2-word sentence (FRISBEE ERASE), four 3-word modifier sentences (Modifier + Direct Object + ERASE), five 3-word sentences of the type Indirect Object + Direct Object + ERASE, and two 4-word sentences of the type Modifier + Indirect Object + Direct Object + ERASE. All testing was in the Class A format described earlier and only a single error was made over these 11 sentences (taking the surfboard to the speaker when given SPEAKER SURFBOARD ERASE). With this training, ERASE achieved the desired effect of requiring Akeakamai to attend to the terminal word of sentences having an earlier sequence of Indirect Object + Direct Object.

With ERASE successfully in the vocabulary, and Akeakamai now attending to all action words, it was possible to teach IN. To complete a successful IN response the dolphin must search for and take the designated direct object, transport it to the designated indirect object, and then raise the direct object up and into or onto the indirect object. In contrast, the FETCH response requires that the dolphin transport the direct object to the side or underside of the indirect object, without any attempt to raise it above the indirect object, so that the FETCH response may be clearly distinguished from the IN response. For the first stage of training, IN was used alone, and Akeakamai was allowed a free choice of direct and indirect object. After she learned to respond reliably to IN as a single word, Akeakamai was tested in the Class A format with the 3-word novel sentence BASKET HOOP IN ("put the hoop in the basket") to which she responded correctly and without hesitation. Correct performance on this first presentation represented a remarkable conceptual leap from a single word to a full 3-word relational sentence.

Table 9 shows the results of a test of Akeakamai's responses to corresponding FETCH and IN sentences. The test was carried out over a six-day period

Table 9. *Responses of Akeakamai to corresponding FETCH and IN sentences*

Sentence given	Response	Sentence given	Response
BASKET BALL FETCH	+	BASKET BALL IN	+
BASKET FRISBEE FETCH	+	BASKET FRISBEE IN	+
BASKET HOOP FETCH	(NET HOOP FETCH)	BASKET HOOP IN	+
BASKET PIPE FETCH	+	BASKET PIPE IN	(SFBD PIPE IN)
*BASKET NET FETCH	(BASKET SRFBD FETCH)	*BASKET NET IN	(NET HOOP IN)
NET BALL FETCH	(NET BALL IN)	NET BALL IN	+
NET FRISBEE FETCH	+	NET FRISBEE IN	(SPEAKER FRISBEE IN)
NET HOOP FETCH	+	NET HOOP IN	(NET HOOP FETCH)
NET PIPE FETCH	+	NET PIPE IN	+
NET BASKET FETCH	+	NET BASKET IN	(BASKET BALL IN)
SRFBD FRISBEE FETCH	+	SRFBD FRISBEE IN	+
SRFBD HOOP FETCH	+	*SRFBD HOOP IN	+
Percent correct:	75.0		58.3
No. IO errors	1		4
No. DO errors	1		2
No. Action errors	1		1

Note. A wholly correct response is indicated by +. Error responses are shown in parentheses. SRFBD = SURFBOARD; IO = Indirect object; DO = Direct object.
*Novel sentence.

in April 1983. At each of two daily sessions, one of the FETCH sentences and one *noncorresponding* IN sentence (e.g., BASKET BALL FETCH *versus* NET PIPE IN) appeared within a block of 16 sentences of various kinds. Either the FETCH or the IN sentence appeared within the first eight sentences given, and the remaining type within the second eight sentences. The order of appearance of FETCH and IN sentences was counterbalanced over sessions. The location at which the FETCH or IN sentence appeared within the series of sentences given at a session was determined by a random schedule with the constraint that there be a minimum of three 'distractor' sentences between the pair—e.g., if one sentence was the eighth item in the list the other sentence could occur no sooner than the twelfth item. The schedule of sentences was constructed so that no word of the particular FETCH or IN sentence appeared during the previous three sentences. The responses of the dolphins were judged by the blind observer technique described for earlier tests and all responses were videotaped.

Table 9 shows that Akeakamai responded wholly correctly to 9 of 12 FETCH sentences and to 7 of 12 IN sentences. Her performance on the FETCH sentences (75% correct) was superior to the levels attained during the calibration testing approximately one year earlier (Table 7). Her performance on IN sentence did not differ significantly from that on FETCH sentences ($z = 0.42$, $p > 0.05$). Importantly, there was only one confusion of FETCH for IN and one confusion of IN for FETCH throughout the total of 24 sentences. Clearly, the relational differences implied by the two words were well understood.

Before this test, Akeakamai had not transported the net to another object. Originally, the net was fixed to the side of the tank and was relocatable only by the trainers. Only recently, it was permitted to float free and thus be transportable by the dolphins. Akeakamai's errors on BASKET NET FETCH and on the corresponding BASKET NET IN, both novel sentences, and both requiring a transport of the net, may reflect this lack of experience or expectation for transporting the net. We have since demonstrated that with additional training Akeakamai will in fact reliably transport the net to other objects. Interestingly, the one remaining novel sentence in this series, SURFBOARD HOOP IN, which requires that the floating hoop be carried to and placed on top of the surfboard, was executed perfectly. Akeakamai has, of course, transported a hoop on many prior occasions.

In summary, this brief study has demonstrated that there is no necessary restriction of the relational properties between objects to simple transport responses. In spite of extensive prior practice with the fetch response, a second contrasting relational response was quickly learned and incorporated into the existing lexicon and syntactic rules.

Semantic processing and symbolic representation

An important issue in assessing the linguistic competency of apes has been whether the symbols used in the languages taught take on referential qualities. Do the symbols come to represent objects or events in the real world or are they merely convenient nonlinguistic devices that allow the apes to obtain reward? Savage-Rumbaugh and her colleagues (Savage-Rumbaugh and Rumbaugh, 1978; Savage-Rumbaugh *et al.*, 1980) have shown that reference may not develop without the application of special, intensive training procedures that emphasize the varied, functional use of the symbols. Here, we provide examples and data that bear on whether the symbols used in our languages have taken on referential qualities for the dolphins. Specifically discussed are semantic generalization, context generalization, displacement, and the dolphins' ability to report that specified objects are absent from their tank.

Semantic generalization

Two forms of semantic generalization were identified in this study. One was the extension of an object word learned with respect to one exemplar of a class of objects to other exemplars of that class. The second was the extension of an action word, learned with respect to a particular object, or within a limited context, to other objects and contexts. Both types of semantic generalization were shown by both dolphins, but the second type—the generalization of an action word—is perhaps the more interesting of the two.

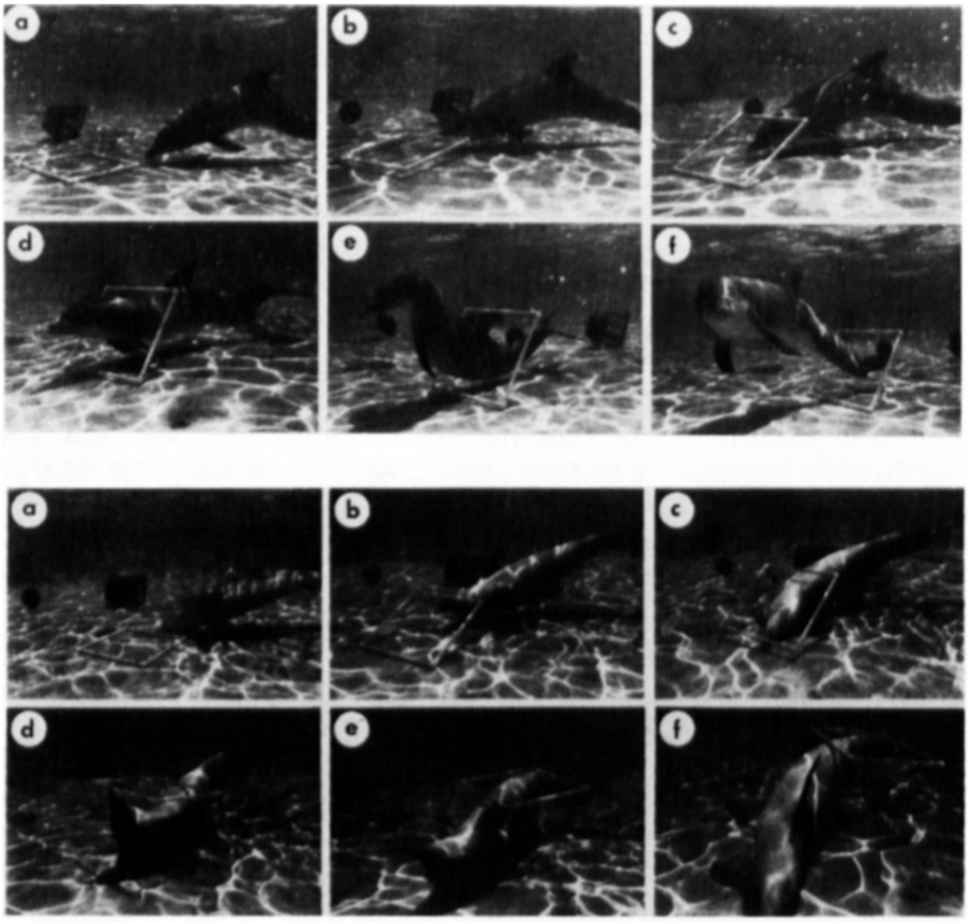
Semantic generalization of an object word across a class of objects was a normal event in our study as part of the established training procedures. Thus, the word HOOP was taught with respect to a particular, large octagonal hoop constructed of plastic pipe. This design proved easy for the dolphins to demolish so a large square hoop was substituted, without any decrement in performance. Similarly, small hoops, large hoops of much thicker pipe than those used previously, hoops of dark colored pipe as well as white pipe, and hoops that sank to the bottom of the tank instead of floating, were introduced. In all cases, these hoops were responded to immediately when a sentence containing the word HOOP was given. There were always additional named objects present in the tank, when new hoops were introduced. Every object we used initially has undergone some change, because of wear and tear, because of a new program goal that required some modification (e.g., construction of objects that sank to the bottom), or because of a deliberate choice by us to vary objects. The word PERSON is an interesting case of semantic generalization. Originally, PERSON was taught relative to one particular individual, a trainer named Cathy, who held her arm in the water. The dolphins responded to Cathy's arm when given an instruction containing PERSON, e.g., touching her arm with the tail when given the sentence PERSON TAIL-TOUCH. Later, without any specific training, we demonstrated that a leg in the water, an elbow, or the whole person floating in the water would do as well as an arm for eliciting a response to PERSON. Still later, and again without specific training, both dolphins immediately responded correctly to a second person who was arbitrarily chosen and then to any person at all.

Another interesting example of the generalization of meaning across objects of a class occurred recently when Akeakamai was taught the word WINDOW, a reference to any of four underwater windows spaced evenly about the tank. To teach WINDOW a particular one of the four windows was chosen and Akeakamai's station was moved nearby that window. Akeakamai learned WINDOW within a single session, as judged by her reliable response to the particular window when given the sentences WINDOW MOUTH or WINDOW PEC-TOUCH embedded randomly within a string of other sentences not containing WINDOW. Two sessions later, Akeakamai was moved to another station that was distant from the training window and half-way between two other windows. In response to the first WINDOW sentence given from this station, Akeakamai immediately swam to the window to her left. Later in the session she was given a second window sentence and chose the window to her right. When her station was moved once again, she immediately went to the most convenient window of the four. Hence, although we taught WINDOW in reference to a particular window, Akeakamai immediately generalized the name to all other windows in the tank.

Extension of responses to action words were almost always immediate. At the earliest stage of training, when we were using only single action words and objects were not yet named, any arbitrary familiar or novel object thrown in the tank was responded to appropriately when the dolphins were given an action word. This generalization of action words continued throughout the later stages of training. Thus, Phoenix was taught THRU using the object HOOP and the sentence HOOP THRU. Later, when the novel sentence GATE THRU was given, Phoenix immediately swam through the open gate in her tank. Later, the sentence GATE THRU was given for the first time with the gate closed. In response, Phoenix swam to the gate, hesitated, then pushed it open and swam through. Still later, after the modifiers SURFACE and BOTTOM had been taught using a variety of objects, the novel sentence BOTTOM HOOP THRU was given. A weighted hoop was lying flat on the bottom of the tank and a bouyant hoop was suspended vertically near the surface. Phoenix swam to the bottom hoop, probed under it with her rostrum until one side was lifted off the tank floor and the hoop was nearly vertical, and then swam through for a correct response. Figure 8, top series, illustrates this now typical response of Phoenix to the sentence BOTTOM HOOP THRU.

A similar test was later made of Phoenix's response to the novel sentence BOTTOM HOOP UNDER. Phoenix's characteristic response to UNDER is to swim beneath the specified object belly up (in contrast, Akeakamai swims under objects dorsal up). On approaching the bottom hoop, Phoenix turned belly up, raised one side of the square hoop off the bottom with her rostrum, and proceeded to swim under it belly up. However, she in fact swam *through* the partially raised hoop and was not reinforced. At a second trial of BOTTOM HOOP UNDER, given later in that same session and without any intervening training, Phoenix raised both sides of the hoop off of the bottom and succeeded in swimming completely under the hoop belly up. Figure 8,

Figure 8. *Examples of responses that were generalized spontaneously by Phoenix with no special training.* Top: *Phoenix responding to the sentence BOTTOM HOOP THRU. (a) Approaching the hoop that is lying flat on the tank bottom—the BOTTOM BASKET is visible, as is the SURFACE HOOP; (b) probing under edge of hoop with rostrum to begin lift—BOTTOM FRISBEE visible; (c)–(f) hoop raised to near-vertical position allowing Phoenix to swim through it.* Bottom: *Phoenix responding to the sentence BOTTOM HOOP UNDER. (a) Lifting edge of hoop while in semi-inverted posture—Phoenix almost always goes under objects belly up. BOTTOM FRISBEE and BOTTOM BASKET are visible; (b)–(f) using her rostrum to move the hoop in a horizontal position along her body, Phoenix continues her inverted swim while passing completely under the hoop. The top sequence was approximately 7 seconds in duration and the bottom sequence approximately 10 seconds. Timing was as in Fig. 7.*



bottom series, illustrates this now typical response of Phoenix to the sentence BOTTOM HOOP UNDER. These observations demonstrate that THRU and UNDER were very general concepts for the dolphins and reveal the assertiveness of the dolphins in manipulating their tank world in order to achieve these desired actions.

Other actions to bottom objects were similarly generalized spontaneously. For example, in response to a sentence involving a bottom object and the action TOSS, e.g., BOTTOM PIPE TOSS, Phoenix brings the specified object to the surface and then tosses it into the air. This was an untaught response and may have developed spontaneously as a generalization of the previously learned tossing of floating objects, or it might have reflected the fact that underwater tosses are not rewarded because they cannot be detected by an observer. Also, when asked to spit at a bottom object, e.g., BOTTOM PIPE SPIT, Phoenix spits in air directly over the specified object. Underwater spitting, like tossing, is not observable by us.

During experimentation with some unusual syntactical arrangements, we noted additional cases of spontaneous action generalization. We presented to Phoenix the sentences FRISBEE FETCH THRU HOOP and FRISBEE FETCH UNDER HOOP. In each case, Phoenix swam to the frisbee, carried it on her rostrum to the hoop, and then swam with it through the hoop (first case) or under the hoop (second case). Also, in the initial presentation of FRISBEE FETCH THRU GATE, Phoenix took the frisbee through the gate rather than touching the frisbee to the gate as in her typical response to the sentence FRISBEE FETCH GATE.

Several examples demonstrate that, Akeakamai, like Phoenix, was proficient at extending old responses to new situations. The action OVER was difficult to perform when an object had drifted too close to the tank wall. Akeakamai (as well as Phoenix) pushed any object away from the wall, and away from any other nearby objects before attempting to leap over it. She also pushed objects out from beneath the low overhanging wooden outriggers that project over the tank before attempting to leap over the objects. An additional example occurred with the action TOSS, which was trained as a toss of any dolphin-transportable object. During a study of the dolphins' responses to anomalous sentences (Herman *et al.*, Reference Note 1) we gave the sentence WATER TOSS. We considered the sentence to be semantically anomalous, since the stream of water flowing from the suspended hose was nontransportable and hence, we believed, not tossable. Akeakamai, however, went to the water stream and jerking her head rapidly through it, sent out a large spray of water. The blind observer immediately labeled the behavior "WATER TOSS." Phoenix was later tested with the same sentence and performed exactly as did Akeakamai.

Training of the word IN was discussed in the previous section. During the very early training, an interesting untrained generalization of IN occurred spontaneously. For the first time, Akeakamai was given the instruction IN with the ball already in the basket and no other object or receptacle available. Akeakamai reached into the basket with her mouth, took the ball out, retreated a short distance, and then swam back and replaced the ball in the basket. This response demonstrated the spontaneous extension of the concept IN to include the necessity of having the object outside of the receptacle before putting it in.

Context generalization and displacement
Context generalization refers to the dolphins' ability to extend the training context to new situations, including new training sites and new locations or arrangements of objects. As was described in the Methods section, context generalization, like some forms of object generalization, was a general feature of our training procedures. Both dolphins progressively increased the generality of their understanding of the training context to include the completely variable positions of transportable and relocatable objects, as well as their own changes in location when the training stations were changed. It was still technically possible, however, for the dolphins to encode objects in terms of their spatial locations immediately prior to an instruction. To increase the generality of the concept of 'object' as a set of distinctive features or attributes, and to discourage the encoding of objects strictly by their spatial locations, at times we moved objects to hidden locations in the tank (spatial 'displacement'). This necessitated the development of search strategies based on nonspatial attributes of objects, as demonstrated by the ability of the dolphins to receive a sentence, conduct a successful search for the designated hidden object, and carry out the designated response to it.

Later, during temporal displacement procedures, we gave the dolphins Object + Action sentences involving transportable objects, with no transportable object present in the tank at the time of instruction. Immediately after a sentence was given, seven transportable objects were thrown into the tank at once by four tankside assistants, with one assistant located at each quadrant of the tank. The assistants, crouched behind the tank wall, remained hidden from the dolphins' view until signalled to throw in the pre-designated objects. Each assistant threw in either one or two objects and no assistant had knowledge of which object would be specified by the sentence. The locations of assistants were changed at each trial as were the objects assigned to the individual assistants. The correct object, the one specified by the 2-word sentence, appeared with nearly equal frequency at each quadrant; the probability of a correct chance response to an object was approximately 0.14. In tests using these displacement procedures and scored by the blind-observer technique, Akeakamai and Phoenix achieved identical scores of 81.4% correct responses to the 43 2-word sentences that each was given ($p < 0.001$, summed binomial distribution test). Akeakamai was subsequently tested using extended displacement procedures in which the delay between the end of a 2-word Object + Action sentence and the appearance of the objects in the tank was either 0, 7, 15, or 30 seconds. There was also a control condition in which the objects were introduced just before the sentence was given. A total of 75 trials was given, with each delay condition and the control condition tested 15 times, in balanced blocks of 5 trials. The ordering of the 5 conditions was balanced across blocks. The procedures were identical to those described for the earlier displacement test, except that 49 unique 2-word sentences were used across the 75 trials, so that some sentences appeared twice, widely separated by intervening sentences. The results were that Akeakamai made no errors at all in the control condition or in the 0-second delay condition. She made one error each at the 7-second and 15-second delay condition (= 93.3% correct responses), and five errors at the 30-second delay condition (= 66.7% correct responses, $p < 0.001$ by summed binomial distribution test). Overall, Akeakamai made 90.7% wholly correct responses. At the 30-second delays, her errors were all the choice of incorrect object, while executing the correct (specified) action.

Reporting absent objects

During the testing of responses to anomalous sentences (Herman *et al.*, Reference Note 1) Phoenix and Akeakamai were both given three 'probe' sentences in which all of the named objects, except for one, were present in the tank at the time of instruction. The 'missing' object was then referred to in a 2-word sentence. Akeakamai searched for up to 55 seconds and Phoenix for up to 38 seconds for the missing object, then each spontaneously returned to her trainer without performing any named action. Encouraged by this seeming ability to report the absence of an object, as well as to act appropriately on one that was present, we formalized the 'reporting' procedure. Using Akeakamai as subject, we introduced a distinctive 'NO' paddle at tankside. We taught her to press this paddle when we pointed at it. Taking advantage of her already established tendency to report back to her station on not finding a designated object, we then gave her a sentence in which only the named object was absent from the tank. Akeakamai conducted a search and again reported back to her station spontaneously. Her trainer then pointed at the nearby NO paddle. Akeakamai immediately pressed the paddle and was rewarded. That was the extent of training necessary; during subsequent NO paddle probes, only a single prompt was necessary. Over the next several months, one or two missing-object probes were inserted into blocks of 16 regular trials. These probes were all 2-word sentences instructing Akeakamai to take some action to an object not present in the tank (all objects but the one specified were present). Of a total of 115 such probes given, in which the missing object was randomly any of nine named objects that could be removed from the tank, Akeakamai correctly pressed the NO paddle on 93 trials (80.9% correct responses, $p < 0.001$). Her average search time before pressing the NO paddle was 15.0 seconds. On the 22 error trials, Akeakamai performed the designated action to an alternate object that was present in the tank. The 81% correct-performance level greatly exceeded the chance level of 11.1%, although it was below the 94% level for 2-word sentences that Akeakamai achieved during the calibration test (Table 7). The lowered performance level on the missing-object task may reflect some forgetting of the referents during the extended search process, similar to the effect of delay noted during the extended displacement tests. Also, the missing-object task, an 'if–then' paradigm, ought to impose a greater conceptual burden on the dolphin than does the normal paradigm in which all objects are present and the NO paddle is not in the tank. That is, the missing-object task requires that the dolphin carry out the specified instruction if the named object is present; if that object is absent, then the task requires that the dolphin report the absence by pressing the NO paddle.

The results of the displacement procedures, and of the NO-paddle paradigm, demonstrate the ability of the dolphin to understand references to objects not within its immediate perceptual field. This is a first approximation to the displacement characteristic of human language (Hockett, 1960). Additionally, both procedures suggest that the object names had acquired strong referential qualities, since they produced searches for the particular object specified by the symbol or sign. These searches could be carried out successfully only if the symbols or signs referenced the attributes or features of the object. The examples given of generalization of object attributes across different exemplars and across different situational contexts adds to the evidence for the referential qualities of the symbols.

Preliminary tests of understanding of additional linguistic features

Recursion

Recursive rules are a property of all natural languages and, in principle, allow for the generation of an infinite set of sentences. An important type of recursive rule involves the conjoining of sentences. In phrase-structure grammar this would be expressed as a rewrite rule in which a sentence is rewritten as a sentence plus an optional sentence [S → S (and S), where S stands for sentence]. The optional sentence may recur any number of times, e.g., S → S and S (and S). As a first approximation to testing the dolphins' understanding of recursive rules, we simply generated a set of two conjoined sentences and observed whether the dolphin provided multiple appropriate responses.

Phoenix was chosen as subject for this test, and a set of conjoined sentences was given to her without any specific training or instruction. Two forms of conjoined sentence were used: (*a*) PHOENIX + Object + Action + Object + Action, and (*b*) PHOENIX + Object + Action + PHOENIX + Object + Action. The word PHOENIX normally prefaces all sentences given to Phoenix, but is not counted in enumerating the number of words in a sentence. In the first case (Type *a*), PHOENIX does not preface the second sentence of the conjunctive pair, but in the second case (Type *b*), it does. The word PHOENIX is also used after an incorrect response to a sentence to call Phoenix back to her station. Hence, its use in Type *b* sentences may be ambiguous: it may be interpreted as a prefix to the second sentence of the pair, or as a terminator of an incorrect response to the first sentence.

A conjoined sentence was inserted into a block of 16 normal sentences that represented all or nearly all of the syntactic forms in the language (Table 2). The 'Class A' procedures described earlier for testing responses to novel sentences were used here also. As usual, a videotape record was made of the dolphin's responses. The blind observer's task was to label the responses of the dolphin, including multiple responses if they occurred. One conjoined sentence, or occasionally two, was inserted at random locations into a block of 16 regular sentences. Within all sentences, the successive object names were the same, but the actions were different. Successive words were separated from one another by the usual 0.25-second silent interval. Phoenix was allowed approximately 30 seconds to complete her response to conjoined sentences unless she terminated responding earlier.

Table 10 shows the 15 conjoined sentences given and the labels assigned to Phoenix's responses by the blind observer. The first eight conjoined sentences were all Type *a*. Phoenix performed the two designated actions in six of these eight cases. In a seventh case, PHOENIX HOOP MOUTH HOOP TAIL-TOUCH, the videotape record suggested that the first designated action MOUTH indeed occurred, ut the blind observer was uncertain of the classification of the response, as it was made underwater and was partially obscured by the surfboard. After the tail-touch response, and after some delay, Phoenix also touched the hoop with her pectoral fin. In the final case of the eight, PHOENIX HOOP TAIL-TOUCH HOOP TOSS, only the first action was carried out, repeatedly. No tossing component appeared.

The last seven conjoined sentences were all Type *b*. Repeating the word PHOENIX led to some interesting behaviors. For any sentence, regular or

Table 10. *Responses of Phoenix to conjoined sentences*

Sentence given	Blind-observer report (= dolphin's response)	
Type A		
PH HOOP MOUTH HOOP TAIL-TOUCH	?+	HOOP ??; HOOP TAIL-TOUCH ... HOOP PEC-TOUCH. Video shows apparent MOUTH response during "HOOP ??"
PH PIPE TAIL-TOUCH PIPE OVER	++	PIPE TAIL-TOUCH; PIPE OVER
PH PIPE OVER PIPE TOSS	++	PIPE OVER; PIPE TOSS
PH SRFBD TOSS SRFBD OVER	++	SRFBD TOSS; SRFBD OVER
PH HOOP TAIL-TOUCH HOOP TOSS	+−	HOOP TAIL-TOUCH (repeatedly)
PH SRFBD OVER SRFBD TAIL-TOUCH	++	SRFBD OVER; SRFBD TAIL-TOUCH
PH WATER TOSS WATER TAIL-TOUCH	++	WATER TOSS; WATER TAIL-TOUCH; (sequence spontaneously repeated again)
PH BASKET TOSS BASKET OVER	++	BASKET TOSS; BASKET OVER
Type B		
PH HOOP OVER PH HOOP TOSS	?++	HOOP TOSS; HOOP OVER (*reverse* sequence to instruction)
PH BASKET TAIL-TOUCH PH BASKET UNDER	+?	BASKET TAIL-TOUCH; Phoenix then inverted as she normally does when swimming under object, and touched basket again with tail
PH FRISBEE UNDER PH FRISBEE TOSS	++	FRISBEE UNDER; FRISBEE TOSS
PH WATER UNDER PH WATER OVER	?++	WATER MOUTH; WATER OVER (repeated OVER)
PH SRFBD TOSS PH SRFBD TAIL-TOUCH	++	SRFBD TOSS; SRFBD TAIL-TOUCH
PH PIPE TAIL-TOUCH PH PIPE TOSS	−+	PIPE TOSS (repeatedly)
PH PERSON OVER PH PERSON TAIL-TOUCH	+−	PERSON OVER

Note. Sentences are listed in the order given. PH = PHOENIX; SRFBD = SURFBOARD. Scoring key: ++, Both responses executed correctly; +−, First action executed, but not second; −+, Second action executed, but not first; a ? in place of a + or − indicates scoring uncertainty; a ? preceeding two elements indicates special case (reverse sequence; or, two actions performed, but one of the actions was not specified in the sentence).

conjoined, Phoenix typically begins responding while the sentence is still being presented. In response to the first Type *b* sentence, PHOENIX HOOP OVER PHOENIX HOOP TOSS, Phoenix swam toward the hoop on hearing PHOENIX HOOP OVER, aborted (turned away) on hearing the second PHOENIX, but returned on hearing HOOP TOSS. She tossed the hoop a short distance and then repeatedly jumped over it. (From its start to finish, the indicated conjoined sentence played for 7.25 seconds.) In response to the next conjoined sentence, PHOENIX BASKET TAIL-TOUCH PHOENIX BASKET UNDER, Phoenix appeared to give a conjoined response, by touching the basket with her tail flukes while in an inverted position. Phoenix always swims under an object inverted (belly up). On the remaining five conjoined sentences, Phoenix performed the designated two actions in two cases, and also performed two actions in a third case, but the first action was not the one designated. On the final two sentences given, Phoenix performed only a single response. In one case, it was the second action designated, and in the other case, it was the first action designated.

In summary, the results show that in the majority of the cases Phoenix responded to two conjoined sentences requiring that two responses be performed to a designated object, by performing two responses to that object. Performance was most stable when the sentences were joined without repeating her name, yet Phoenix could respond appropriately under either condition. Although she tends to attempt to execute a sentence in linear order, as it unfolds, this was not a necessary strategy for Phoenix. Thus, in one case she executed the designated actions in the reverse order of their occurrence in the conjoined sentence, and in another case repeated the correct sequence of two responses twice. In a third case, she appeared to combine the two actions into a novel single joint response. Hence, the semantic intent of the entire conjoint sentence appeared to be understood in these cases. In the very first Type *b* sentence given, the reappearance of PHOENIX caused a temporary abort response. The meaning of PHOENIX was then apparently reinterpreted as a sentence initiator in the context of the remainder of the string, as Phoenix then returned and completed the designated action. In only one other Type *b* sentence did the reappearance of PHOENIX lead to an apparent aborting of response. When given PHOENIX PIPE TAIL-TOUCH PHOENIX PIPE TOSS, Phoenix failed to carry out the first named action, limiting her response to tossing the pipe repeatedly. The reappearance, then, of the word PHOENIX seemed at times to disrupt Phoenix's processing of the conjoint sentence, and possibly led to multiple interpretations of the intent of those sentences.

Further study of responses to conjoined sentences is indicated, including sentences in which the object names vary, instead of or in addition to varying the action names. In the earlier section on semantic generalization we reported that Phoenix spontaneously responded appropriately to the linking of actions in the structurally novel sentences FRISBEE FETCH THRU HOOP, FRISBEE FETCH UNDER HOOP, and FRISBEE FETCH THRU GATE. These latter results, together with the results reported here for conjoined sentences, are sufficient to illustrate that the responses of the dolphins are not constrained to the sentence forms illustrated throughout most of this paper, but may be extended to include appropriate responding to recursive forms including conjoined constituents and conjoined sentences. It is worth noting, also, that the presence of a modifier slot allows for recursion in that, in principle, multiple modifiers could be used before an object name to create sentences having an indefinitely long number of words. At present, the modifiers for each dolphin are restricted to one mutually exclusive pair, so that additional modifiers would have to be taught to each dolphin to explore this recursive potential of the language.

Nonlinear characteristics of language processing

To understand complex sentences in natural languages, it is often necessary to interpret or reinterpret the meaning or function of earlier words in a sentence on the basis of a word or words occurring later in the sentence (Lashley, 1951; Chomsky, 1957). In the inverse grammar of Akeakamai's language the function of the first object word in a sentence—as indirect object or as direct object—cannot be determined until a succeeding word or words occur. If the immediately succeeding word is an action, then the first object word functions as direct object. If the succeeding word is an object word, or a modifier followed by an object word, then the first object word functions as indirect object. In the latter case, the occurrence of FETCH or of IN as the terminal word confirms the function as indirect object. In contrast, the occurrence of ERASE cancels all functions.

Here, we studied nonlinear processing further by testing Akeakamai's responses to 3-word anomalous sentences constructed as Object + Object + Action, but using an action word that takes only a direct object (e.g., OVER or SPIT) rather than the expected FETCH or IN that take both direct and indirect object. Sentences of this type are anomalous in that the occurrence of the second object name implies that the function of the first object name is as indirect object, but the terminal action word neither confirms that interpretation nor cancels the sentence. How Akeakamai operates on the anomalous sentences would be instructive of her ability to reinterpret the meaning of an early word in the sentence on the basis of a later occurring *nonadjacent* word.

The procedures used paralleled those described for testing conjoined sentences with Phoenix. A single anomalous probe was inserted into a block of 16 normal sentences in a context-free manner. A blind observer labeled Akeakamai's responses. Table 11 shows the 12 probe sentences given and the labels applied to Akeakamai's responses by the blind observer. The labels describe the responses fully. In all but one case, Akeakamai responded to the anomalies by rejecting any response to the first object word and operating on the remaining two words as a legitimate Object + Action segment. For example, when given WATER HOOP TAIL-TOUCH, she swam to the hoop and touched it with her tail flukes. She made no attempt to carry the hoop to the stream of water, or to otherwise respond to the water. The one exception to the pattern was the response to SURFBOARD BALL TOSS. Here, Akeakamai began her response by tossing the ball energetically, but then took it to the surfboard and attempted to place it on top. The blind observer labelled the behavior SURFBOARD BALL IN. Overall, these results evidenced Akeakamai's ability to process a sentence by interpreting and reinterpreting early words as a consequence of either adjacent or nonadjacent words occurring later in the sentence. This illustrates clearly Akeakamai's ability to process a sentence by other than sequential left-to-right strategies.

Table 11. *Responses of Akeakamai to anomalous sentences of the form Object + Object + Action, where the action takes only a direct object*

Sentence given	Blind-observer label (response)
WATER HOOP TAIL-TOUCH	HOOP TAIL-TOUCH
PERSON PIPE PEC-TOCH	PIPE PEC-TOUCH
SURFBOARD BALL TOSS	(SURFBOARD BALL IN)
SURFBOARD BASKET TOSS	(NET TOSS)
NET FRISBEE OVER	(PIPE OVER—then FRISBEE OVER repeatedly)*
HOOP SURFBOARD UNDER	SURFBOARD UNDER
WATER BALL MOUTH	BALL MOUTH
BALL HOOP PEC-TOUCH	HOOP PEC-TOUCH
PIPE NET SPIT	NET SPIT
PHOENIX FRISBEE TAIL-TOUCH	FRISBEE TAIL-TOUCH
FRISBEE PIPE UNDER	PIPE UNDER
BASKET SURFBOARD OVER	SURFBOARD OVER

Note. Sentences are listed in the order given.
*Leaped over the pipe while swimming towards the frisbee.

General discussion

As emphasized in the introduction to this paper, the key issue addressed by this study was sentence processing ability. We stressed the understanding of sentences rather than the ability to produce sentences. The work in teaching language to apes has focused mainly on production and has not resolved the issue of the ability of these animals to process sentences. Indeed, there are strong claims that apes have not demonstrated this linguistic essential, in either the production or comprehension mode (e.g., Bronowski and Bellugi, 1970; Savage-Rumbaugh *et al.*, 1980; Seidenberg and Petitto, 1979, 1981; Terrace, 1979; Terrace *et al.*, 1979). In contrast, the evidence presented in this paper affirms that dolphins are able to understand sentences, as expressed within the grammar of the artificial acoustic or gestural language taught to them. Whether a dolphin can also "create a sentence" (cf. Terrace *et al.*, 1979) is an empirical issue that can be resolved only by further direct work on language production (see Richards *et al.* (1984) for a start in this direction).

The major points of evidence for the understanding of sentences by the dolphins are reviewed in the following sections. Where feasible, comparisons are made with findings from the teaching of languages to apes, and with findings from studies of the understanding of languages by children.

Lexical novelty

Of paramount importance to the demonstration of sentence understanding was the ability of both dolphins to respond correctly to novel sentences drawn from all of the sentence forms shown in Table 2. Premack (1976) has described this insertion of new lexical items into familiar sentence frames as lexical novelty. We noted that the understanding and use of novel sentences was considered a hallmark of human language ability. The dolphins responded wholly correctly to the bulk of the well over 100 novel sentences that each was given. The sentences ranged in length from two to five words and were of a variety of syntactic forms. There were no redundant elements (except possibly for the word FETCH prior to the introduction of ERASE or IN), no 'stock' phrases (cf. Rumbaugh, 1977; Thompson and Church, 1980), and chance performance levels were on the order of 4% or less according to a conservative model of chance. Most of the responses to the novel sentences were tested within a context-free format that controlled for nonlinguistic cues and for observer bias. It is significant that even where errors in responding occurred, the main semantic and syntactic intent of the sentence was almost always understood. Rarely was an error response a *non sequitur*.

For example, when Akeakamai was given, for the first time, the 4-word imperative NET LEFT BALL FETCH ("take the ball on your left to the net"), she responded by taking the ball on her left to the individual representing PERSON (= PERSON LEFT BALL FETCH). Typically, errors on sentences were restricted to a single lexical element and were mainly confusions within a semantic category. Substituting one named object for another, or one modifier for another, would be examples. Thus, the responses to the great majority of the error sentences, like the wholly correct responses, showed an appreciation for the syntactic and semantic features of the languages.

During the 1982 calibration tests Phoenix responded wholly correctly to 85% of the 368 unique sentences given her, and Akeakamai responded wholly correctly to 83% of the 308 unique sentences given her. Both novel and familiar sentences were included in these totals. Although the trends showed that performance on familiar sentences was higher than on novel sentences, suggesting some practice effect, comparisons were difficult because of the different numbers of sentences given within each syntactic form. However, with but a single exception, the differences in performance levels on familiar *versus* novel sentences within any syntactic category were not significant. Overall, then, the results demonstrated that specific training on given sentences was not required for the understanding of those sentences. Instead, using the provided vocabulary and syntactic rules, new sentences could be generated that were immediately understood by the dolphins.

There are few quantitative data on children's production of novel word combinations, a fact easily verified by perusal of Abrahamson (1977), the major compendium of the literature on child language learning. The data for comprehension are somewhat more complete and reveal that young children have difficulty in understanding many of the unusual and, presumably, novel sentences given them (e.g., J. de Villiers and de Villiers, 1973). For our purposes, one of the most relevant studies of children's understanding of lexical novelty may be that of Sachs and Truswell (1978). Children between 1:4 and 2:0 years of age, who were in the one-word stage of language production, were given simple 2-word instructions. A limited set of object and action words was selected and the words combined and recombined to form imperatives—e.g., "kiss dolly" or "kiss truck". An average of 15.8 instructions of these types was given to the total of 12 children, and the mean number of totally correct responses was 58%. Performance scores for individual children were not given, but some children reportedly carried out correct responses to some of the "unusual" instructions, defined as instructions that they were not likely to have experienced before (lexical novelty)—e.g., "tickle box" and "kiss plane." On the face of it, the study has parallels with our procedures for studying the dolphins' comprehension of familiar and novel 2-word sentences. During the 1982 calibration tests, the dolphins each responded wholly correctly to approximately 94% of the familiar 2-word sentences given them. Novel 2-word sentences, given at irregular intervals over the 4-year period of our study, yielded 68% to 70% correct responses (Tables 3 and 4—Category A). According to these results, the dolphins were considerably more accurate in processing the 2-word sentences of their artificial languages than were these young children in processing the 2-word sentences of their natural language. Of course, as with comparisons of artificial language skills of apes and natural language skills of children, we must keep in mind the limitations imposed by the substantial differences in the scope of the artificial and natural languages, as well as differences in language experience, learning and testing conditions, motivations, possible context cues, and so forth (Ristau and Robbins, 1982, p. 236; cf. Bindra, 1981). What we are emphasizing here, however, is the use of the child data to illustrate that the type and levels of linguistic processing exhibited by the dolphins are substantial.

Premack (1971, 1976) appears to have collected a sizable body of data suggesting a capability for lexical novelty by the chimps Sarah, Peony, and Elizabeth. For example, after Sarah was familiar with the sentence SARAH GIVE APPLE MARY, directing her to give the apple to the trainer, the novel combination SARAH GIVE ORANGE MARY was presented and responded to correctly. However, as pointed out by Terrace (1979), and acknowledged by Premack (1976) in discussion of his own results, only the meanings for the symbols for objects might have been learned, as these were the only symbols contrasted with alternative symbols during a testing session. Additionally, several critics (B. Gardner and Gardner, 1975; R. Gardner and Gardner, 1978; Seidenberg and Petitto, 1979; Terrace 1979) have stressed that the majority of Premack's (1976) data does not include performance on the critical first trial of a transfer test. Instead, Premack reports cumulative data for the first ten trials. Terrace (1979) makes a persuasive case that performance on the order that Premack reports, about 80% correct responses, could easily be a result of context constraint and simple learning-set formation. With the dolphins, on the other hand, we have provided extensive Trial-1 data obtained by methods that were context free, and which included controls for other nonlinguistic cues and for observer bias. Also, in contrast to the work described by Premack, the number of alternative responses available to the dolphins was very large.

Seidenberg and Petitto (1979), referring to the work of the Gardners, state that "there have been no rigorous tests of the apes' abilities to comprehend signs, a remarkable omission in light of recent theoretical work on the differences between comprehension and production ..." (p. 201). Extensive limitations were noted in the procedure used by the Gardners (B. Gardner and Gardner, 1975) to test the chimp Washoe's responses to *wh*-questions. Particular issue was taken with the policy of scoring answers as correct if they were from the designated 'target category,' such as noun for answers to *what*-questions and locatives as answers to *where*-questions. By this policy, answers could be scored as correct even if they failed to 'make sense'. Also noted were the lack of a description of the preparations for the test, and the failure to report the actual responses of Washoe. A later report by B. Gardner and Gardner (1979) gives more detailed data on responses to *wh*-questions by the chimps Pili, Tatu, and Moja. The percentages of appropriate replies given by each chimp ranged widely across the different *wh*-questions, from as low as 12% to as high as 100%. Some examples of replies were given, but most of the specific replies were omitted. Also, the Gardners stated that the same methods that were used earlier with Washoe were used again. Presumably, then, the same shortcomings pointed to by Seidenberg and Petitto (1979) would apply here as well.

Patterson (1978b, 1981) claimed that the gorilla Koko understood novel phrases given in sign or spoken English. However, Terrace *et al.* (1981) noted that the relevant details of Koko's training were unavailable, making it difficult to attribute Koko's performance to true comprehension, as opposed to learning sets, rote drilling, nonlinguistic cueing, or the like. Furthermore, Terrace *et al.* emphasized that even if comprehension of the phrases were shown, it would not constitute a demonstration of the comprehension of *sentences*.

Fouts (1978), citing an unpublished paper by Fouts, Chown, Kimball and Couch (1976), reported that the chimp Ally was able to understand commands requiring him to select one of five objects and deliver it to one of three locations. Fouts stated that some of the commands were novel, obtained by vocabulary substitutions at the object and location positions. In principle, this procedure is similar to some of our own approaches and it would be interesting to know the full details of the training and testing methods and of the results. Unfortunately, the report in Fouts (1978) lacks any detail about these items, so that the same reservations noted for the work of Patterson would apply here also. Finally, the novel 'sentences' constructed by the chimp Lana in the Rumbaugh project (Rumbaugh *et al.*, 1973; Rumbaugh, 1977) were later shown to be largely rote productions of lexigrams with little or no understanding of the references of many of the lexigrams (Savage-Rumbaugh *et al.*, 1980; also see Ristau and Robbins, 1982; Thompson and Church, 1980).

Structural novelty

A second line of evidence for sentence understanding by the dolphins was their ability to deal with structural novelty. Structural novelty differs from lexical novelty. The latter involves the substitution of a new lexical item or items into a familiar syntactic form, while the former refers to a new syntactic construction that may be accomplished by the addition of a new structural slot to a sentence form, or by more complex changes (Ristau and Robbins, 1979; Premack, 1976; cf. Fodor *et al.*, 1974). The ability to process structural novelty may thus express a more complex linguistic skill than does the processing of lexical novelty. For both dolphins, novel syntactic forms that extended familiar syntactic forms were responded to correctly on their first presentation. Phoenix responded correctly to her first instance of the new form Direct Object + FETCH + Modifier + Indirect Object, which was a conflation of two familiar forms: Modifier + Object + Action and Direct Object + FETCH + Indirect Object. Similarly, Akeakamai responded correctly to her first instance of the new syntactic form Modifier + Indirect Object + Direct Object + FETCH and also responded correctly to her first instance of the form Indirect Object + Modifier + Direct Object + FETCH. Like the case for Phoenix, these new forms combined two simpler and familiar 3-word syntactic forms, in this case Modifier + Object + Action and Indirect Object + Direct Object + FETCH. For both dolphins, responding to these new forms continued reliably as new instances were given at irregular intervals over a several month period. In all cases, the new instances were embedded within lists of sentences of a variety of syntactic forms.

In addition to these illustrations, Phoenix's appropriate responding to sentences having linked action words (FETCH THRU or FETCH UNDER), her appropriate multiple responding to newly conjoined sentences, and Akeakamai's ability to respond appropriately to a meaningful segment within an otherwise anomalous string of words, provided further examples of these dolphins' ability to process structural novelty. The latter two examples are taken up again later.

Premack (1976) could find no evidence for the *production* of structural novelty by his apes, a point emphasized by Fodor *et al.* (1974) in their critique of the accomplishments of the chimp Sarah. However, Premack (1976, p. 15) does report that the chimpanzee "can *comprehend* five or six sentence forms structurally different from any on which it was trained" (italics added). It would be interesting to know the details for each of these forms. However, Premack gives but a single example, stating that the chimps were able to understand a sentence of the type "Sarah (or Peony or Elizabeth) take red dish," after having been taught separately only sentences of the type "Sarah (or Peony or Elizabeth) take X," where X could be 'dish' or 'red' or, presumably, other words (also see Premack, 1971, p. 211). There does not seem to be any substantial evidence from the other studies of ape language abilities of the production or understanding of novel sentence forms. Ristau and Robbins (1979) suggested that the chimp Lana (Rumbaugh, 1977) may have produced novel sentences that extended beyond lexical novelty. However, these authors later deferred (Ristau and Robbins, 1982) to subsequent reports from Rumbaugh and his associates (Savage-Rumbaugh *et al.*, 1980) that, on closer evaluation, Lana in fact failed to demonstrate any ability to process syntactic information.

Premack (1971) emphasized that Sarah could understand a word that was taught in the context of one syntactic structure when it was later used in a different syntactic structure. Of course, this is precisely what was done throughout most of our extensive testing of the dolphins' responses to lexically novel sentences. A new word was taught in the simplest of contexts, either by itself or in a 2-word sentence frame. Later, it was used in more complex syntactic forms (e.g., 3-word or 4-word sentences) and the understanding of the new sentences in which it was embedded was tested by examining Trial-1 data. As with Premack's illustrations, this is not the same as the understanding of structural novelty because each syntactic structure was, with the exceptions noted earlier, specifically trained.

In summary, the dolphins have exhibited some understanding of structural novelty, as did, apparently, the chimps tutored by Premack. Also, like Premack's chimps, words taught in the context of one familiar syntactic form were immediately understood when used in a different familiar syntactic form. In further research with the dolphins, it will be important to continue to test for their understanding of novel syntactic structures.

Sensitivity to word order (syntactic understanding)

Semantically reversible sentences

A further line of evidence for sentence processing ability was the dolphins' understanding of semantically reversible sentences. These sentences required the transport of one named object to another named object, with both objects capable of being transported. The order of appearance of the object words in the sentence indicated their function as direct or indirect object. For Phoenix, the direct object was the first named object, and for Akeakamai, it was the second named object. Responses to these types of sentences are particularly revealing of the dolphins' understanding of syntax. During the 1982 calibration tests Phoenix responded wholly correctly to 77% of the 128 semantically reversible 3-, 4-, and 5-word sentences given her. More than half of these were novel sentences. During the same calibration series, Akeakamai responded wholly correctly to 59% of the 69 3- and 4-word semantically reversible sentences given her. Again, more than half of these were novel. Recall that the inverse notation of Akeakamai's FETCH rule appears to place a greater demand on attentional and memory resources than does Phoenix's 'left-to-right' rule. Nevertheless, as with the prior data reviewed, the performance levels of both dolphins very greatly exceeded chance expectations, which were on the order of no more than 4% correct responses.

An important index of the dolphins' understanding of the syntactic structure of these semantically reversible sentences was the extreme rarity of reversal errors. In only one instance for Phoenix, and in none for Akeakamai, was a specified indirect object taken to a specified direct object. If the rules had not been well understood, a reversal error rate on the order of 50% might have been expected. In fact, the correct direct object was selected and transported in over 94% of Phoenix's semantically reversible sentences and in over 95% of Akeakamai's. Errors were mainly the selection of the incorrect indirect object, or its modifier, or (for Akeakamai) the modifier of direct object. That both dolphins could carry out the instructions conveyed by the FETCH sentences showed that syntactic forms need not be engineered to favor sequential linear response chaining or be organized in any particular sequence. The ability of the dolphins to respond to wholly arbitrary syntactic forms, and that the syntactic forms for the FETCH sentences were radically different for the two dolphins, provide analogies with the ability of adult humans to process the diverse syntactic forms that can be found across natural languages.

A number of studies have examined the ability of children to process word-order information in semantically reversible sentences. For example, a child may be provided with appropriate toys or puppets and asked to enact sentences such as "The dog chased the butterfly," or its semantic reversal, "The butterfly chased the dog" (Strohner and Nelson, 1974). Young children have difficulty in processing this type of syntactic information correctly, and tend to rely instead on context cues or semantic cues that derive from their experiences or expectations; for example, they ignore the improbable event that the butterfly chased the dog, and instead make the dog chase the butterfly (also see Bever, 1970; Clark *et al.*, 1974). The de Villiers (J. de Villiers and de Villiers, 1973) showed that children with a mean length of utterance (MLU) of 1.5 morphemes per utterance, or less, were unable to use word-order information present in semantically reversible active or passive sentences. Children with MLUs between 1.5 and 3.0 understood the reversible active forms, but not the passive forms, while children with MLUs of 3.0 or greater understood both forms. MLUs of less than 1.5 characterize children in Stage I of sentence learning (Brown, 1973), while MLUs of 3.0 or greater characterize Stages IV or V. The de Villiers noted that the ability to understand the function of word order alone, without relying on semantic cues, develops at MLUs of greater than 1.5—corresponding roughly to a chronological age of greater than 24 months—which is later than the appearance of 'correct' word order in spontaneous speech (also see Chapman and Miller, 1975). Strohner and Nelson (1974) reported that 3-year olds consistently used extra-syntactic strategies in processing semantically reversible sentences, resulting in many errors in comprehension. In contrast, 5-year olds were able to utilize the syntactic information and interpreted the sentences correctly. Similar results were obtained by Chapman and Miller (1975), who concluded that "... the young English-speaking child's use of word order information as a cue to subject and object status (in semantically reversible sentences) is limited" (p. 18).

A study by McNeill *et al.* (1971) is interesting for our purposes in that it examined the effects of variations in the ordering of direct object and indirect object on responses of Japanese children to 3-word imperative sentences. In the Japanese language, the direct object (DO) and indirect object (IO) are marked by suffixes and may appear in either order. The verb (V) always appears last in the sentence. (One legitimate syntactic form is IO + DO + V, which is the form for the 3-word FETCH and IN sentences in Akeakamai's gestural language.) The children were required to move one named toy (the DO) so that it touched the other named toy (the IO). The chance performance level was 50% correct responses in that only two toys at a time were available to the child. Over all orderings of IO, DO, and V, and all conditions of marking the IO, or the DO, or both, children between 2:3 and 3:1 years gave 53% correct responses, no better than chance. The two older groups (3:7 to 4:6 and 5:0 to 5:7) gave 82% and 71% correct responses, respectively. During the 1982 calibration tests, Phoenix gave 88% correct responses to her 3-word form (DO + V + IO), while Akeakamai gave 60% correct responses to her 3-word form (IO + DO + V). It should be recalled that chance levels for the dolphins were less than 4%, since there was no restriction on choice of objects.

Hoban (1983) studied the responses of children between 2:6 and 5:11 years of age to anomalous imperative sentences constructed like those given the dolphins by Herman *et al.*, Reference Note 1. The goal of the Hoban study was to help reveal the children's "sense of grammaticality" (e.g., cf. Brown *et al.*, 1964; P. de Villiers and de Villiers, 1972; Shipley *et al.*, 1969; Petretic and Tweney, 1977); a similar goal for the dolphins characterized the Herman *et al.* study. The results of Herman *et al.* revealed that in responding to syntactic anomalies the dolphins depended greatly on their acquired knowledge of the syntactic structure of their respective languages. The dolphins' responses to these anomalies were mainly rejections, indicated by their refusal to respond, or transformations, indexed by lexical substitution. An example of a lexical substitution would be to jump over the frisbee (= "FRISBEE OVER"), if given the reversed syntax, OVER HOOP, rather than the correct syntax HOOP OVER. The dolphins rarely acted on all elements of a syntactically ungrammatical command, carrying it out as if the word order were undisturbed. In contrast, Hoban found that children of all ages were as likely simply to execute a syntactically reversed command as they were to reject it or to transform it by lexical substitution.

Perhaps we can conclude from this brief review that the dolphins' understanding of the function of word order, as revealed by their utilization of syntactic information, was well developed in comparison with that reported for very young children. However, we have deliberately tutored the dolphins in the importance and function of word order. In contrast, children may experience relatively less tutoring. With deliberate instruction, children (of from 30 to 40 months of age) may show at least temporary gains in their ability to use syntactic information (Nelson, 1977; Nelson *et al.*, 1973).

Among the researchers into ape language, Premack (1971, 1976) has made the most extensive investigations of syntactic understanding. For example, the preposition ON was used to describe semantically reversible relations between objects—e.g., RED ON GREEN *versus* GREEN ON RED. Plastic symbols were used for the indicated words. The ape was required to place one colored object on top of another in accordance with the instructions given by such strings. Premack reports good performance in these tests. However, as stressed by Terrace (1979), the tests for understanding of these relations were limited in that generally only two objects were available at a time, there was no contrasting preposition, and there were considerable contextual cues available. Also, once again, the Trial-1 data on transfer tests were incomplete. Consequently, it is not possible to evaluate to what degree Sarah was able to use syntactic information, as opposed to lexical, semantic and/or context information in processing the sentences given. In contrast, our procedures for testing responses to novel semantically reversible sentences, or to novel sentences containing modifiers whose location in the sentence relative to that of objects determined meaning, or to novel syntactic forms, provided Trial-1 data under controlled conditions and gave extensive evidence of syntactic processing. Also, the recent testing of Akeakamai demonstrated that she could reliably discriminate between FETCH and IN in parallel sentences containing direct and indirect objects. FETCH may be interpreted as functionally equivalent to the preposition 'to' (= 'take to') and IN as functionally equivalent to the preposition 'into' or 'onto' (= 'put into' or 'put onto').

Seidenberg and Petitto (1979) doubted that any of the apes trained in sign language were sensitive to syntactic structure. Three criteria for such structure were given: (*a*) that signs in isolation have particular meaning; (*b*) that different linear combinations of signs have different meaning; and (*c*) that each type of ordering is not specific to a unique set of lexical items. In our studies, these criteria were fully met by the semantically reversible sentences. The ability of the dolphins to respond to these sentences correctly gives the first substantial evidence of syntactic processing of a string of lexical items by animals.

Modifier placement

Additional evidence for syntactic processing is found in the dolphins' responses to sentences having modifiers of direct and/or indirect object. For both languages, the modifier always precedes the object modified. However, an interesting case occurs in Akeakamai's grammar for 4-word sentences of the type Indirect Object + Modifier + Direct Object + FETCH. Here, the modifier is sandwiched between two object words but is intended to modify only the direct object. In its proximity, however, it might as easily be attached to the indirect object. Moreover, Akeakamai has had experience with modified indirect objects in the sentence form Modifier + Indirect Object + Direct Object + FETCH. Nevertheless, in those sentences in which the modifier was sandwiched between the indirect and direct object names, Akeakamai almost always correctly attached the modifier to the direct object. In effect, Akeakamai had to utilize the concepts of adjacence and precedence. The adjacence rule allows her to attach the modifier only to the first object word in the form Modifier + Indirect Object + Direct Object + FETCH. The precedence rule allows her to relate the modifier only to the *second* object word in the form Indirect Object + Modifier + Direct Object + FETCH. In summary, the understanding of the function of object names as direct or indirect objects, and of how modifiers may be attached to object names, further illustrate the considerable sensitivity of the dolphins to syntactic structure.

Alternative relational terms

We have already noted that Akeakamai's knowledge of the FETCH grammar generalized readily to the alternate relational word IN. Akeakamai clearly recognized the semantic distinction between FETCH and IN, as indicated by the rarity of performing one action when given the other (Table 9), but, at the same time, also appreciated their syntactic similarity. Of ultimate importance for the demonstration of syntactic knowledge was the finding that Akeakamai immediately understood the complete IN syntax, Indirect Object + Direct Object + IN, after having been exposed to IN only as a single word.

On the first occasion that an IN sentence was given—BASKET HOOP IN—Akeakamai swam to the hoop, carried it to the basket, and correctly placed it inside. All of Akeakamai's named objects were present in the tank at the time, and the test was made using procedures that guarded against nonlinguistic cues and observer bias.

Semantic processing and context generalization

Throughout the period of this study the dolphins gave indications that they were responsive to semantic information as well as to syntactic information. Semantic processing was shown by the ready generalization of names across objects of a class—e.g., new exemplars of HOOP, PERSON, or WINDOW were responded to correctly immediately. Other examples of semantic processing were found in the ability to generalize action words to new contexts or new objects. There were many instances of correct responses to novel sentences in which familiar actions were paired with newly named objects. Most interestingly, when confronted with objects or situations that made performing a requested action difficult, the dolphins rearranged the circumstances to make the response possible or unambiguous. Pulling the surfboard away from the tank wall before leaping over it in response to SURFBOARD OVER; taking the ball out of the basket in order to place it back in, in response to the word IN; lifting the hoop lying flat on the tank bottom into a nearly vertical position in order to be able to swim through it, in response to BOTTOM HOOP THRU; and designating the intended indirect object among a clustered group by carefully positioning the transported direct object against only one object in the cluster are but a few examples of the deeper level of understanding of the meaning and intent of an action. During the testing of responses to anomalous sentences (Herman *et al.*, Reference Note 1) there were even occasions when the dolphins performed actions appropriately that we thought were not possible. One example, given earlier, was when both dolphins immediately tossed the stream of water in response to WATER TOSS, a sentence we had prejudged to be semantically anomalous. We have since incorporated WATER TOSS into the languages as a legitimate sentence.

Modifiers of object, place or direction were also understood very generally. Phoenix responded appropriately to SURFACE and BOTTOM whether she was at the surface herself, or the bottom of the tank, and regardless of the location of the objects relative to her in the horizontal plane. Akeakamai correctly responded to LEFT and RIGHT as ego-referenced terms, relative to her, regardless of where she was positioned around the rim of the circular tank at the time that a sentence containing a modifier was given. An interesting case was that of the gestural string Modifier + Indirect Object + Direct Object + FETCH. For sentences of this type, Akeakamai was at times required to swim in a direction opposite to that signified by the modifier in order to retrieve the direct object and bring it back to the indirect object. For example, when given the sentence LEFT BALL FRISBEE FETCH (= "take the frisbee to the ball on your left"), one ball would be to her left and another to her right. If the single frisbee was also to her right, Akeakamai was required to swim to her right to retrieve the frisbee, ignoring the ball nearby that was to her right when she began the trial, and swim back across the tank to the ball that was to her left when she began the trial. That she was able to do this correctly in most cases suggests an impressive ability to represent and maintain the relative locations of objects abstractly. It also suggests that the modifier was attached to the object modified, e.g., to the left ball in the sentence LEFT BALL FRISBEE FETCH rather than being represented as an action, e.g., GO LEFT. Both dolphins also showed broad generalization across situational contexts. Various signers were used for Akeakamai, different instructional stations could be used, and objects could be tethered or be freely floating about the tank, all with no substantial effect on performance. Also, during formal instructions each dolphin was relatively impervious to the behaviors of its companion in the tank although that companion might be leaping over it, playing ball nearby, etc. This task-oriented behavior contrasted sharply with the normally intense attention each dolphin gives the other in nontraining situations, and with the high levels of distractibility reported for apes in all of the language projects.

Lexical processing and linguistic reference

Lexical processing was evident or inferred by a number of behaviors. This included a lack of response to those objects or fixtures in the tank that had not yet been named, and a readiness to respond to such objects when they were newly named. Although assigning names to new objects was a relatively protracted affair early in training, at later stages in training it was usually sufficient to present a new sign (gesture or sound, as appropriate) in the presence of a new object, or in the presence of an old object that was unnamed, and call attention to that object through some extrinsic cue (e.g., tapping on the tank wall near the object). The association of the new sign with the unnamed referent was then made immediately by the dolphins. The word WATER was taught to both dolphins in this way, as was SURFBOARD and NET and, most recently (for Akeakamai), WINDOW. In other work (Herman *et al.*, Reference Note 1) the dolphins' knowledge of the lexical boundaries of their languages was revealed in that unfamiliar ('nonsense') gestures or sounds that were occasionally inserted into otherwise meaningful sentences led to rejection of the sentence, or to the lexical substitution of an appropriate word in the vocabulary for the nonsense word. In these latter cases, attention was *not* directed to unnamed objects.

In general, we have observed a major qualitative shift during the course of the project in the way both dolphins appeared to process the names of objects. In the early stages, the dolphins had great difficulty in identifying objects located outside of a small circumscribed area near their own location. Apparently, the dolphins initially tended to encode the identity of the object in terms of its location at the time the instruction was given. If the object changed its location easily–e.g., if it was driven across the tank by the wind—errors in responding to that object name were frequent. The placement of the training objects within easy reaching distance in a spatially constrained situation in some of the chimpanzee language projects may have resulted in a similar spatial encoding strategy being developed by the chimps, and consequently in a failure to develop a true referential concept (cf. Savage-Rumbaugh *et al.*, 1980). In our project, on the other hand, the situation was analogous to a chimp sitting in a room in which objects floated randomly about in the air. From necessity, both dolphins over time had to develop an ability to encode and search for objects in terms of object attributes rather than object locations. This development of a 'search image' (see discussion in Dawkins (1971) on the distinction between perceptual changes in search behavior and changes in the search path) apparently allowed the dolphins to locate hidden objects and to respond effectively even if the named objects were not present in the tank at the time of instruction, as was demonstrated by the 'displacement' testing results, and by the ability to report that the *specific* object referred to in a sentence was not present in the tank. The displacement testing showed that spatial encoding, while a convenient mnemonic device in situations allowing its use, is not a necessary strategy and may even be counterproductive if object locations change frequently. When the situation required it, the dolphins were able to depart from mnemonic strategies using location cues to the more generally useful search-image strategy. This was particularly evident in the 'missing-object' study, in which searches were made for an average of 15 seconds for the missing object, before the dolphin reported on the NO paddle that the object was absent. The types of searches conducted—e.g., looking above the water surface for the high floating ball or the person at tankside, or swimming near the bottom looking up for the flat floating frisbee or pipe—indicated that highly specific visual search images were used. There was also evidence for the use of acoustic search images. During the displacement testing, the dolphins often seemed to orient toward the object specified in the sentence solely by the characteristic sound that object made as it struck the water. Recall that during displacement testing multiple objects were flung into the tank after the sentence was given.

These results reveal the extent to which the names used for objects were understood by the dolphins as symbolic representations of those objects. In their discussions of symbolic representation, Savage-Rumbaugh *et al.* (1983) have suggested that if an ape can use a symbol to refer to a *specific* absent food, rather than to just food in general, then it may have "moved beyond associationistic symbol usage to true representational usage" (p. 23). They also state that a key question for demonstrating symbolic representation is whether an ape can search out and locate an object that was not visibly present when the experimenter requested that specific object of the ape. These criteria were met, in the receptive mode, in our demonstrations with the displacement paradigm and the missing-object paradigm. Of course, the bulk of the current receptive performance of the dolphins is characterized by an ability to respond to the specific objects referred to by the language symbols.

In general, our methods of working with the dolphins suggest a training strategy by which an animal may be encouraged to form more complex cognitive representations in order to carry out the tasks specified by sentences. This training emphasizes responding to objects in a variety of situational contexts, and more closely resembles the natural environment of a child forming a referential concept than does the constrained situation in which a referential concept has failed to appear in some of the chimpanzee projects.

Linguistic features of artificial languages

The dolphins' performance in these sentence processing tasks in part reflected the characteristics of the artificial languages we created. To what extent do these artificial languages model important features of natural languages? As in natural languages, tacit knowledge of the syntactic rules underlying the language was necessary for a correct interpretation of the function of lexical items in a sentence, and for an understanding of the unique semantic proposition being expressed. This is most obvious for the inverse rules in Akeakamai's gestural language. The function of the first object word in a sentence cannot be determined until succeeding words have occurred. For example, in the sentence BASKET OVER, BASKET functions as a direct object; in the sentence BASKET SURFBOARD FETCH or BASKET SURFBOARD IN, BASKET functions as an indirect object; and in the 'sentence' BASKET SURFBOARD ERASE, BASKET has no definable function, ERASE in effect acting as a metalinguistic instruction cancelling all previous lexical items. Finally, in an anomalous construction such as BAS-

KET SURFBOARD OVER, the word OVER causes Akeakamai to ignore BASKET, but to retain SURFBOARD as a direct object and to leap over it. Thus, as in natural languages, both syntactic and semantic processing are necessary to interpret the meaning of a sentence. Also, as in natural languages, a simple left-to-right processing strategy is inadequate to parse most of the sentences of the language. In Akeakamai's language the functions of early words may, in many cases, only be understood (parsed) on the basis of succeeding words, a characteristic of natural language processing stressed by theoreticians (e.g., Chomsky, 1957; Lashly, 1951).

In responding to their artificial languages the dolphins appear to attach the modifiers to the object names. We may be justified, therefore, in defining the modifier + object as one constituent of a sentence. Further research would be necessary to define this or other constituents with confidence. Also, in further research it would interesting to attempt to interpret the processing strategies of the dolphins in reference to strategy models, or other models of comprehension processing (cf. Foss and Hakes, 1978, Ch. 4).

Thus far, our syntactic rules have been limited to sentence forms expressed in the imperative mood. The use of the imperative mood has allowed us to study comprehension easily, as is the case with the studies of young children cited earlier, but the imperative mood is not a necessary constraint of the languages. In further work, the study of the understanding of sentences expressed in the indicative mood is planned. For example, a declarative sentence can be given the dolphin, informing her about the state of some object in the tank (e.g., "the ball is [not] in the tank") or about relations among objects (e.g., "the ball is in the basket"). To test comprehension, one might then follow the declarative statement with an imperative requiring some action to the object named in the prior statements. The response of the dolphin can indicate its understanding of the declarative statement—e.g., understanding would be shown by not searching for the ball after being informed that the ball was absent or by looking in the basket if told that the ball was there. A question form that asks about objects can also be used to test comprehension. For example, the dolphin might be asked: "Is the ball in the tank?" Comprehension would be shown by an appropriate "yes" or "no" response. Preliminary tests have been made which demonstrate that Akeakamai can respond appropriately, yes or no (indicated by a press on one or another of two alternative paddles), to questions about the presence or absence of named objects.

Within the imperative mood, a large number of unique sentences can be created, limited in number only by the size of the lexicon. Currently, almost 500 unique sentences can be generated for the acoustic language and more than double that number for the gestural language. Each new lexical item added to the vocabulary greatly enlarges the number of sentences available, although that number is still countable. The addition of recursive features to the language, as was done in preliminary form through the conjoined sentences or linked actions given to Phoenix, allows, in principle, for an infinity of sentences to be generated. It is noteworthy that without specific training, Phoenix responded to most of the conjoined sentences by performing multiple appropriate responses, and to the linked actions by carrying out appropriate integrated responses.

Other features of natural languages are represented in our languages. The lexicon is open and can be added to as desired A variety of semantic entities are represented in the vocabulary. Although the vocabulary is limited in the number of words, the words can be combined and recombined, according to the constraints of the set of syntactic rules, into a large number of uniquely meaningful sentences. The acoustic and gestural signs are discrete and arbitrary and bear no obvious iconic relation to the things signified. The syntactic rules are also arbitrary, and for 3-word and longer relational sentences the rules differ across the two languages. However, within a language there is a logical consistency of rules across the different types of sentences. In the case of 3- and 4-word sentences more than one type of sentence can be constructed within each language. For some sentences, word order is an important determinant of meaning: the same words arranged in different orders convey different instructions. Although our trainers can easily exchange roles as sender or receiver of gestural signs (cf. interchangeability criterion of Hockett (1960)), as demonstrated in some of our blind observer techniques in which messages are transmitted to trainers via gestures, we have not yet implemented extensive techniques for language production by the dolphins. Thus, the dolphins (rather than the languages) have not yet demonstrated interchangeability.

Implications for cognitive structures and processing

That two different language mediums were used with roughly equal success implies that the cognitive skills underlying comprehension competency in the dolphin are very general and not specialized with respect to either the auditory or visual modality. In many learning tasks with animals, modality-specific learning constraints are evidenced (Hinde and Stevenson-Hinde, 1973; Seligman, 1970). Although acoustic information of almost any type is easily processed and manipulated by the bottlenosed dolphin, severe constraints on visual learning occur when the visual information is represented by static forms or simple brightness levels (Herman, 1980). No such visual-learning constraints occurred with the gestures used in this study. The gestures provide visual information as a spatial-temporal pattern of movements and are qualitatively different from the simple static forms or brightness images that, despite good visual acuity (Herman *et al.*, 1975), cause much difficulty for the bottlenosed dolphin. The patterned character of the gestural signs is analogous to the patterned character of the acoustic signals used with Phoenix, and to many other types of acoustic information as well. That is, an acoustic signal 'unfolds' a pattern over time; it is this temporal structure which contains the bulk of the information for recognizing the sound. Thus, the good levels of performance achieved in the acoustic and gestural modes may reflect the in-common temporal-patterning character of the information to be processed. If so, amodal centers for the processing and integration of temporal-pattern information may be particularly well elaborated in the bottlenosed dolphin and may function as important cognitive acquisition devices.

In their ability to utilize both acoustic and visual information in these tasks, the dolphins have shown a greater response flexibility than have the 'linguistic' apes, who appear to be largely restricted to the visual modality, at least for the production of language (e.g., see the early work of Kellogg and Kellogg (1933) and Hayes (1951)). Patterson (1978b) and Fouts (Fouts *et al.*, 1976) have used both spoken English and American sign language in interactions with their apes. In some cases, both speech and signing are used simultaneously. That the two language forms have very different structural rules (B. Gardner and Gardner, 1979; Seidenberg and Petitto, 1979) should, in theory, make such joint communication problematical. At the least, careful dissection of what is actually understood in each medium is required. Critiques of Patterson's (1978b) tests of Koko's understanding of vocal and signed instructions have already been noted (Terrace *et al.*, 1981). The work reported in Fouts *et al.* (1976) was restricted to the transfer of object reference from spoken English to signs, and did not involve sentence understanding.

For both dolphins, the lexical and syntactical constraints on words and on groups of words must be understood in order to make a correct semantic interpretation of the sentence. Much of Akeakamai's language cannot be understood by parsing the information given by a string of words from left to right. In the case of some of the anomalies described the words to be related were not adjacent to one another in the sentence. That Akeakamai was able to extract meaning from the sentences given her under these conditions suggests an impressive ability to construct a representation of the world referred to by her language and of the variety of propositions about that world that may be stated by the language. Phoenix's performance, while accomplished within a language in which the left-to-right structure was generally consistent with how the information must be evaluated, was nevertheless equally impressive in its demonstration of lexical and syntactic processing, and of representation. These features of the dolphins' processing of sentences greatly expand the earlier descriptions of the cognitive abilities and characteristics of bottlenosed dolphins (Herman, 1980).

Summary and conclusions

This study has demonstrated that bottlenosed dolphins can understand imperative sentences, and that, in so doing, they utilize both the semantic and the syntactic components of the sentences.

The dolphins were able to cope with different language modes, auditory (Phoenix) or visual (Akeakamai), and with different grammars, respectively linear or nonlinear (inverse). Both dolphins understood the significance of constituent order, in that different orders correlated with different meanings. Within the nonlinear grammar, Akeakamai demonstrated her ability to assign and reassign functions to earlier words in a sentence, i.e., to parse the sentence, on the basis of a succeeding word or words. She also understood that the word ERASE canceled all operations on prior words. ERASE thus appeared to function as a metalinguistic term, similar to an English phrase such as 'Forget it!' That modifier placement also modulated meaning, as determined by the criteria of adjacence and precedence, was also understood by Akeakamai. Akeakamai's modifiers were ego-referenced terms (RIGHT and LEFT) while Phoenix's were environmentally-referenced terms (SURFACE and BOTTOM), yet both types were used appropriately by the respective dolphins.

The concept that signs stand for referents seems to come easily to the dolphins at their present stage of development, although there was initial difficulty in assigning signs to objects (but not to actions). All of the signs used were discrete, arbitrary, and noniconic. The essential features of the gestural signs were apparently extracted easily by Akeakamai, as there could be considerable variability in signs across trainers, in the location of trainers, etc., without disruption of Akeakamai's performance. By their nature as computer-generated sounds there was relatively little variability within given sounds in Phoenix's language. Both dolphins generalized readily from one instance of a class of referent to other exemplars of that class. Both dolphins generalized their action responses broadly, for example, by manipulating object placement or position in order to carry out requested actions on the objects. Both were able to respond appropriately to sentences given with no objects present in the tank (displacement), by operating on the designated object when all objects were later introduced at once. Also, both dolphins were able to 'report' spontaneously that a particular object referred to was absent, by searching for the missing object and then returning to their stations without taking any action. The report procedure was later formalized for Akeakamai, who reported on a 'NO' paddle that the object searched for was absent. These various demonstrations were strong indications that the signs had acquired word-like (referential) characteristics.

Both dolphins understood lexically novel sentences and both understood structural novelty, as well. The data on lexical novelty were extensive and revealed the dolphins' ability to understand new combinations of words incorporated into any of the five or six different sentence forms tested. The data on structural novelty included several examples in which new structural slots were added to sentences.

Preliminary tests showed that Phoenix, without any specific training, tended to give appropriate multiple responses when sentences were conjoined and to give appropriate integrated responses when two action words were linked to form a new response instruction. This was further evidence for the understanding of structural novelty and also demonstrated the immediate understanding of recursive features added to the language.

The performance of the dolphins in these various tasks stands apart from models of sequences of behavior as rotely learned linear S-R chains (e.g., Keller and Schoenfeld, 1950; Skinner, 1938; see Terrace (1983) for further discussion). The concept of a chain as "composed of a (linear) series of responses joined together by stimuli that act both as conditioned reinforcers and as discriminative stimuli" (Reynolds, 1968, p. 53), still serves as a technological model for the development of 'complex' behaviors in animals, including pigeons, pet dogs, and porpoises trained in oceanariums. In the oceanarium, to train a dolphin to swim through a gate, after teaching it to swim through a hoop, the animal is retrained specifically, and usually at length, in the new behavior, i.e., a new chain of responses is painfully constructed (e.g., Batteau and Markey, 1968). In contrast, by utilizing the concept of a sentence as a sequence of recombinable lexical elements held together by syntactic rules, we need only replace the word HOOP with the word GATE in the imperative form HOOP THRU in order to achieve the desired response immediately. We rely on the dolphin's understanding of the concepts of object and action names, and of the laws for their combination, rather than on her understanding of the contingencies between stimulus, response and reward. Also, in contrast to demonstrations that animals may learn to order their responses in a fixed sequence to a largely invariant set of nonlexical stimuli (e.g., four different-colored lights that must be pecked by a pigeon in a prescribed order; Straub *et al.*, 1979; Terrace, 1983), we are dealing with a lexicon that is open and a linguistic system having the property of recombinability of elements to form new sequences. Furthermore, it is not the lexical items themselves that are to be operated on, but their referents.

Most conceptions of natural communication within nonhuman animal species emphasize the rather limited and fixed repertoire of messages that may be transmitted among the members of the group (e.g., Smith, 1977). The use of arbitrary vocal signals to reference different predators has been reported for a number of species of birds and mammals (e.g., Ryden, 1978; Seyfarth *et al.*, 1980; but cf. Dennett, 1983), but we know of no well-documented instances in the natural world of the creation or understandung of new symbols. That the dolphins in this study were able to understand that arbitrary symbols referred to real-world objects, and that they were able to understand novel messages comprised of new arrangements of these symbols, is a departure from what is generally accepted about natural forms of animal communication. Possibly it should alert us to look more carefully and creatively at natural communication in animals (cf. Griffin, 1981; also see Marler, 1977; Ristau and Robbins, 1982). It may also be that the realization of these potentials for processing new forms of information reflects the enhancing effects on knowledge structures and cognitive processes of special, intensive, and protracted education, such as we gave our dolphins and as is the case with human formal education.

Finally, our work, in its emphasis on comprehension rather than production, is a radical departure from the bulk of the language work with apes. Savage-Rumbaugh *et al.* (1980) reviewed extensive data from the ape language studies, and concluded that production does not necessarily (or even usually) imply comprehension. Researchers of child language have long been sensitive to the differences between production and comprehension (e.g., Bloom, 1974; Chapman and Miller, 1975; Fraser *et al.*, 1963). Savage-Rumbaugh *et al.* (1980) noted, as did Seidenberg and Petitto (1979, 1981) and Terrace (1979), the paucity of tests for comprehension in most of the ape language studies. The most extensive prior work on comprehension has been that of Premack (1971, 1976). Some of the limitations in that work were noted earlier, as were limitations in the reports of comprehension in the work of other researchers into ape language abilities. It does seem unfortunate that research into animal language has chosen to emphasize production, when comprehension is much easier to control and measure. As McNeill (1970) stated in his discussion of reasons for studying comprehension in humans "in comprehension the investigator knows what the input to the process is—it is the sentence comprehended. Thus, when comprehension fails, the source of trouble can be located. The same cannot be said for production" (p. 11). Our procedures for studying language comprehension in bottlenosed dolphins have been successful along the lines suggested by McNeill: the input is well defined, both for the investigator and for the animals, and quantitative measures of comprehension capabilities and limitations relevant to general and specific linguistic issues are obtainable. The results we have obtained thus far demonstrating the understanding of sentences by bottlenosed dolphins invite the reconsideration of animal linguistic competency and its continued study by these techniques. Expanded research with the dolphins is needed to explore the boundaries of the competency established, including the ability for productive language and limitations on productive language relative to receptive language. Especially important will be studies that further reveal how the dolphins process the information contained in the sentences, and the concepts that they hold about the language elements and language tasks. It seems likely to us, also, that the application of our language-comprehension procedures to apes or other animals would prove interesting and fruitful.

Appendix

The probability of a correct chance response to a sentence

A useful method for evaluating the chance probability of a correct response by each dolphin to a particular sentence is to build models that can generate the languages. The probability that the model will generate the sentence can then be determined.

Different models for determining chance probabilities can be constructed, depending upon assumptions about the use of semantic and syntactic information. For example, finite-state models can be used to generate many of the sentences of natural languages. These models are not adequate for fully describing human languages, however, because any finite-state model powerful enough to generate complex sentences incorporating syntactic relationships between nonadjacent words will also generate nonsense sentences (Chomsky, 1965). In generating a sentence, finite-state models (Markov processes) take into account only the present state (the current word in a sentence) and the transition probabilities for the succeeding word. For that reason, they are often referred to as left-to-right models.

Each of the artificial languages of this study can be generated by an appropriate finite-state model. Without evidence of a need for a more complex model at the present stage of language development, the finite-state model is a reasonable conservative choice for expressing chance probabilities. It should be understood, however, that a model that is sufficient for generating the sentences of a language is not necessarily sufficient for processing the information contained in the sentences (Peters and Ritchie, 1967). To parse a sentence, for example, it may be necessary to depend on right-to-left relations or on relations between nonadjacent words. Hence, as discussed elsewhere in this paper, the dolphins may not be able to understand some of the sentences given them through a simple left-to-right processing strategy.

The chance probabilities obtained for the finite-state model are shown in Table A1, as a function of each sentence form in each language. For that reason, it may also be referred to as a syntactic form model. To generate these probabilities, a separate path for each syntactic form is generated. Additionally, within each form, where appropriate, restrictions on the choice of semantic element are placed dependent on the function of the word in the sentence. Thus, in relational sentences only transportable items may be used as direct objects. Further restrictions are necessary to exclude certain combinations that are nonsensical, such as SPEAKER THRU, an instruction to swim through the underwater speaker. By these procedures, the probability of a correct chance response to a sentence of a given syntactic form reduces to one over the number of legal sentences of that form that can be expressed in the language under consideration. The number of possible sentences in each syntactic category within each language were obtained from Tables 6 and 7. The derived chance probability values ranged from 0.0114 to 0.0357 for Phoenix and from 0.0071 to 0.0167 for Akeakamai. Since the number of possible sentences has grown considerably since the data for Tables 6 and 7 were generated, as discussed elsewhere in this paper, the tabled probability values are actually high for the present state of the languages. In an absolute sense, however, they are quite low and reveal that the probability of a correct chance response is in all cases very improbable. In evaluating the numeric data given in the Results section of this paper, these probabilities were entered into the summed binomial distribution function to determine significance levels for the obtained results.

The material provided in the results sections evidences the dolphins' use of semantic and syntactic information and suggests that evaluating chance probabilities within a syntactic category is appropriate. Additional evidence for the use of semantic and syntactic information by the dolphins is found in Table A2. The table shows the results of chi-squared analyses of the frequency of errors occurring within and outside of the syntactic category represented by the sentence given. A hypothetical example of an error falling outside of the given syntactic category would be Phoenix responding to the Object + Action sentence HOOP OVER by taking the hoop to the speaker, as if given the Direct Object + Action + Indirect Object sentence HOOP FETCH SPEAKER. Similarly, a hypothetical instance of Akeakamai's response departing from the given syntactic category would be her responding

Table A1. *The probability* (p) *of a correct chance response to a sentence as derived from the finite-state model*

Phoenix		Akeakamai	
Sentence type	Probability	Sentence type	Probability
DO + A	0.0122	DO + A	0.0147
M + DO + A	0.0185	M + DO + A	0.0089
DO + A + IO	0.0167	IO + DO + A	0.0167
DO + A + M + IO	0.0357	M + IO + DO + A	0.0071
M + DO + A + IO	0.0114	IO + M + DO + A	0.0119
M + DO + A + M + IO	0.0179		

to the Indirect Object + Direct Object + FETCH sentence, PIPE FRISBEE FETCH, by touching the pipe on her left with her tail as if given the Modifier + Direct Object + Action sentence LEFT PIPE TAIL-TOUCH.

Using the data obtained during the calibration sessions (Tables 6 and 7), which are comprised of responses to all of the sentences in the language at the time of that testing or a representative sample of these, Table A2 shows the total number of sentence errors in each syntactic category and the actual number of these errors which fell outside of the syntactic category. Two methods were used to determine the expected number falling outside of a category ('outlier' errors). One method assumes that errors distribute themselves equally over all syntactic categories. The other assumes that errors distribute themselves in proportion to the number of sentences in each category. In either case, the obtained chi-square values were significant at less than the 0.01 level, indicating that errors fell outside of the given syntactic category significantly less often than would be expected by chance.

An 'independent elements' model that assumes a restriction of choice to the appropriate syntactic form could also be constructed. In this model each semantic element in a sentence of a given form is chosen independently of other semantic elements in that sentence. Selection is accomplished by choosing from among all available representatives of a semantic element. For example, for a 2-word Object + Action sentence it is assumed that the dolphin selects the designated object from among all available objects and then selects the designated action from among all available actions. The probability of a correct response to the sentence by chance would then be given as $1/o \times 1/a$, where o is the number of objects available and a is the number of actions available. Similarly, chance performance on a Modifier + Object + Action sentence would be given as $1/m \times 1/o \times 1/a$, where m is the number

Table A2. *The number of sentence errors in each syntactic category and the observed and expectd number of these errors falling outside of the syntactic category*

Syntax	No. unique sentences	Sentence errors	No. errors outside of syntactic form		
			Observed	Expected[a]	Expected[b]
Phoenix[c]					
DO + A	82	5	1	4.17	3.89
M + DO + A	54	5	3	4.17	4.27
DO + A + IO	60	7	4	5.83	5.86
M + DO + A + IO	28	8	4	6.67	7.39
DO + A + M + IO	88	14	3	11.67	10.65
M + DO + A + M + IO	56	16	4	13.33	13.57
Chi-Square Value[d] (d.f. = 5)				17.84*	16.93*
Akeakamai[e]					
DO + A	68	4	1	3.20	3.41
M + DO + A	112	5	0	4.00	3.79
IO + DO + A	60	24	8	19.20	20.90
M + IO + DO + A	84 (29)	7	3	5.60	5.73
IO + M + DO + A	140 (39)	13	5	10.40	9.08
Chi-Square Value[d] (d.f. = 4)				16.06*	16.59*

Note. Numbers in parentheses indicate the number of sentences actually given during the 1982 calibration tests; numbers not in parentheses are the number potentially available and were used to compute the expected values.

*$p < 0.01$.

[a]Based on assigning 5/6th (Phoenix) or 4/5th (Akeakamai) of the observed sentence errors as 'outlier' errors.

[b]Based on assigning the observed sentence errors as 'outlier' errors proportionally to the number of sentences.

[c]The first three columns of numeric data are from Table 6.

[d]The indicated chi-square values are obtained by comparing the differences between the expected and observed frequencies in the standard chi-square formula.

[e]The first three columns of numeric data are from Table 7.

of modifiers available and *o* and *a* are as previously defined. Using this model, chance probability levels for each syntactic form ranged from 0.0003 to 0.0085 for Phoenix's language and from 0.0007 to 0.0101 for Akeakamai's. These probabilities are considerably lower than those of the finite-state model, and reflect the generation of wholly inappropriate sentences that do not take into account any restriction on the function of words.

Completely random models of choice assume that there are no semantic or syntactic constraints on the choice of words, and allow for highly inappropriate responses to sentences given, i.e., for responses that bear no relation to the instructions given. Such models yield very low probabilities of a correct chance response to a sentence. For example, a model based on random equiprobable choice among all of the sentences available in a given artificial language would yield probabilities on the order of 0.005 to 0.002, depending on the particular language and the stage of training at which the comprehension testing was carried out. Even smaller probabilities could be obtained from models that assume that responses to each word are chosen at random from among all language-controlled responses. Assuming that the number of responses corresponds to the number of words given in the sentence, chance probabilities decrease exponentially as the number of words increases. Probabilities on the order of 0.002 would be obtained for 2-word sentences and on the order 3.5×10^{-6} for 4-word sentences. These models of completely random choice are inappropriate and not conservative, given what is known about the dolphins' responses.

Other models of chance could be developed, but it would be largely an exercise rather than of practical import. For example, models based on the grouping of words into phrases could be developed. Our analyses of such models showed that they yielded probability values which bracketed the values for the finite-state model. In the absence of sufficient information for choosing among these phrase groupings or, indeed, for choosing any phrase-structure model at all, it seemed unwise to consider these models further at this time.

In conclusion, the finite-state model was chosen to represent the levels of responding to be expected by chance. This model takes into account the utilization of syntactic and semantic information by the dolphins and is conservative. It yields higher chance probabilities than do the other models considered, except for portions of the phrase-structure model.

References

Abrahamson, A.A. (1977) *Child Language: An Interdisciplinary Guide to Theory and Research.* Baltimore, University Park Press.

Anderson, J.R. (1980) *Cognitive Psychology and Its Implications.* San Francisco, W.H. Freeman.

Batteau, D.W. and Markey, P.R. (1968) *Man/Dolphin Communication.* Final Report Contract N00123-67-1103, 15 Dec. 1966–13 Dec. 1967. U.S. Naval Ordnance Test Station, China Lake, California.

Bever, T.G. (1970) The cognitive basis for linguistic structures. In J.R. Hays (ed.), *Cognition and the Development of Language.* New York, Wiley.

Bindra, D. (1981) Ape language. *Science, 211*, 86.

Bloom, L. (1974) Talking, understanding, and thinking: Developmental relationship between receptive and expressive language. In R.L. Schiefelbusch and L.L. Lloyd (eds.), *Language Perspectives—Acquisition, Retardation, and Intervention.* Baltimore, University Park Press.

Bronowski, J. and Bellugi, U. (1970) Language, name and concept. *Science*, *168*, 669–673.
Brown, R.W. (1973) *A First Language: The Early Stages*. Cambridge, Mass., Harvard University Press.
Brown, R.W., Fraser, C. and Bellugi, U. (1964) Explorations in grammar evaluation. In U. Bellugi and R.W. Brown (eds.), *The Acquisition of Language*. Chicago, University of Chicago Press.
Caldwell, M.C. and Caldwell, D.K. (1965) Individualized whistle contours in bottlenosed dolphins, *Tursiops truncatus*. *Nature*, *207*, 434–435.
Caldwell, M.C. and Caldwell, D.K. (1977) Social interactions and reproduction in the Atlantic bottlenosed dolphin. In S.H. Ridgway and K. Benirschke (eds.), *Breeding Dolphins; Present Status, Suggestions for the Future*. Washington, D.C., United States Marine Mammal Commission Report No. MMC-76/07. (Available as Report PB 273 673 from the National Technical Information Services, Arlington, VA)
Chapman, R.S. and Miller, J.F. (1975) Word order in early two and three word utterances: Does production precede comprehension? *J Speech Hear. Res.*, *18*, 355–371.
Chomsky, N. (1957) *Syntactic Structures*. The Hague, Mouton.
Chomsky, N. (1965) *Aspects of the Theory of Syntax*. Cambridge, Mass., The MIT Press.
Chomsky, N. (1972) *Language and Mind* (enlarged edition). New York, Harcourt Brace Jovanovich.
Churchill, D.W. (1978) Language: The problem beyond conditioning. In M. Rutter and E. Schopler (eds.), *Autism*. New York, Plenum.
Clark, R., Hutcheson, S. and van Buren, P. (1974) Comprehension and production in language acquisition. *J. Ling.*, *10*, 39–54.
Curtis, G.D. (1979) Wide frequency response of type J9 underwater sound projector in a typical experimental tank. *J. acoust. Soc. Amer.*, *65*, 826–829.
Curtiss, S. (1977) *Genie*. New York, Academic Press.
Dawkins, M. (1971) Perceptual changes in chicks: another look at the 'search image' concept. *Anim. Behav.*, *19*, 566–574.
Dennett, D. (1983) Intentional systems in cognitive ethology: "The Panglossian paradigm" defended. *Behav. Br. Sci.*, *6*, 343–390.
De Villiers, J.G. and de Villiers, P.A. (1973) Development of the use of word order in comprehension. *J. Psycholing. Res.*, *2*, 331–341.
De Villiers, P.A. and de Villiers, J.G. (1972) Early judgments of semantic and syntactic acceptability by children. *J. Psycholing. Res.*, *1*, 299-310.
Devine, J.V. and Jones, L.C. (1975) Matching-to-successive samples: A multiple unit memory task with rhesus monkeys. *Behav. Res. Meth. Instrument.*, *7*, 438-440.
Fodor, J.A., Bever, T.G. and Garrett, M.T. (1974) *The Psychology of Language*. New York, McGraw-Hill.
Foss, D.J. and Hakes, D.T. (1978) *Psycholinguistics: An Introduction to the Theory of Language*. Englewood Cliffs, New Jersey, Prentice-Hall.
Fouts, R.S. (1978) Sign language in chimpanzees: Implications of the visual mode and the comparative approach. In F.C.C. Peng (ed.), *Sign Language and Language Acquisition in Man and Ape: New Dimensions in Comparative Pedolinguistics*. AAAS Selected Symposium 16. Boulder, CO, Westview Press.
Fouts, R.S., Chown, B. and Goodin, L. (1976) Transfer of signed responses in American sign language from vocal English stimuli to physical object stimuli by a chimpanzee (Pan). *Learn. Motiv.*, *7*, 458-475.
Fouts, R.S., Chown, W., Kimball, G. and Couch, J. (1976) Comprehension and production of American sign language by a chimpanzee (Pan). Paper presented at the XXI International Congress of Psychology, Paris, July 18–25, 1976.
Fraser, C., Bellugi, U. and Brown, R.W. (1963) Control of grammar in imitation, comprehension and production. *J. verb. Learn. verb. Behav.*, *2*, 121–135.
Gardner, B.T. and Gardner, R.A. (1971) Two-way communication with an infant chimpanzee. In A.M. Schrier and F. Stollnitz (eds.), *Behavior of Nonhuman Primates*, Vol. 4. New York, Academic Press.
Gardner, B.T. and Gardner, R.A. (1975) Evidence for sentence constituents in the early utterances of child and chimpanzee. *J. exper. Psychol.*, *104*, 244–267.

Gardner, B.T. and Gardner, R.A. (1979) Two comparative psychologists look at language acquisition. In K.E. Nelson (ed.), *Children's Language.* Vol. 2. New York, Halsted Press.

Gardner, R.A. and Gardner, B.T. (1969) Teaching sign language to a chimpanzee. *Science, 165*, 664-667.

Gardner, R.A. and Gardner, B.T. (1978) Comparative psychology and language acquisition. *Ann. N. Y. Acad. Sci., 309*, 37–76.

Griffin, D.R. (1981) *The Question of Animal Awareness: Evolutionary Continuity of Mental Experience.* New York, Rockefeller University Press

Griffin, D.R. (ed.) (1982) *Animal Mind—Human Mind.* New York, Springer-Verlag.

Hayes, C. (1951) *The Ape In Our House.* New York, Harper.

Herman, L.M. (1980) Cognitive characteristics of dolphins. In L.M. Herman (ed.), *Cetacean Behavior: Mechanisms and Functions.* New York, Wiley-Interscience.

Herman, L.M. and Arbeit, W.R. (1973) Stimulus control and auditory discrimination learning sets in the bottlenose dolphin. *J. exp. Anal. Behav., 19*, 379–394.

Herman, L.M. and Gordon, J.A. (1974) Auditory delayed matching in the bottlenose dolphin. *J. exp. Anal. Behav., 21*, 19–26.

Herman, L.M., Peacock, M.F., Yunker, M.P. and Madsen, C.J. (1975) Bottlenosed dolphin: Double-slit pupil yields equivalent aerial and underwater acuity. *Science, 139*, 650–652.

Herman, L.M. and Tavolga, W.N. (1980) The communication systems of cetaceans. In L.M. Herman (ed.), *Cetacean Behavior: Mechanisms and Functions.* New York, Wiley-Interscience.

Hinde, R.A. and Stevenson-Hinde, J. (1973) (eds.) *Constraints on Learning: Limitations and Predispositions.* New York, Academic Press.

Hoban, E. (1983) Children's responses to anomalous imperative sentences. Unpublished Master's Thesis, University of Hawaii, May, 1983.

Hockett, C.F. (1960) Logical considerations in the study of animal communication. In W.E. Lanyon and W.N. Tavolga (eds.), *Animal Sounds and Communication.* Washington, D.C.: American Institute of Biological Sciences, Pub. No. 7.

Itard, J.M.G. (1932) *The Wild Boy of Aveyron.* (trans. by G. and M. Humphrey.) New York, Century.

Johnson, C.S. (1967) Sound detection thresholds in marine mammals. In W.N. Tavolga (ed.), *Marine Bio-Acoustics*, Vol. 2. New York, Pergamon.

Keller, F.S. and Schoenfeld, W.N. (1950) *Principles of Psychology.* New York, Appleton-Century-Crofts.

Kellogg, W.N. and Kellogg, L.A. (1933) *The Ape and the Child.* New York, McGraw-Hill.

Lashly, K.S. (1951) The problem of serial order in behavior. In L.A. Jeffress (ed.) *Cerebral Mechanisms in Behavior.* New York, Wiley.

Lilly, J.C. (1961) *Man and Dolphin.* New York, Doubleday.

Lilly, J.C. (1967) *The Mind of the Dolphin: A Nonhuman Intelligence.* New York, Doubleday.

McNeill, D. (1970) *The Acquisition of Language.* New York, Harper & Row.

McNeill, D., Yukawa, R. and McNeill, N.B. (1971) The acquisition of direct and indirect objects in Japanese *Child Devel., 42*, 237–249.

Marler, P. (1977) The evolution of communication. In T.A. Sebeok (ed.), *How Animals Communicate.* Bloomington, Indiana University Press.

Moeser, S.D. (1977) Semantics and miniature artificial languages. In J. Macnamara (ed.), *Language Learning and Thought.* New York, Academic Press.

Nelson, K.E. (1977) Facilitating children's syntax acquisition. *Devel. Psychol., 13*, 101–107.

Nelson, K.E., Carskaddon, G. and Bonvillian, J.D. (1973) Syntax acquisition: Impact of experimental variation in adult verbal interaction with the child. *Child Devel., 44*, 497–504.

Paivio, A. and Begg, I. (1981) *Psychology of Language.* Englewood Cliffs, New Jersey, Prentice-Hall.

Patterson, F.G. (1978*a*) The gestures of a gorilla: Language acquisition in another pongid. *Br. Lang., 5*, 72–97.

Patterson, F.G. (1978*b*) Linguistic capabilities of a lowland gorilla. In F.C.C. Peng (ed.), *Sign Language and Language Acquisition in Man and Ape: New Dimensions in Comparative Pedolinguistics.* AAAS Selected Symposium 16. Boulder, CO, Westview Press.

Patterson, F.G. (1981) Ape language. *Science, 211*, 86–87.

Peters, P.O. and Ritchie, R.W. (1969) Context sensitive immediate constituent analysis—Context free language revisited. *ACM Symposium on Theory of Computing*, Marina del Rey, California.

Petitto, L.A. and Seidenberg, M.S. (1979) On the evidence for linguistic abilities in signing apes. *Br. Lang., 8*, 162–183.

Petretic, P.A. and Tweney, R.D. (1977) Does comprehension precede production? The development of children's responses to telegraphic sentences of varying grammatical adequacy. *J. Child Lang., 4*, 201–209.

Premack, D. (1971) On the assessment of language competence in the chimpanzee. In A.M. Schrier and F. Stollnitz (eds.) *Behavior of Nonhuman Primates. Vol. 4*, pp. 186-228. New York, Academic Press.

Premack, D. (1976) *Intelligence in Ape and Man.* Hillsdale, New Jersey, Erlbaum.

Reynolds, G.S. (1968) *A Primer of Operant Conditioning.* Glenview, Illinois, Scott, Foresman and Company.

Richards, D.G., Wolz, J.P. and Herman, L.M. (1984) Mimicry of computer-generated sounds and vocal labeling of objects by a bottlenosed dolphin. *J. comp. Psychol., 98*, 10–28.

Ristau, C.A. and Robbins, D. (1979) A threat to man's uniqueness? Language and communication in the chimpanzee (Book review). *J. Psycholing. Res., 8*, 267–300.

Ristau, C.A. and Robbins, D. (1982) Language in the great apes: A critical review. In J.F. Rosenblatt, R.B. Hinde, C. Beer and M-C. Busnel (eds.) *Advances in the Study of Behavior.* Vol. 12, pp. 141–255. New York, Academic Press.

Rumbaugh, D.M. (1977) *Language Learning by a Chimpanzee: The Lana Project.* New York, Academic Press.

Rumbaugh, D.M. (1981) Who Feeds Clever Hans? In T.A. Sebeok and R. Rosenthal (eds.), *The Clever Hans Phenomenon: Communication with Horses, Whales, Apes, and People.* New York, New York Academy of Sciences.

Rumbaugh, D.M., Gill, T.V. and von Glasersfeld, E.C. (1973) Reading and sentence completion by a chimpanzee (*Pan*). *Science, 182*, 731–733.

Ryden, O. (1978) Differential responsiveness of Great Tit nestlings, *Parus major*, to natural auditory stimuli. *Zeitschr. Tierpsychol., 47*, 236–253.

Sachs, J. and Truswell, L. (1978) Comprehension of two-word instructions by children in the one-word stage. *J. Child Lang., 5*, 17–24.

Sands, S.F. and Wright, A.A. (1980) Primate memory: Retention of serial list items by a rhesus monkey. *Science, 209*, 938–940.

Savage-Rumbaugh, E.S., Pate, J.L., Lawson, J., Smith, S.T. and Rosenbaum, S. (1983) Can a chimpanzee make a statement? *J. exper. Psychol.: Gen., 112*, 457–492.

Savage-Rumbaugh, E.S. and Rumbaugh, D.M. (1978) Symbolization, language, and chimpanzees: A theoretical reevaluation based on initial language acquisition processes in four young *Pan troglodytes. Br. Lang., 6*, 265–300.

Savage-Rumbaugh, E.S., Rumbaugh, D.M. and Boysen, S. (1980) Do apes use language? *Amer. Scient., 68*, 49–61.

Schlesinger, I.M. (1977) Miniature artificial languages as research tools. In J. Macnamara (ed.), *Language Learning and Thought.* New York, Academic Press.

Seidenberg, M.S. and Petitto, L.A. (1979) Signing behavior in apes: A critical review. *Cog., 7*, 177–215.

Seidenberg, M.S. and Petitto, L.A. (1981) Ape Signing: Problems of Method and Interpretations. In T.A. Sebeok and R. Rosenthal (eds.), *The Clever Hans Phenomenon: Communication with Horses, Whales, Apes and People.* New York, New York Academy of Sciences.

Seligman, M.E.P. (1970) On the generality of the laws of learning. *Psychol. Rev., 77*, 406–418.

Seyfarth, R.M., Cheney, D.L. and Marler, P. (1980) Vervet monkey alarm calls: Semantic communication in a free-ranging primate. *Anim. Behav., 28*, 1070–1094.

Shipley, E.F., Smith, C.S. and Gleitman, L.R. (1969) A study in the acquisition of language: Free responses to commands. *Lang., 45*, 322–342.

Skinner, B.F. (1938) *The Behavior of Organisms*. New York, Appleton-Century-Crofts.
Smith, W.J. (1977) The Behavior of Communicating: An Ethological Approach. Cambridge, Mass., Harvard University Press.
Straub, R.O., Seidenberg, M.S., Bever, T.G. and Terrace, H.S. (1979) Serial learning in the pigeon. *J. exper. Anal. Behav.*, *32*, 137–148.
Strohner, H. and Nelson, K.E. (1974) The young child's development of sentence comprehension: Influence of event probability, nonverbal context, syntactic form, and strategies. *Child Devel.*, *45*, 567–576.
Terrace, H.S. (1979) Is problem solving language? *J. exper. Anal. Behav.*, *31*, 161–175.
Terrace, H.S. (1983) Simultaneous chaining: The problem it poses for traditional chaining theory. In M.L. Commons, A.R. Wagner and R.J. Herrnstein (eds.), *Harvard Symposium in the Quantitative Analysis of Behavior*. Cambridge, Mass, Ballinger.
Terrace, H.S., Petitto, L.A., Sanders, R.J. and Bever, T.G. (1979) Can an ape create a sentence? *Science*, *206*, 891–902.
Terrace, H.S., Petitto, L.A., Sanders, R.J. and Bever, T.G. (1981) Ape language. *Science*, *211*, 87–88.
Thompson, C.R. and Church, R.M. (1980) An explanation of the language of a chimpanzee. *Science*, *208*, 313–314.
Thompson, R.K.R. and Herman, L.M. (1977) Memory for lists of sounds by the bottlenosed dolphin: Convergence of memory processes with humans? *Science*, *195*, 501–503.
Wilson, E.O. (1975) *Sociobiology*. Cambridge, Mass., Belknap.
Winitz, H. (ed.) (1981) The Comprehension Approach to Foreign Language Instruction. Rowley, Mass., Newbury House.
Wood, F.G. (1973) *Marine Mammals and Man: The Navy's Porpoises and Sea Lions*. Washington, D.C., Robert B. Luce.

Reference Note

1. Herman, L.M., Wolz, J.P. and Richards, D.G. (1983) Processing of anomalous sentences by bottlenosed dolphins (unpublished manuscript).

Résumé

Cette étude porte sur la compréhension des phrases impératives dans des langues artificielles par deux dauphins (*Tursiops truncatus*). Le premier dauphin (Phoenix) a été instruit avec un langage acoustique dont les mots étaient générés par un computer à travers des hauts parleurs sous-marins. Avec l'autre dauphin (Akeakamai) on a utilisé un langage visuel dont les mots correspondent aux gestes de bras ou de mains d'un instructeur. Los mots correspondant à des agents, des objets, des modificateurs d'objets, des actions pouvaient se combiner selon une série de règles syntaxiques pour donner une centaine de phrases significatives de 2 à 5 mots. Ces phrases correspondaient à des ordres enjoignant aux dauphins d'effectuer des actions relatives aux objets dénomés ou aux modificateurs. La compréhension se mesurait par l'acuité de la réponse à l'ordre et était testée de façon à ce que soient éliminés les biais contextuels, les indices non linguistiques et les biais de l'observateur. La compréhension des dauphins a été très supérieure à l'aléatoire pour toutes les formes et tous les sens de toutes les phrases possibles engendrées à partir du lexique et des règles syntaxiques. Elle inclut (*a*) des phrases lexicalement nouvelles; (*b*) des phrases structurellement nouvelles; (*c*) des phrases sémantiquement reversibles exprimant des relations entre objets; (*d*) des phrases où un changement dans la place du modificateur changeait le sens donné; (*e*) des phrases conjointes (Phoenix). Parmi les autres capacités on trouve une généralisation importante et immédiate des items lexicaux aux exemplaires des objets; la capacité de moduler les formes des réponses à des mots d'action pour appliquer ces actions de façon appropriée à de nouveaux objets, à des attributs différents ou des autres localisations; la capacité d'effectuer correctement des

instructions en dépit de changements du contexte, du lieu dans lequel la phrase est présentée ou de l'instructeur qui donne les ordres; la capacité à distinguer entre différents concepts relationnels, à répondre correctement aux phrases en l'absence des objets jusqu'à 30 secondes après l'instruction (tests de déplacement) et la capacité à rapporter correctement que l'objet designé n'était pas présent dans le bassin contrairement aux autres objets (Akeakamai). Le traitement correct d'une grammaire de gauche à droite (Phoenix) ou d'une grammaire inverse (Akeakamai) montre que des règles syntaxiques entièrement arbitraires peuvent être comprises et que la compréhension des mots fonctionnels se présentant tôt dans la phrase est interpretée par les dauphins sur la base des mots suivants inclue, dans au moins un cas, des mots non-adjacents. Cette approche de la compréhension se distingue radicalement de l'emphase sur la production que l'on trouve dans les études des capacités linguistiques des primates. Les résultats obtenus offrent les premières preuves convaincantes de la capacité des animaux à traîter les traits syntaxiques et sémantiques des phrases. La capacité des dauphins à utiliser les modalités visuelles comme les modalités acoustiques dans ces tâches souligne la dépendance amodale de leur capacité de compréhension des phrases. On présente des comparaisons entre les performances des dauphins, celles des primates entrainés pour le langage et celles des jeunes enfants, sur des tâches reliées et pertinentes.