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34 Exploring the Cognitive World of the Bottlenosed Dolphin

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An exceptionally large brain, a high degree of sociability, and easy trainability make the bottlenosed dolphin (*Tursiops truncatus*) an ideal species for studying intellectual processes and potential. Accordingly, our long-term research program into dolphin cognition, now spanning some 30 years, with as many as 22 years of study of individual animals, has been directed toward the description and analysis of these processes and potential. The philosophy guiding this approach is that the intellectual potential of a long-lived, presumptively intelligent species (such as the dolphin) is best revealed through a long-term program of intensive, special education in a culture that values education. Since these conditions surely favor the emergence of the full flower of human intellect, can comparable conditions also reveal the intellectual potential of other targeted species? To this end, we have worked intensively with different individual animals, using a broad-brush, multilevel approach that includes studies of sensory processes, cognitive characteristics, and communication. These different areas of study have increased our understanding of the perceptual, cognitive, and social worlds of the dolphin.

The brain of the adult bottlenosed dolphin is about 25 percent heavier than the average adult human brain (Ridgway 1990). Inasmuch as larger mammals tend to have larger brains, a more meaningful metric is to compare actual brain size with that expected for the species' body size (i.e., relative brain size) (Jerison 1973). Measures of relative brain size place the bottlenosed dolphin, and two or three other closely related delphinid species, second only to humans and well above the great apes (Marino 1998; Ridgway and Tarpley 1996). The dolphin cortex has a degree of fissurization and a surface area exceeding that of the human brain, although its depth (thickness) (ca. 1.3–1.8 mm) is shallower than that of the human brain (ca. 3.0 mm) (Ridgway 1990). In addition, the size of the cerebellum relative to the total brain is significantly larger in the dolphin than in the human (Marino et al. 2000). Recent work has demonstrated that the cerebellum is involved in cognitive processing in addition to its role in motor control (Leiner et al. 1995; Fiez 1996).

Social living and social pressures may be major selection forces driving the evolution of intellect (Humphrey 1976; Herman 1980); among cetaceans, as well as among other highly social mammalian species, social living can lead to the development of new behaviors and traditions through cultural transmission mechanisms, such as imitation and teaching (Rendell and Whitehead, 2001). Bottlenosed dolphins, as well as many other species of toothed whales (odontocetes), live in complexly organized social units (e.g., Conner et al. 1992). To function effectively within these units, the young dolphin must undergo extensive learning about the conventions and rules of the society, about cooperative and collaborative activities, and about the identities and even personalities of group members and associates (Herman 1991). The protracted period of development and dependence of young dolphins on their mothers and other group members allows the time and opportunity for extensive social learning to take place.

Dolphins maintained in oceanaria or in research facilities can readily transfer their social awareness and responsivity to the human caregivers. If the caregivers acknowledge and give proper attention to the social nature of the dolphin, a strong interest in humans can develop that allows for a close and cooperative long-term working relationship between the two species. Under these conditions, it becomes possible to work with a dolphin for protracted periods within behavioral research or training paradigms (e.g., Defran and Pryor 1980).

At the end of the 1960s, when I began to work with bottlenosed dolphins, there was little substantive material on the cognitive abilities of this

species, such as might be obtained from experimental studies using the rules for scientific evidence (a few exceptions were studies by Bastian 1967; Kellogg and Rice 1966; Pryor et al. 1969). Instead, there was at times relatively unrestrained speculation about such things as dolphin language, oral traditions, and philosophies, inferred from the large brain of this species (see e.g., Lilly 1961, 1967).

My goal then was to establish factual bases for inferences about intelligence and other cognitive traits of dolphins through experimental laboratory behavioral research. To do this, I would have to study not only intelligence, but also fundamental issues about dolphin sensory abilities and learning. In the late 1960s, research on dolphin sensory processes was almost entirely focused on the dolphin's auditory and vocal abilities, especially echolocation (see e.g., Busnel 1967; Au 1993). Because of findings of exceptional hearing capabilities, a highly developed echolocation system, and the large extent of the auditory cortex (Ridgway 1990), dolphins were generally regarded as strict auditory specialists, making their way through their world primarily through sound—either passively listening or actively echolocating. Vision was typically believed to be relatively poor, or to be a secondary sense of minor functional value compared with echolocation (for a brief review of this early view, see Kellogg and Rice 1966).

I began my work by mapping out some basic learning and memory abilities of dolphins, studying their sense of vision, and filling in some unstudied areas on hearing. We (my students, research colleagues, and I) used the preliminary phases of these studies to develop a better understanding of stimuli and procedures that would best reveal competencies. Later studies built on the procedural knowledge that we and the dolphins had acquired, as well as the accumulating declarative and conceptual knowledge gained by the dolphins. It was soon apparent that dolphins were highly trainable (Defran and Pryor 1980), but that teaching models were in many cases more efficient and more effective than training models based on traditional instrumental conditioning techniques.

Our teaching models employ techniques that may commonly be used with young children, such as showing and demonstrating. In dolphins this entails such things as touching the dolphin with the correct object of a pair, pointing toward the correct location for a response, or actually leading the dolphin toward the correct object or location. When introducing new problems, we take care that they are at an initial level likely to lead to success, and then increase the difficulty and complexity at a rate or in contexts that tend to promote overall success. For example, a new discrimination or transfer test will generally be presented in a probe fashion, embedded among earlier established discriminations or previously successful transfer tests. Hence, even if the probes are responded to incorrectly, successful responses to the familiar materials are highly likely and the overall success rate will be high. Under such conditions, the dolphins develop a positive attitude toward the introduction of new materials, often offering spontaneous responses, and seemingly anticipating success.

Using these procedures, we have carried out studies of sensory abilities, cross-modal matching, memory, conceptual processes, vocal and motor mimicry, language understanding, self-awareness, and the mental representations that may underlie performance in these various cognitive tasks. Some of our more important findings in these areas are reviewed here.

Visual Processes

The degree to which a species can process complex information through different sensory systems, and the extent to which these systems are integrated and can serve as interfaces to higher cognitive centers, provide some measure of the cognitive flexibility of the species. The eye of the dolphin has clearly undergone many progressive

adaptations to the underwater world (Dawson 1980). Our study of the visual acuity of bottlenosed dolphins revealed that good resolution was maintained both in air and underwater (Herman et al. 1975) and was roughly equivalent to that of pinniped species and many nonprimate terrestrial mammals. Color vision is absent or weak, as it is in most nonprimate mammals (Madsen and Herman 1980). Furthermore, we found that the visual system can clearly serve as a valuable interface to higher cognitive centers that deal with concepts, abstractions, and representations (Herman 1990).

Sensory Integration

Our findings on cross-modal matching have shown that the dolphin's visual and echolocation senses are highly integrated and that each directly yields object-based percepts that easily translate across these senses (Pack and Herman 1995; Herman et al. 1998). These and other related findings reveal that the perceptual world of the dolphin is monitored and richly organized through both the auditory and the visual domains. Dolphins should no longer be regarded as strict auditory specialists, but as multimodal animals, interfacing with their world through vision as well as hearing and echolocation.

Memory and Concept Learning

Memory is the bedrock on which learning and other higher cognitive processes rest. We have carried out extensive studies of short-term memory in dolphins as well as their capability for rule learning and for the development of abstract concepts (Herman et al. 1993b, 1994). In keeping with our findings on good visual acuity, our studies have shown that immediate memory for things seen (Herman et al. 1989) and for sounds heard (Herman and Gordon 1974; Thompson and Herman 1977) are each of high fidelity and endurance. In the Thompson and Herman (1977)

study, the dolphin was able to reliably indicate whether a probe sound occurring at the end of lists of sounds ranging from two to as many as six different sounds was or was not a member of that list. A strong recency effect was found, with sounds early in the list remembered less well than sounds late in the list. In studies of concept learning, Herman and Arbeit (1973) demonstrated that a dolphin could learn a generalized win-stay, lose-shift rule in a two-alternative forced-choice test using pairings of novel sounds. The development and nearly errorless application of an identity-matching concept was also shown in the previously cited visual and auditory memory studies. A dolphin was also able to learn and apply a same-different rule to new pairings or triplets of objects (Herman et al. 1994; Mercado et al. 2000).

Imitation

Imitation is a complex skill and a demanding cognitive trait. However, the definition of imitation, and which animals can imitate, are currently matters of intense debate among researchers (see. e.g., Whiten and Ham 1992; Heyes 1993). If imitation is within the capabilities of a species, it can be an efficient mechanism for social learning.

Dolphins are capable of extensive vocal and behavioral mimicry, a seemingly unique ability among nonhuman animals. Dolphins have demonstrated motor imitation of other dolphins or of humans (Richards et al. 1984; Herman, in press). In these studies the dolphin understood imitation as a concept that could be applied to any newly modeled sound or behavior; furthermore, imitation occurred only if the experimenter requested it through an abstract symbolic sound or gesture.

Dolphins, as imitative generalists (Herman, in press), must be able to mentally represent the behaviors of others or of themselves in order to copy or reproduce those behaviors. When a dolphin imitates a human's motor acts, it must in some cases form analogies between its body im-

Figure 34.1
Motor mimicry of a human (graduate student Amy Miller) by the dolphin Elele. The behavior is not trained. Dolphins are excellent motor mimics of each other in their natural world and, remarkably, easily transfer this skill to imitate human motor acts. In doing so, the dolphin must relate its body image to the human's perceived body plan, creating analogies in some cases. In the image, the dolphin uses its raised tail as an analogy to the human's raised leg, as well as imitating the back bend of the human.

age and the human's body plan. For example, if the human raises a leg in the air, the dolphin will raise its tail (figure 34.1), and if the human waves his or her arms, the dolphin will wave its pectoral fins. The unquestionably extensive imitative abilities of the dolphin may derive from the naturally occurring highly synchronous or closely coordinated natural behaviors often seen among pairs or groups of dolphins. Synchrony may function to assist in tasks such as foraging and prey capture, but may also be an expression of social affiliation.

Language Learning

Semantics and syntax are considered the core attributes of any human natural language (Pavio and Begg 1981). Our studies of language comprehension have revealed capabilities in the dolphin for processing both semantic and syntactic information (Herman et al. 1984; Herman 1986; Herman and Uyeyama 1999). The primary syntactic device used in our language studies has been word order. The dolphin is capable of understanding that changes in word order change

meaning. It can respond appropriately, for instance, to such semantic contrasts as *surfboard person fetch* (take the person to the surfboard) and *person surfboard fetch* (take the surfboard to the person).

In these language studies, the dolphin demonstrated an implicit representation and understanding of the grammatical structure of the language. For example, the language-trained dolphin Akeakamai was able to spontaneously understand logical extensions of a syntactic rule (Herman et al. 1984) and was able to extract a semantically and syntactically correct sequence from a longer anomalous sequence of language gestures given by a human (Herman et al. 1993a). To perform this extraction, the dolphin in some cases had to conjoin nonadjacent terms in the sequence. For example, the anomalous string glossed as *water speaker Frisbee fetch* violates a syntactic rule in that there is no rule that accommodates three object names in a row. However, embedded in this sequence are two semantically and syntactically correct three-item sequences, *water Frisbee fetch* (bring the Frisbee to the stream of water), and *speaker Frisbee fetch* (bring the Frisbee to the underwater speaker). In sequences of this type, the dolphin almost always extracted one or the other of the correct three-item sequences and operated on that implicit instruction. In theory, in responding to these anomalous sequences, the dolphin utilized its implicitly learned mental representation or schema of the grammar of the language to include not only word-order rules but also the semantic rules determining which items are transportable and which are not (neither the stream of water nor the underwater speaker affixed to the tank wall can be transported). No explicit training was given for these rules.

Representation

One of the issues in animal language studies is whether the symbols used to refer to objects or actions function as representations of those things; this is the problem of linguistic reference. For example, when a tutored ape uses a symbol for candy, does it understand that the symbol refers to or represents candy, or does it merely treat the symbol as a means to obtain candy (by using it on seeing candy present)? Much of the early ape language work failed to show that the symbols used were understood referentially (Savage-Rumbaugh 1986). The clearest indication that the dolphin Akeakamai understood the gestural symbols of her language referentially was her ability to report "yes" or "no" (by pressing one or another of two paddles) in response to gestural questions asking whether specific gesturally named objects were or were not present in her tank world (Herman and Forestell 1985). The ability to understand symbolic references to absent objects is one of the clearest indicants that the symbols represent the referent. In addition, the dolphin understood that if an experimenter pointed to a distal object, it was a reference to that object (Herman et al. 1999).

Television scenes are representations of the real world and, as humans, we respond to them as we might to the real world but understand that they are not the real world. A cat might respond to a television image of a moving bird in the same way it would respond in the real world, failing to discriminate between the representation and the real world. In other cases, the cat or other animals might simply ignore the television scene, seemingly failing to recognize that anything meaningful or relevant is occurring. The latter behavior has been reported, for example, for language-trained common chimpanzees, who only learned to respond appropriately to television scenes after long periods of watching their human companions responding (Savage-Rumbaugh 1986).

In contrast, all four of our dolphins, on the very first occasion that they were exposed to television, responded spontaneously and appropriately to televised images of people gesturing to
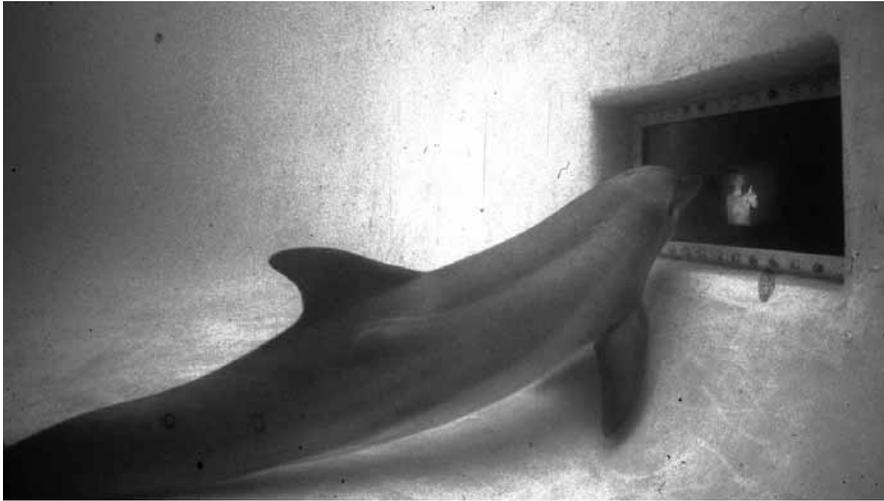
Figure 34.2
The dolphin Akeakamai watching the image of a person projected live on a television screen placed behind an underwater window. Akeakamai watches a sequence of gestures by the trainer expressed to her in a familiar gestural language. The sequence conveys an instruction to the dolphin, who then carries out the instruction as accurately and reliably as she does when instructions are conveyed to her in the real world. No training was involved in responding to TV images. Akeakamai responded accurately to TV instructions the first time she experienced them, which was also the first time she experienced television of any sort.

them (Herman et al. 1990). They responded in the same way as they did to live people, faithfully carrying out the gestural instructions conveyed by the image (figure 34.2). The dolphins understood, however, that the television scene was not the real world. For example, if the trainer tossed a ball in the air and then gestured to the dolphin to imitate the action, the dolphin did not attempt to retrieve the ball in the television scene, but used one in its real world.

Self-Awareness

Self-awareness is a multidimensioned concept that has usually been studied through the mirror self-recognition mark test (Gallup 1970). We chose to ask a different question about self-awareness: was a dolphin aware of its own recent behaviors (Mercado et al. 1998)? We taught the dolphin an abstract gesture, which we called "repeat." If this gesture occurred, it signaled the dolphin to do again what it just did; in essence to imitate its own behavior. A behavior was to be repeated only if that particular gesture was given. As an alternative to the repeat signal, some other gesture might be given that called for a behavior different from the one just executed. The demonstrated ability of the dolphin to reliably repeat or not repeat its previous behavior indicated that it maintained a mental representation of the behavior last performed and updated that as each new behavior was performed.

Conclusions

It seems clear that many of the studies we undertook would not have been possible, and

many of the dolphin capabilities described would have gone unrevealed, without the implementation of the initial guiding educational philosophy. Immersion in a long-term program of intensive special education results in the accumulation of knowledge, concepts, rules, strategies, and a general level of intellectual sophistication that allows for the understanding and solution of a broad range of increasingly complex problems or tasks. Many of the later studies we carried out were not anticipated earlier (for example, interpretation of television scenes) because the groundwork was not yet in place, and the next step was not evident. The educational approach we used with the dolphin, a species with a life span stretching into the 40s or 50s, is not possible of course with short-lived species, but is applicable to such interesting species for cognitive investigation as elephants and the great apes. The work we have carried out with dolphins has expanded our understanding of the perceptual and cognitive world of this species, and certainly has demonstrated that the dolphin's reputation for intelligence is well earned.

Intelligence is of course a term with many definitions and interpretations, but I prefer to view it as flexibility of behavior (Herman and Pack 1994). By flexibility, I mean the ability to organize and carry out behaviors that are appropriate to new situations, new contexts, or new events, and that are not necessarily genetically determined or part of the species' naturally occurring repertoire of behaviors. Flexibility is demonstrated then by the animal's ability to go beyond the boundaries of its naturally occurring behaviors or the context of its natural world.

Perhaps the most daunting task facing potential investigators of dolphin cognition is to find a place where such studies can take place. Facilities such as our Kewalo Basin Marine Mammal Laboratory in Honolulu are rare, and opportunities for research may be limited mainly to oceanaria or marine parks. At such places, however, the investigator may be constrained by the competing uses of the animals for demonstrations or display. This situation may be improving, though, as the benefits of research, its educational value, and even its display value come to be appreciated by the managers of these oceanaria and parks. Given the availability of facilities, and the access to animals, there is almost an unlimited opportunity for new discoveries about dolphin cognition. Topics such as theory of mind, social awareness, imitation, productive language, interanimal communication, and much more, are relatively unstudied and await only the investigator and the opportunity.

Acknowledgments

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