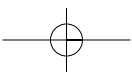
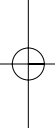
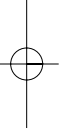
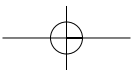
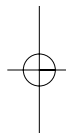
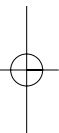
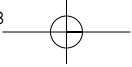


Part VI

Behaviour and cognition in symbolic environments





Chapter 20

Intelligence and rational behaviour in the bottlenosed dolphin

Louis M. Herman

Abstract

A rational animal is defined as one that can perceive and represent how its world is structured and functions, and can make logical inferences and draw conclusions that enable it to function effectively and productively in that world. Further, a rational animal is able to incorporate new evidence into new perspectives of the world and can then modify its behaviours appropriately—in effect creating a new or revised model of the world in which it is immersed. Rational behaviour is necessarily built on the bedrock of general and specific intellectual capacity. Intelligence, a multidimensional trait, may appear to various degrees in various behavioural, cognitive, or social domains. Data and observations are presented on dolphin cognitive performance and on apparent rational responses within four intellectual domains within the context of a variety of empirical studies that we have conducted. These domains are: (a) the declarative (semantic or representational) domain (does the dolphin display knowledge or understanding about things?); (b) the procedural domain (does the dolphin exhibit competency in means, operations, or methods?); (c) the social domain (does the dolphin reveal social awareness and appropriate responsiveness in social interactions or relations?); and (d) the domain of the self (does the dolphin exhibit knowledge or awareness of itself?). In each case, the particular experimental paradigms are briefly outlined and instances of apparent inferential or creative acts within each paradigm are given.

20.1 Introduction

The bottlenosed dolphin (*Tursiops truncatus*) is a highly social, cosmopolitan species found throughout the temperate and tropical zones of the world's oceans. It is a compelling subject for study of cognitive attributes and abilities. Early motivations for

such study were reports of the remarkable development of the bottlenosed dolphin brain (e.g. Kruger 1966; Lilly 1961), including its large size and the extensive fissurization of the cerebral cortex. The surface area of the cortex exceeds that of the human brain, although the total cortical volume is only about 80 per cent of the human volume (Ridgway 1990). In absolute size, the bottlenosed dolphin brain is somewhat larger than the human brain (Ridgway 1990). However, because larger animals tend to have larger brains, in part to control the greater bulk of somatic tissue, comparative brain studies focus on *relative* size, expressed as a ratio of brain mass to body mass (Jerison 1973; Lashley 1949). An 'encephalization quotient' (EQ) (Jerison 1973) may be computed from the mean values for a species, expressed mathematically as $EQ = \text{brain weight}/0.12 (\text{body weight})^{0.67}$. The exponent 0.67 refers to the general relationship between mammalian brain mass (Mbr) and body mass (Mbo), or $Mbr = aMbo^b$. An exponent, b , of 0.75 is sometimes offered instead of 0.67. Values of EQ greater than 1.0 indicate a brain mass greater than that expected for the corresponding body mass. The largest EQ values (~ 7.0) occur for humans; second are four dolphin species, including the bottlenosed dolphin, with EQs ranging from 4.14 to 4.56 (Marino 2002). These values surpass those of non-human primates, including the great apes, the latter with EQs ranging from 2.09 to 3.86 (Jerison 1973; Marino 1998; Ridgway 1990).

Developmental and social factors add to the interest in bottlenosed dolphin cognitive abilities. These animals are long-lived and enjoy a protracted period of nurturance and development, not unlike the human. In the wild or in captivity, male dolphins may live into their 40s and females into their 50s (Reynolds *et al.* 2000). Physical growth continues until 15 to 20 years of age. Age at sexual maturity differs somewhat among different populations of bottlenosed dolphins, but, in general, female sexual maturity occurs between 7 and 9 years of age (range 5–12) and males between 10 and 13 years. This protracted period of development, together with the close sustained affiliation of the calf with the mother and her associates, allows the youngster the time and opportunity to learn and develop the multitude of behavioural and social skills necessary for effective functioning within its world. The social world, in particular, can be highly intricate and complex (see for example various chapters in Reynolds *et al.* 2000).

Early work with bottlenosed dolphins housed in aquaria or in marine parks revealed their ready trainability and their high degree of sociability, furthering interest in the study of their behaviours, sensory capabilities, and cognitive skills. Much of the early research focussed on sensory features, especially the hearing and sound production systems, and was principally carried out at US Navy facilities or was Navy sponsored (e.g. see Wood 1973). These studies documented the dolphin's¹ remarkably well developed echolocation (sonar) system, capable of detecting differences among objects

¹ Unless otherwise specified, henceforth the term 'dolphin,' when used alone, refers to the bottlenosed dolphin *T. truncatus*.

in size, shape, material composition, thickness, and many other factors (see various chapters in Busnel and Fish 1980, and later reviews in Au 1993; also see Herman *et al.* 1998). Based on these competencies and on the large size of the auditory area of the brain and the eighth (acoustic) cranial nerve, some insisted that the large size of the dolphin brain is merely an evolutionary response to the advantages of echolocation and not an indicant of general processing power or intelligence. This specious argument re-emerges frequently. For example a recent article in Smithsonian magazine states:

... not all marine biologists agree that dolphins and other cetaceans are especially smart. Though a dolphin has an impressive ability to be trained to perform tricks, skeptics say that this behavior reflects not intelligence—the capacity to make choices based on weighing possible consequences—but conditioning, a programmed response to a stimulus like food. In that view, dolphins are no more intelligent than dogs, horses, or for that matter parrots. In addition, notions about the dolphin's exceptional intelligence have been based on the observation that they have disproportionately large brains. Again, some scientists point out that the animal's brain is wired chiefly for sonar processing and motor control, not 'thinking' (Dowling 2002, p. 49).

In contrast to these types of statements, Pabst *et al.* (1999) state strongly that 'there is insufficient evidence to assert that odontocetes (toothed whales, including dolphin species) use relatively large areas of the cerebral cortex for auditory processing' (p. 59). Further, if the large dolphin brain were primarily for auditory processing, we would expect to find that there was little remarkable about dolphin cognitive abilities. As I stated in an early review of dolphin cognitive characteristics '... descriptions (of the dolphin brain) hint at the intellectual potential of the species, which ultimately depends on brain structure and organization. . . However, it is behavior, not structure, that measures the intellectual dimensions and range of the species. . .' (Herman 1980, pp. 363–364). Behavioural studies we carried out during the years subsequent to 1980, as well as many completed earlier, have catalogued a wealth of data on dolphin cognitive traits and abilities that together provide compelling evidence for a level of intelligence commensurate with expectations based on the size, structure, and development of the brain.

The concept of 'intelligence' is thus highly germane to any discussion of dolphin cognitive capabilities and of rational behaviour, but there is far from a consensual definition of it, especially for animals. In my view, however, intelligence manifests itself in *behavioural flexibility*, the ability to modify or create behaviour adaptively in the face of new evidence or changes in world conditions (cf. Herman and Pack 1994). The intelligent animal, in principle, can go beyond the boundaries of its familiar world, and beyond its biologically programmed or learned repertoire of behaviours that enable successful responding in that familiar world, to function effectively in new worlds or in new world conditions.

Intelligence is a multidimensional trait that may appear to various degrees in various behavioural, cognitive, or social domains. Effective functioning in multiple domains

would suggest rich behavioural flexibility. In this chapter, I consider four domains in which we have obtained data on dolphin cognitive performance and rational responding. These are: (a) the declarative (semantic or representational) domain (does the dolphin display knowledge or understanding about things?); (b) the procedural domain (does the dolphin exhibit competency in means, operations, or methods?); (c) the social domain (does the dolphin reveal social awareness and appropriate responsiveness in social interactions or relations?); and (d) the domain of the self (does the dolphin exhibit knowledge or awareness of itself?). I use these domains to categorize our findings and to illustrate the behavioural flexibility of the dolphin that extends even to unusual innovative behaviours. Creating new effective responses or new solutions to problems provides strong evidence for behavioural flexibility and for an understanding of the conditions existing at the moment within a particular domain. These four domains are of course not entirely independent of one another. For example knowledge of oneself may influence how one responds in particular social settings. Knowledge of how something works may define or enhance one's concept of the thing itself.

Rational behaviour is, then, necessarily built on the requisite bedrock of general and specific intellectual capacity. To understand what I mean by rational behaviour, I begin with the following premise: *a function of a mind is to create a model of the world.*² This model then influences our perceptions and our behaviours, and may allow us to function effectively in that world, provided our model reasonably reflects reality. However, there is not just one world, but many worlds within our life experiences. For the human, the model of the world may differ with context, situation, or culture; as a simple example, consider the different world models of a teenager for home, work, school, sports, and peer group relationships. A model that yields effective behaviour in one situation may be inappropriate or even counterproductive in another. When we bring the dolphin from the wild into the laboratory situation, it enters a radically different world. The ability of the dolphin to function effectively, even creatively, within that new world is contingent on its learning how that world is structured, how it operates, who the actors are, what features are significant, what rules and contingencies apply, and much more; effective functioning, in turn, provides inferential evidence that the dolphin has created an accurate model of that world.

A rational animal may then be defined as one that can perceive how the current world it occupies is structured and how it functions, and can then make logical inferences and draw conclusions that enable it to function effectively and productively in that world. Further, a rational animal is able to incorporate new evidence into new perspectives of the world and can then modify its behaviours appropriately—in effect creating a new or revised model of the particular world in which it is immersed.

² Jerison (1973) has argued similarly that 'the construction of the model (of the world) ... is the work of the brain.' (p. 17).

Can we find evidence, in our structured laboratory settings, for these types of rational responding by the dolphin? To answer this question, I return to the different domains described earlier and examine the evidence for flexible and appropriate responding within those domains. Much of the evidence is taken from our published literature, but some is taken from observations or procedures that may not have appeared in these reports. In each case, the essentials of the paradigm in effect are summarized briefly to provide an appreciation of that context, and then specific instances are given in which rational responding seems evident within that paradigm.

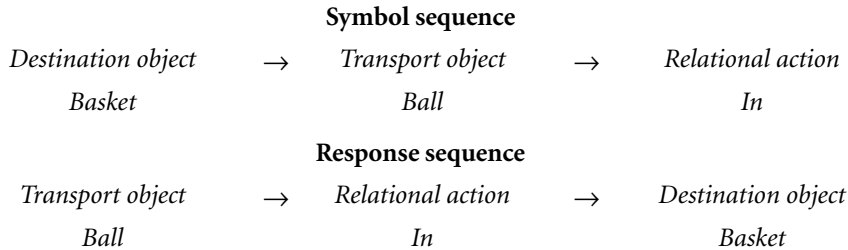
20.2 Declarative and procedural domains

Intelligence within the declarative domain can be revealed by the ability to perceive the nature, properties, or characteristics of things and to understand symbolic or direct references to those things. Intelligence within the procedural domain can be revealed by the capacity to understand how things function or how to do things (see Anderson 1978 for a discussion of declarative and procedural knowledge). Declarative and procedural knowledge may exist independently or may intertwine. We understand, for example, what the word 'car' refers to, but we may not know how to drive. These two domains are discussed together here, because for some of the paradigms we have employed, both declarative and procedural knowledge is required—knowing what things are and knowing how to manipulate those things. Five paradigms requiring declarative or procedural knowledge, or both, are presented in the following sections.

20.2.1 Understanding of the semantic and syntactic components of a symbolic system: knowing what things are and how to manipulate them

We constructed a language-like symbolic system to test the dolphin's understanding of complex instructions delivered through sequences of gestures, with the sequences governed by both semantic and syntactic rules (Herman *et al.* 1984; Herman 1986). The most complex instructions were expressed through so-called relational sequences, which required the dolphin to construct a relationship between two objects, by transporting one to the side of another (indicated by use of the action term Fetch) or by placing one object on top of or inside of another (indicated by use of the action term In/On). To insure that the dolphin was processing the entire sequence as a cohesive unit, and not simply responding to each gesture in turn ('word-by-word' processing), we constructed an 'inverse' grammar. In this grammar, the order in which the gestural symbols appear is uncorrelated with the order in which responses to those symbols must occur. The dolphin cannot, therefore, respond to each symbol in turn as it occurs, as it might in a linear (left-to-right) grammar, but must wait until the entire sequence is completed before it can know

what to do. For example consider the symbol sequence and the corresponding response sequence illustrated below:



The gestural symbol sequence *Basket Ball In* requires the dolphin to place the floating ball in the floating basket. *Basket* is the first symbol given, but it signifies the destination object, the last item in the response sequence. *Ball* is the second symbol presented, but it signifies the transport object, the first object that must be responded to. *In*, the final symbol, defines the type of relationship to construct, but is the second operation in the response sequence. In the sequence illustrated, *Basket* functions grammatically as the indirect object of the verb *In*. However, in other sequences, the occurrence of *Basket* in the first position does not necessarily signal that it will have a grammatical function as indirect object. Thus, a symbol sequence might be, for example, *Basket Over*, in which case *Basket* functions grammatically as the direct object of the verb and the dolphin would be required to act directly on the basket by leaping over it. Thus, the grammatical function of an initial object symbol is not clear until additional symbols appear. In addition to the constraints on interpretation already listed, the symbol sequence *Basket Ball In* might instead have terminated with *Fetch* rather than *In*, in which case the dolphin would be required to bring the Frisbee to the side of the basket, rather than put it inside. The sequence might also have terminated with the gestural symbol *Erase*, which nullifies the preceding terms and requires the dolphin to do nothing other than attend again to the experimenter.

All of this is understood functionally by the dolphin as implied by its appropriate responding to a variety of relational sequences. To carry out the instruction conveyed by a relational sequence of symbols, the dolphin must take account of both the semantic value or referent of the symbol and the order in which symbols occur, as governed by the syntax inherent in the inverse grammar. For example the two three-symbol sequences illustrated below consist of the same three terms but the order of the destination and transport objects are reversed in the second sequence relative to the first. The first sequence instructs the dolphin to bring the swimmer to the surfboard while the second requires that the surfboard be brought to the swimmer.

Surfboard swimmer fetch
Swimmer surfboard fetch

20.2.1.1 Evidence for rational responding

There were many occasions when the dolphin demonstrated apparent inferential reasoning to achieve a solution to a new semantic proposition or new syntactic structure. Three examples can be given. First, many semantically reversed sequences of the type just illustrated were given to the dolphin Akeakamai ('Ake') and many had not been experienced by her previously. That is, they were novel instructions. Nonetheless, in the majority of cases, she was able to carry out the instructions correctly, in effect inferring that various semantic entities could be inserted into the slots within familiar syntactic frames (Herman *et al.* 1984; Herman 1986).

Second, we probed Ake's responses to anomalous sequences that violated either the semantic rules or the syntactic structure of sequences (Herman *et al.* 1993). For example, the sequence *Water Phoenix Fetch*, although structured correctly syntactically, is a semantic anomaly in that it asks Akeakamai to transport the dolphin Phoenix to the stream of water entering the pool. Phoenix cannot or will not be transported. Ake responded to this request, and to most other semantic anomalies of this type, by not taking any action at all, instead remaining at station 'staring' at the experimenter. In effect, she rejected the instruction. When given a gestural sequence that violated a syntactic rule, Ake typically decomposed the sequence to find a subset of items that were syntactically and semantically proper and acted on that. For example the sequence *Speaker Water Pipe On* is a syntactic anomaly in that there is no syntactic structure that allows for three object names in a row. Ake responded to this sequence by essentially conjoining the items *Speaker Pipe On*, a proper instruction, and placed the length of pipe floating in her pool on top of the speaker affixed to the pool wall. Note that in this case, as well as in many other similar anomalous sequences of this type, she conjoined nonadjacent items.

Third, Ake was not only familiar with three-item relational sequences of the type illustrated above, but was also familiar with a *non-relational* three-item sequence consisting of a locative term (*Left* or *Right*) followed by an object term, and then by an action term. For example, *Left Hoop Though* instructs Ake to swim through the hoop to her left (and not through the one to her right). To probe Ake's ability to infer solutions to new syntactic structures, for the first time, and without any training, we gave her a four-item sequence combining the relational and non-relational structures (Herman *et al.* 1984). Her understanding was immediate. Examples of four-item structures are *Right Hoop Frisbee Fetch* and *Hoop Right Frisbee Fetch*. The first sequence instructs Ake to take the Frisbee to the hoop on her right while the second instructs her to take the Frisbee on her right to the hoop. She also immediately understood, without training, five-item semantically contrasting sequences, such as *Right Basket Left Ball In* (put the ball on your left in the basket on your right) and *Left Basket Right Ball In* (put the ball on your right in the basket on your left) (Herman 1986). Ake therefore correctly inferred the properties of these new four- and five-word sequence structures, and made the appropriate response, strictly from her knowledge of shorter structures.

Fourth, Ake was able to rearrange objects in her pool spontaneously and appropriately in order to carry out the instruction given to her. Examples of spontaneous rearrangements innovated by Ake include: (a) lifting a hoop lying flat on the bottom of the tank into an upright position and then darting through it to complete the instruction *Hoop Through* ('swim through the hoop'); all previous instructions of this type were to hoops floating at the surface or suspended midway in the water column; (b) moving a surfboard resting against the wall of the pool to the centre of the pool and then leaping over it, in response to the instruction *Surfboard Over* ('jump over the surfboard'); and (c) removing a ball already in a basket and then quickly replacing it in the basket in response to the instruction *Basket Ball In* ('put the ball in the basket'). These examples illustrate the dolphin's ability to rearrange the physical objects of her world in order to effect a solution to a problem. They also illustrate that the various items of her language system were understood at the level of a concept—for example, what *through*, *over*, and *in* mean in a general sense.

20.2.2 Improvising an efficient strategy: fetching multiple objects at once

At the conclusion of a session examining competency in the gestural language paradigm, there may be as many as 11 objects floating about in the dolphin's pool, most of which may have been referred to during the course of testing. To end the session, the tankside experimenter, using the single gesture *Fetch*, asks Ake to retrieve the objects so they may be removed from the pool. Ake understands that in the absence of a specified destination object preceding the *Fetch* gesture, all objects are to be brought to the experimenter.

20.2.2.1 Evidence for rational responding

Initially, we expected that Ake would bring back one object at a time, as *Fetch* had been trained in that manner, and that after each retrieval the experimenter would simply repeat the *Fetch* gesture to request another object, until all were returned. Instead, Ake spontaneously developed a strategy of bringing back multiple objects at once. Typically, she 'rounds up' several objects and then carries the group back at once, perhaps wearing a hoop around her head, pushing a Frisbee with her rostrum, pushing a pipe with a pectoral fin, and carrying the surfboard on her back. Apparent planning can be seen in her retrieval strategy, in that she will usually first swim to the most distant object, carry it closer to another object, and then carry the two to a third object, and so forth. On her first retrieval attempt, as many as three or four objects may be gathered and brought *en masse* to the experimenter. As the number of objects is reduced, fewer objects are available for retrieval, and fewer are brought back at once.

An interesting extension of her fetching behaviour may occur between testing sessions or in the evenings. During these free intervals, Ake sometimes can be heard producing a distinctive, loud whistle, her head lifted high out of the water. We have

learned that she is calling to us to take a piece of debris she is holding in the tip of the mouth (e.g. it may be a leaf that blew into her outdoor pool). She holds the item gently; it is clearly visible to us. When someone responds by coming to the edge of the pool Ake will swim to that person and offer the debris. The person takes the offering and then goes to the fish kitchen, returning after a few minutes with a fish for Ake, as well as one for each of the other dolphins who are waiting patiently at poolside next to Ake. The behaviour is obviously rewarded but was not explicitly taught. Also, Ake's distinctive calling behaviour was of her own design.

20.2.3 Tests of referential understanding: understanding references to absent objects

A strong indicant that a symbol elicits the concept or the properties of an object is an understanding of a reference to the *absent* object. We understand the referent of the word 'car,' although no car may be immediately present. To test Ake's understanding that symbols refer to things, we constructed a paradigm in which she was required to report whether an object referred to by a symbolic gesture was present or not in her pool (Herman and Forestell 1985). Two paddles were placed along the wall of the pool, one to the left and one to the right of the dolphin, who was positioned facing the experimenter. A press of the right paddle meant *Yes (present)* and a press of the left paddle meant *No (absent)*. The experimenter, who stood outside the pool wall facing Ake, showed her from one to three objects from an available set of nine different objects, throwing each in turn over the dolphin's head and into the pool. The experimenter then gave a symbolic gesture referring to an object (which may or may not be one of those shown to Ake) and then gave a second gesture glossed as 'question.' For example the gestural sequence *Ball Question* meant, 'Is there a ball in your pool?' Ake could respond *Yes* or *No*. Overall, Ake was as accurate (80–83 per cent correct for 182 queries) at reporting absence, as she was at reporting presence, providing compelling evidence for declarative knowledge—that the gestural symbols we used for the objects represented those objects.

20.2.3.1 Evidence for rational responding

The ability of Ake to create a reasonable and informative response to a problem that went beyond the boundaries of what she had been explicitly taught was illustrated when we began to give relational sequences within the reporting paradigm (Herman *et al.* 1993). For example, instead of asking *Hoop Question*, we might give her a relational instruction such as *Hoop Frisbee Fetch* (= bring the Frisbee to the hoop). However, both objects might be present, or only one of them, or neither. If both were present, Ake simply carried out the instruction—taking the Frisbee to the hoop, in conformance with the inverse grammar. If both were absent, or if the transport object was absent (e.g. the Frisbee), she directly pressed the *No* paddle, indicating that the action could not be completed or initiated. But, if the destination object was absent

(e.g. the hoop) she created, on the very first occasion, an innovative response that greatly surprised us. Our expectation was that she would again press the *No* paddle, to indicate that the instruction could not be done, or that an object was absent. Instead, she swam to the transport object (the Frisbee) and brought it the *No* paddle, in effect reporting that the Frisbee was present but its destination, the hoop, was not. Ake has used that same type of response ever since if given a missing destination object within this paradigm, regardless of the particular destination or transport objects specified. For example on the first occasion that we gave her the gestural instruction *Surfboard Person Fetch* (bring the person floating in the pool to the surfboard), with the person present but the surfboard absent, Ake swam to the person and pushed her from the centre of the pool directly to the *No* paddle.

20.2.4 Understanding of representations of the real world: television scenes

Savage-Rumbaugh (1986) provided an extensive review of responses of home-reared chimpanzees or language-trained chimpanzees to television scenes. All of the chimpanzees received extensive exposure to television, but, uniformly, all showed, at best, only fleeting interest in the television scenes. In the case of the home-reared chimpanzee Lucy, even scenes of familiar humans, dogs, or children failed to elicit a response. Apparently, the images or scenes were not processed as representations of the real world. Similarly, Savage-Rumbaugh's own language-trained apes, Sherman and Austin, failed to show initial interest in television, even to scenes portraying their own familiar surroundings. To develop her chimps' appreciation of television scenes, Savage-Rumbaugh exposed them daily, 30 minutes per day for months, to television scenes or film of other chimps. During this time, the experimenters would exclaim and vocalize when interesting scenes appeared. Sherman and Austin's attention to the television scenes gradually increased, and eventually they began to exhibit appropriate overt responses to the scenes.

20.2.4.1 Evidence for rational responding

Despite this history of initial non-responsiveness of chimpanzees to television scenes (and, in my experience, similar non-responsiveness of dogs and cats), we nevertheless decided to probe the initial interest of the dolphins Ake and Phoenix to television scenes (Herman *et al.* 1990). Neither dolphin had been exposed to television of any sort previously. Given the results with apes, we expected to see an initial lack of response, which we would then follow with a long period of exposure and training to achieve appropriate responding to television scenes. To our astonishment, however, no training was needed. Both dolphins attended immediately and appropriately to the televised scenes we presented. For these initial scenes, we placed a 13-inch (diagonal measurement) black-and-white television set behind an underwater window and projected on it an image of a trainer being filmed live in a remote studio. We also

placed a video camera next to the television set, looking out through the window. The image from this camera was fed back to a television screen in the studio, enabling the 'TV trainer' to see the dolphin peering into the window. The dolphin and trainer were thus linked electronically. We first directed Ake (gesturally) to swim down to the window, where she saw the image of the TV trainer, about 8 inches high, giving her an instruction in the familiar gestural language. Ake turned from the window and carried out the instruction immediately and correctly. She was given 14 different instructions altogether and completed all but two correctly. We then directed Phoenix to the window and gave her 19 different gestural instructions. She completed all but one correctly.

Subsequently, we tested Ake's responses to degraded images of the trainer, to examine how abstract gestural information could be and still be understood. In a series of steps, we first showed only the gesturing trainer's arms and hands on the television screen, then only the hands, and, finally, only two circles of white light moving about the screen. Two 3-inch-diameter sponge balls held by the gesturing trainer, whose body parts were totally obscured, produced the moving circles. Almost no degradation in performance was observed under the first two conditions. In the final condition, Ake remained significantly above chance, although below the level of the other conditions. Nonetheless, when we tested our staff with this latter display, only the most experienced staff outperformed the dolphin in interpreting the instructions embedded within the moving circles of light. This result supported the hypothesis that Ake had developed rich representations of the gestural symbols and that she used those representations to make sense of stimuli that bore little physical similarity, other than movement pattern, to the gestures displayed by the full-body image of the trainer.

Hiapo and Elele, who had arrived at our facility some 9 years after Ake and Phoenix, showed a similar responsiveness to television scenes as did Ake and Phoenix. However, Hiapo and Elele may have observed television images informally while we were testing Ake and Phoenix. In later studies, however, we showed that all four dolphins were not only able to carry out gestural instructions conveyed by a televised person, but could imitate that person's behaviours (see later section on imitation). Further, Elele was able to carry out match-to-sample tests as accurately as she did in the real world when the sample object was displayed on the television screen and only the alternative objects appeared in the real world (Pack and Herman 1995). No special training was required for Elele to use the television displays in this manner.

20.2.5 **Knowing how to integrate behaviours: combining multiple discrete behaviours holistically**

All of the dolphins understand many individual gestural signs (ca. 80) that are not part of the language vocabulary and that elicit particular behaviours. Some examples of behaviours elicited by a single gestural sign are *back dive*, *blow bubbles*, *tail wave*, *open mouth*, *spiral swim*, *spit water*, and *pirouette*. In addition, sequences of these discrete

signs may be given, in which case the experimenter is asking the dolphin to perform each of the behaviours in the sequence.

20.2.5.1 Evidence for rational responding

Initially, only a few sign combinations were used, consisting of the single-sign instruction *spit water*, or *open mouth*, or *wave pectoral fins* followed by the generic sign for *swim*. In response, the instructed dolphin (all dolphins were exposed to this sequential signing) swam at the surface while spitting water, or while keeping its mouth open, or while wiggling its pectoral fins. These responses may have been shaped, but our records on this early training are incomplete. However, all dolphins spontaneously extended the behaviour from swims to jumps and from two discrete behaviours to three or more. For example in response to a sequence of three gestures glossed as *pectoral fin wave*, *tail wave*, and *jump*, Phoenix will leap into the air in a porpoising dive while simultaneously wiggling her pectoral fins and waving her tail. Another example is the sequence of three gestures *spit*, *pectoral fin slap*, and *swim*. In response, Phoenix spits water from her mouth while swimming on her back and slapping a pectoral fin on the water surface. Specific combinations such as these are not trained; new combinations are carried out reliably as an integrated response in almost all cases. As the number of individual elements increases above three, one or more may drop out, possibly reflecting forgetting of some of the instructed behaviours. Clearly, however, the dolphins' ability to execute or attempt to execute an integrated behavioural response to new sequences of action signs implies that each has developed a concept of 'combinations.'

20.2.6 Knowing how to improvise behaviours: understanding the concept of 'create'

All four dolphins are familiar with a gestural sign that we gloss as *create*. No specific behaviour is required in response. Instead, the gesture asks the dolphin to create a behaviour on its own—any behaviour or even multiple behaviours. In formal tests, the dolphin Elele's responses to the create sign were tested over the course of 18 sessions of 24 trials each (Braslau-Schneck 1994). For eight of these 24 trials, the trainer gave the create sign, so that there were 144 trials of this type altogether over the 18 sessions. For the remaining 16 'filler' trials in a session, the trainer interacted socially with the dolphin at tankside, giving specified gestures only for behaviours that maintained the dolphin in a relatively simple activity such as allowing herself to be stroked, or engaging the dolphin in some game such as putting rings on a stick. The eight create trials were organized into two blocks of two consecutive trials and one block of four consecutive trials, with blocks separated from each other and from the beginning of the session by at least two filler trials. Responses to filler trials were reinforced with fish reward and social praise. To avoid training of responses to create trials, these responses were not reinforced.

20.2.6.1 Evidence for rational responding

Elele most often offered multiple behaviours per create trial. Over the 144 create trials, Elele offered 323 behaviours, 72 of which were unique. Of these 72, 38 were novel, in that they had not been seen before or were not under stimulus control. An important component of this demonstration was the understanding of the create gesture itself. Elele only offered self-initiated behaviours if given this gesture. Clearly then, Elele understood 'create' at the level of a concept.

20.3 Social intelligence

Dolphins live in complex, fluid societies, with individual affiliations ranging from close bonding to more fleeting transient associations (e.g. Reynolds *et al.* 2000). The dolphin social network is often described as a 'fission–fusion' society because of the interplay of relatively permanent and temporary associations (Connor *et al.* 2000). The closeness of an affiliation is often seen, for example, in pairs or small groups of animals performing highly synchronous swimming and leaping behaviours. Social knowledge for a dolphin seems to be about attending to others and knowing others, both categorically in terms of gender and age class as well by one's history of interactions with particular individuals. Additionally, social knowledge also entails knowing how to collaborate or compete with others, as in foraging, feeding, or reproductive activities. Additionally, social knowledge involves interpreting other's behavioural and vocal signals as well as producing such signals for others. Here, I consider three aspects of social knowledge or social interactions that we have studied in our laboratory: (a) joint attention; (b) behavioural synchrony; and (c) imitation.

20.3.1 Joint attention: understanding human pointing and gaze

Manual pointing or gazing by humans serves to call another's attention to an object, event, or place of interest. Human pointing or gazing is thus a social, triadic transaction, involving the co-ordination of the attention of the informant and the observer to the same target or event, and may be termed referential pointing or gazing. Implicit in adult human pointing or gazing is not only the intent to manage the attention of another individual but also the expectation that the observer understands the referring function of the action.

Wild chimpanzees have not been observed using pointing gestures to direct another's attention (Tomasello and Call 1997). In laboratory conditions characterized by extensive contact with humans, chimps can learn to use pointing to direct a human's attention to something desired, such as a piece of food or a place to go. Paradoxically, however, they fail to understand the human's intention when the human points at something. For example in the Povinelli *et al.* (1997) study, the experimenter sat between two boxes, one of which contained food, and pointed at the baited box. The chimp chose that box reliably only when the experimenter's outstretched arm and

hand almost touched the box. However, when the experimenter was positioned away from the boxes by 3 meters or so, the chimp no longer reliably approached the indicated box. The chimp thus failed to understand referential pointing. Understanding of human gaze by chimpanzees is also only marginally effective. Povinelli *et al.* (1997) found that none of the eight chimps he tested performed above chance in initial trials using human gaze (or gaze plus pointing) to direct attention to the baited box. Similar results were reported by Call *et al.* (1998).

In contrast to these negative findings with chimpanzees, domestic dogs can select the object pointed to or gazed at by a human handler (Hare *et al.* 1998; Soproni *et al.* 2001). The dog's understanding of these human communicative signals is most likely the product of selective breeding and domestication, as human-reared wolves do not show this capability (Hare *et al.* 2002).

Dolphins, like chimpanzees, are of course not domesticated animals. We tested Ake's understanding of referential pointing by placing three objects in the pool, one to her left, another to her right, and a third behind her, each at approximately 3 metres distance (Herman *et al.* 1999). We could then refer to these objects by pointing at them or by using the familiar gestural language symbols. In either case, the dolphin was required to choose the referenced object and take the particular action to it (for example, leaping over it, swimming under it, touching it with the tail, etc.) as directed by a gestural action symbol that immediately followed the object indicator. For example, we can instruct Ake to swim under a hoop either through the symbolic gestural sequence *Hoop Under* or by pointing at the hoop and then signing *Under*. We also tested gaze comprehension by Ake and Phoenix by turning the head left or right to look at an object, and asking the dolphin to take a signalled action to that object (Pack and Herman 2004).

20.3.1.1 Evidence for rational responding

Surprisingly, Ake not only understood a direct point to a distal object, made with arm and finger extended, but also immediately understood a cross-body point (Herman *et al.* 1999). For the cross-body point, the left arm is extended across the body to indicate an object to the pointer's right, or the right arm is extended across the body to indicate an object to the left. Although Ake had been exposed to human direct pointing previously during informal sessions with trainers, she had never before been exposed to cross-body pointing. Her immediate understanding of this novel form of pointing reinforces the idea that the dolphin understood pointing, in either form, as a reference to an object. In addition, both Ake and Phoenix showed spontaneous understanding (without any prior training) on their first trials of human-directed gaze (also see Tschudin *et al.* 2001, for an additional demonstration of spontaneous understanding of human gaze by dolphins). The immediacy of understanding of gaze by Ake and Phoenix extended to static as well as to dynamic forms of gaze. In static gaze, the dolphin sees only the terminal position of the head, left or right, while in dynamic gaze

the dolphin views the active head movement from straight ahead to either the left or right side. Static pointing was also immediately understood by both dolphins.

Furthermore, Ake demonstrated spontaneous understanding of complex pointing sequences. She immediately responded correctly (without training) to sequences of two points, each to a different object, and then followed by the symbolic gesture *fetch*, by taking the object pointed to second to the object pointed to first. Thus, she applied the same inverse grammatical rule to a sequence of two points that she normally did to a sequence of two symbolic object gestures followed by the symbolic gesture *fetch*. For example, in response to the sequence *point at surfboard, point at pipe, fetch*, Ake swam to the floating pipe and transported it to the floating surfboard, the same type of response she takes if given the wholly symbolic gestural sequence *surfboard pipe fetch*.

It may seem surprising, given the dolphin's armless anatomy, that it would so easily understand the human pointing gesture, while chimps do not. Elsewhere (Herman *et al.* 1999), we speculated that the dolphin may understand pointing because it possesses an acoustic analogue of pointing in its natural world, through its highly focused echolocation beam. It has been shown, for example, that one dolphin can detect what another is inspecting through echolocation, simply by listening to the echoes returning from the emitter's beam (Xitco and Roitblat 1996). The 'eavesdropping' dolphin, positioned next to the echolocating dolphin, is able to identify the object of interest to the echolocating dolphin, in effect sharing attention with the echolocator. That the dolphin also understands the referring function of gaze as directed by human head movements may signal that it has developed a profound appreciation for human attentional signals in general, and the value of sharing in that attention.

20.3.2 Behavioural synchrony: carrying out behaviours together

We devised a gestural sign we termed 'tandem.' This sign, when followed by a second sign denoting an action, directs a pair of dolphins to carry out that action together, synchronously. For example, the gestural sequence *tandem backdive* directs the pair to join together and perform a back dive in close synchrony. Two different pairs of dolphins, Ake and Phoenix and Hiapo and Elele, were separately exposed to the requirements of the tandem sign and both pairs have responded to it reliably and roughly equivalently.

20.3.2.1 Evidence for rational responding

Once the tandem sign was taught, using only a few actions, both pairs carried out a variety of additional behaviours synchronously, as requested gesturally by the experimenter. An example of a complex sequence carried out synchronously is the three-item gestural sequence *tandem kiss jump*. In response, the pair swim away together and then leap out of the water touching each other's rostrum (beak) in mid-air. Of particular interest was how a pair might respond to the sequence *tandem create*. In effect, this sequence asks the pair to select or create together a behaviour of their own choosing,

and carry it out synchronously. Typically, the pair will first swim about side-by-side, generally for a longer time than when given a specific behaviour to perform synchronously, then apparently select some behaviour in common and execute it in close synchrony. The selected behaviours may range from simple types, such as synchronous tail waves, to a complex spinning leap while spitting water from their mouth. We have not been able to determine how the dolphins manage this task. Their apparent joint performance may be a case of near-simultaneous mimicry, one following the other's action closely, but we have not been able to confirm this through detailed video analyses. Alternatively, underwater intention movements by one dolphin may guide the second dolphin to select that same behaviour. Clearly, there are other possibilities as well, and further study of mechanisms is needed.

Importantly, behavioural responses to the *tandem create* sequence were not taught. Instead, after a pair had been exposed to many multiple instances of the tandem sign followed by a sign for a specific behaviour, they were exposed for the first time to the *tandem create* sequence. Each executed the same self-selected behaviour, in close synchrony with the other. Their spontaneous response was apparently accomplished through generalization of their knowledge of expected responses to the *create* gesture and their knowledge of the synchronous requirement of the *tandem* gesture.

20.3.3 Mimicry: copying sounds and copying the motor behaviours of others

Both the definition of imitative behaviour and which animals may exhibit such behaviour have been areas of considerable discussion and debate (e.g. Whiten and Ham 1992, Zentall 1996). Three premises have guided our approach to the study of imitation by dolphins: (i) evidence for imitative ability is strongest if imitation can be demonstrated to a variety of behaviours and in a variety of contexts; (ii) although the genesis of imitative ability may derive from social factors, its expression may also appear in non-social contexts; and (iii) if imitation is understood conceptually by the subject, it should generalize to many situations, and be controllable by abstract symbols (Herman 2002). Here I consider three different areas in which we have demonstrated imitative abilities of dolphins: (a) vocal mimicry; (b) motor imitation of dolphins and humans; and (c) imitation of behaviours viewed on a television screen.

20.3.3.1 Evidence for rational responding

Bottlenosed dolphins are highly vocal animals and use sounds for echolocation, communication, and emotional expression (Herman and Tavolga 1980). We trained Ake to imitate vocally a variety of electronically generated 'model' sounds broadcast into her pool through an underwater speaker (Richards *et al.* 1984). In response to the model sound, Ake vocalized into an adjacent hydrophone. She mimicked a variety of different waveforms, including pure tones (sine waves), triangle waves, and slow frequency modulation. Some models were imitated accurately on Ake's first attempt,

illustrating her development of a generalized concept of mimicry. Reliability of mimicry over successive exposures to a given model was excellent. There were two instances when model sounds were played that were out of Ake's preferred vocal range, one above and one below that range. In each case, Ake accurately reproduced the sound contour, but at an octave below the high frequency model and an octave above the low frequency model.

Octave generalization of the type displayed by Ake is a rare phenomenon in the animal world. Tests for octave generalization of pitch contours in starlings, cowbirds, and a mockingbird yielded negative results (Hulse and Cynx 1986; Hulse 1989). The birds instead focussed on the absolute frequencies of the pitch series and could not recognize a tonal series as the same when it was shifted by an octave. Rats and monkeys also fail to evidence octave generalization (D'Amato and Salmon 1984). In contrast to these frequency constraints of birds, rats, and monkeys, Ralston and Herman (1995) demonstrated excellent octave generalization of pitch contours in the dolphin Phoenix. Thus, dolphins appear to possess a particularly robust form of frequency contour perception, as do humans. This may serve dolphins well in recognizing variants of the different communicative whistle sounds produced by familiar dolphin associates (Herman and Tavolga 1980).

In addition to these demonstrations of dolphin vocal imitation, our studies have shown that dolphins are exceptional behavioural imitators of other dolphins and, surprisingly, of humans (Xitco 1988; Herman 2002). In formal tests of imitation, we use a gesture we call 'mimic' that directs the dolphin to imitate the behaviour of a live model, either another dolphin or a human. In the case of a human model, the dolphin must relate its body image to the body plan of the human, and draw analogies where necessary. For example if the human raises a leg in the air, the dolphin raises its tail. If the human waves an arm, the dolphin waves its pectoral fin. These correspondences were not explicitly taught. Opaque correspondences occur as well, in that movements of the human's head, nodding or shaking, are copied by corresponding movements of the dolphin's head. The dolphin, of course, cannot see its own head. Within the formal mimicry context, the dolphins attempt imitation only if the *mimic* sign follows the behavioural demonstration. If some other sign is given, for example, *spiral swim*, the dolphin will respond to that sign and ignore the behaviour of the model. That imitation of novel behaviours has been carried out successfully, and that imitation, or an attempt at it, will occur only in the presence of the mimic gesture, implies an understanding of mimicry as a general concept applicable to any behaviour observed.

As a natural follow-up to the dolphins' earlier success in responding to televised gestural instructions (Herman *et al.* 1990), we explored their ability to imitate television scenes of humans or dolphins performing behaviours. For our first attempt, we filmed a human or dolphin performing a behaviour in one of two interconnected tanks, while another dolphin watched the ongoing behaviours on a television screen located behind an underwater window in the second tank (Herman *et al.* 1993). The television camera

was located almost 30 metres distant from the performing models, yielding a rather small image on the television screen, reflecting the limits of the zoom lens we were using. In addition, we did not use the mimic gesture after a behaviour, waiting to see whether imitation would occur spontaneously. Not surprisingly, perhaps, mimicry was not immediate. Imitation did occur, however, once we increased the size of the image (by using a different lens) and, additionally, presented the mimic sign after the behavioural demonstration. The mimic sign was given either by the person demonstrating a behaviour, or by switching to a person on screen giving the mimic sign after a dolphin model completed a behaviour. With these changes, the dolphins (Phoenix and Ake) responded to the televised images in the same way as they did to live models, for example by nodding their head up and down or side to side in imitation of a human doing the same, or by pirouetting when the human or dolphin model pirouetted. The dolphins thus correctly inferred that they could respond to the television models in the same way as they did to live models.

20.4 Self-knowledge: awareness of oneself

Here we asked what a dolphin may know or understand about itself. Traditionally, self-awareness in animals has been tested through the mirror self-recognition (MSR) test. Chimpanzees and at least one gorilla and one orang-utan have passed this test, showing evidence that they recognized the image in the mirror as their own (see various chapters in Parker *et al.* 1994). Recently, Reiss and Marino (2001) demonstrated mirror self-recognition in bottlenosed dolphins. Self-awareness may, however, exist in many forms, not just self-recognition. We tested two additional forms: (a) awareness of one's own behaviours; and (b) awareness of one's own body parts.

20.4.1 Awareness of one's own behaviours

We developed a procedure that required the dolphin Phoenix either to repeat the behaviour she had performed last or choose a different behaviour, depending on whether she observed a gesture we glossed as 'repeat' or a gesture we glossed as 'any' (Cutting 1997; also summarized in Herman 2002). For this paradigm, Phoenix was restricted to five different behaviours: jump over an object (*over*), swim under it (*under*), touch it with the tail (*tail-touch*), touch it with the pectoral fin (*pec-touch*), or mouth it (*mouth*). A typical trial began with Phoenix given a gesture requiring her to perform a particular one of the five behaviours to an object in the water, such as *tail-touch* or *under*. After completing the behaviour to the object, Phoenix was given either the sign *repeat* or the sign *any*. The *any* sign instructed her to choose any of the five behaviours other than the one she had just completed. The *repeat* sign directed her to perform the same behaviour again (see also Mercado *et al.* 1997, 1998). This procedure was repeated three times and Phoenix was rewarded only if she completed the entire four-item sequence correctly. An example of a sequence given was *Mouth, Repeat, Any,*

Repeat. Here, in succession, Phoenix correctly mouthed the object, mouthed again, leaped over the object, and finally leaped over again.

20.4.1.1 Evidence for rational responding

To successfully complete a sequence, Phoenix had to maintain a mental representation of the behaviour she last performed, update that with each succeeding behaviour, semantically process the *repeat* or *any* gesture, and then either self-select the same behaviour for *repeat*, or choose a behaviour from the remaining four if given *any*. Phoenix was highly successful at this task completing correctly between 79 and 95 per cent of 160 different four-item sequences, depending on the particular sequence type given. An interesting example of apparent inferential reasoning occurred when, for the first time, we began a sequence not with a specific directed behaviour, but with the *any* sign. Here, Phoenix was being asked, in effect, to begin a sequence herself by choosing any of the five behaviours. Phoenix waited in front of the experimenter for approximately 12 seconds, watching and seemingly waiting for a specific instruction. The experimenter remained motionless. Phoenix then turned toward the object and leaped over it (*over*), apparently concluding that she could initiate the sequence on her own. She then successfully completed the remainder of the four-item sequence as successively instructed by the experimenter.

20.4.2 Awareness of one's own body part: displaying named body parts and using them in unique ways as instructed by symbolic gestures

Children, even at the relatively young age of two, can point to as many as 20 of their different body parts in 'show me' interchanges with a caregiver (MacWhinney *et al.* 1987; Witt *et al.* 1990). These young children can also carry out a variety of simple verbal instructions referring to their body parts (e.g. 'wash your hands,' 'brush your hair,' 'push the ball with your foot,' 'push the ball with your hand'). Clearly, we credit the young child with an understanding that the words we use for body parts refer to or represent those body parts.

Can an animal understand symbols as references to or as representing its own body parts? To conclude that it can, at least three conditions must be met: (a) different body parts must be reliably associated with different symbols (e.g. 'pectoral fin' vs. 'tail' vs. 'rostrum'); (b) different symbolically referenced body parts must be used in the same or in analogous ways (e.g. 'touch the ball with your pectoral fin' vs. 'touch the ball with your tail' vs. 'touch the ball with your rostrum'); and (c) the same symbolically referenced body part must be used in different ways (e.g. 'shake your rostrum' vs. 'touch the Frisbee with your rostrum' vs. 'toss the Frisbee with your rostrum'). In addition, an inference that the animal understands symbols as representations of its body parts is strengthened under Conditions *b* and *c* if the animal is able to use its body parts in novel ways in response to a symbolic reference, especially if it occurs the first time such novel use is requested.

Thus, a dog that offers its paw in response to a verbalization such as 'give me your paw' is not of itself evidence that the words are understood as representing its paw. Instead, it can only be concluded that the dog is making a learned instrumental response to a discriminative stimulus. To decide otherwise would require fulfilling conditions *a* to *c*.

We examined whether the dolphin Elele could develop referential understanding of gestural symbols for her different body parts, by fulfilling conditions *a* to *c* (Herman *et al.* 2001). The ability of Elele to carry out these different body-part tasks reliably would provide strong evidence for her understanding of symbols as representing her body parts.

20.4.2.1 Evidence for rational responding

Elele's responses revealed both semantic and topographical knowledge of her body parts. She not only understood symbolic gestural references to any of nine different body parts (*rostrum, mouth, melon, dorsal fin, pectoral fin, side, belly, genitals, and tail*), but also successfully used the same body part to carry out different symbolically referenced actions (e.g. she was able, on instruction, to *display* her rostrum, or *shake* it, or use it to *touch* a basket or *toss* a Frisbee). She was also able to use different body parts to carry out the same action (e.g. touch a basket with her pectoral fin, side, tail, or mouth). Two examples of novel body-part requests completed successfully on the first occasion given were *Frisbee dorsal fin touch* (touch the floating Frisbee with your dorsal fin—a response not in the natural or learned repertoire of Elele) and *surfboard genital toss* (toss the surfboard with your genital region—completed by swimming under the surfboard in an inverted position and then thrusting her pelvic region upwards against the board). These and other novel responses strengthened the conclusion that the gestural symbols we used for those body parts represented those body parts to Elele.

In humans, the identification and conscious control of one's own body parts is dependent on the development and maintenance of a body image (e.g. Gallagher 1995; Sirigu *et al.* 1991). In carrying out novel body-part instructions, such as those illustrated above, Elele, in effect, had to conceive of (ideate) those body-part responses that would satisfy the instruction. The results of these dolphin body-part studies (Herman *et al.* 1999), as well as the findings reviewed earlier, of versatile motor-mimicry capabilities (Herman 2002), testify to the development in the dolphin of a well-articulated body image that can be consciously accessed for effective body-part responses to even highly abstract instructions or observed motor events.

20.5 General discussion

This chapter began with the argument that rational behaviour is a derivative of intelligence manifested in one or more domains, and that a fundamental function of intellect is to allow the animal to construct a model of its world, or of multiple worlds as it encounters new or changed conditions or contexts. To construct a representative

model, the animal must perceive and interpret the structural and functional components of the world in which it is currently immersed. Rational behaviour, then, involves responding adaptively to the perceived elements and dynamics of that world, inferring, extrapolating, deducting, concluding, or creating behaviour as necessary. I presented evidence of rational responding by bottlenosed dolphins that met one or more of these characteristics of rationality, as exhibited in our various behavioural studies at the Kewalo Basin Marine Mammal Laboratory. The major points of evidence may be recapped as follows.

20.5.1 Declarative and procedural domains

The question posed about the declarative (semantic or representational) domain of intellect was does the dolphin display knowledge or understanding about things. The question posed about the procedural domain was does the dolphin exhibit competency in means, operations, or methods. The evidence gave strong affirmative answers to both questions, through the results of a variety of experiments and observations. Both questions addressed the issue of the intellectual flexibility of the dolphin in responding to new or changing world conditions.

Ake's inferential and extrapolative abilities were demonstrated within the gestural language system we developed for communicating instructions to her. After exposure to a limited number of exemplars of sentence frames, Ake was able to reliably interpret and act on new instructions given to her when new semantic elements were inserted into the various semantic slots of sentence frames (i.e. object, action, relationship, and locative slots). Further evidence for semantic processing was found in her rejection of semantic anomalies and by her apparent understanding of the intent of an instruction by rearranging object to enable her to complete an instruction, such as lifting a hoop off the bottom of the pool in order to swim through it. Syntactic processing was convincingly illustrated by her appropriate responding to semantically reversed sequences, by her immediate ability to interpret new and more complex syntactic structures that combined elements of simpler structures, and by her extraction of semantically and syntactically correct subsets of instructions embedded within longer syntactically anomalous sequences. This suite of abilities required both declarative and procedural knowledge—understanding of the referents of the gestures and understanding how to respond to them appropriately.

Ake created an ostensibly efficient strategy for returning all floating objects to the experimenter after being given the generic 'fetch' command. Her strategy was to gather multiple objects together and return the group to the experimenter, rather than retrieving one at a time. The strategy was not always time efficient, however, as multiple objects might be gathered together, some then escaping and requiring regathering perhaps several times, but it did minimize the number of discrete swimming trips required and seemed to us, admittedly anthropomorphically, to be more interesting and enjoyable to the dolphin than fetching single objects.

Ake's understanding of the referents of the gestures we used for the various semantic entities is illustrated by some of the examples cited above. More stringent evidence was obtained through her accurate responses in experiments that specifically asked her to report, through pressing one of two paddles, whether a 'named' object was present or not in her pool. Within these experiments, she created a new type of response that was unanticipated by us when she was asked, for the first time, to take an object that was present to an object that was absent. Here, she transported the object that was present to the paddle signifying 'absent.' Further, and rationally, if both objects were absent, or if the object to be transported was absent, she simply pressed the 'absent' paddle immediately.

Ake and Phoenix, on the first occasion that each was exposed to a TV image of a person signing to them, immediately carried out the person's gestural instructions. It was as if each inferred that the television scenes were representations of the real world, despite radical differences in image size, clarity, dimensionality, and context, and that she could therefore respond in the same manner as she did to real-world scenes. Further, Elele inferred immediately that objects shown on a television screen could be matched with objects displayed in the real world.

All four dolphins understand a concept of 'combinations' when given a sequence of gestures, each calling for a different action. Rather than selecting and producing one of the actions only, or carrying out several actions successively, the dolphins construct a response that integrates the multiple behaviours into a single act.

Creativity was formally demonstrated in studies that asked the dolphins, through a specific gesture we called 'create,' to vary their behaviour in any way, as long as each successive behaviour was different from the immediately preceding behaviour. Elele demonstrated impressive behavioural variability, exhibiting 323 behaviours, 72 of which were unique, during 144 trials, each asking her to create her own behaviour. Elele only offered self-initiated behaviours if given the 'create' gesture. Clearly then, Elele understood 'create' at the level of a concept in that she only offered variable behaviours if given the create gesture.

These results illustrate both declarative and procedural knowledge in several different contexts, and provide evidence of inferential reasoning and innovative responding.

20.5.2 The social domain

Here, the question asked was does the dolphin reveal social awareness and appropriate responsiveness in social interactions or relations. Again, for answers, I referred to the results of studies at our laboratory and, again, the answers were in the affirmative.

Dolphins and dogs, but not chimpanzees or other great apes, understand the referring function of the human pointing gesture. Ake and Phoenix both understood and acted on direct points to objects as a reference to that object. Furthermore, both dolphins, on their first exposure to cross-body pointing, responded appropriately, in essence inferring that the direction of the arm's extension, rather than which arm it

was, called attention to an object. In addition, Ake, when presented with a sequence of points immediately understood that she could respond in the same manner as she did to sequences of symbolic gestures, by applying the same inverse grammatical rule. Both Ake and Phoenix also immediately understood the referring function of human-directed gaze. The complexity of the dolphins' responses and interpretations of human pointing or gazing at objects, and that none of these responses were specifically taught, signal that they have developed a profound appreciation for human attentional signals in general, and the value of sharing in that attention.

Pairs of dolphins (e.g. Ake–Phoenix or Hiapo–Elele) understood the concept of acting together synchronously in response to a specific gestural instruction to do so. In addition to carrying out specifically requested behaviours in close synchrony, they were proficient at choosing their own behaviours to carry out together in response to the gestural sequence *tandem create*. The mechanism by which the dolphins achieve this co-ordinated and inventive response is not clear. Even if it involves real-time mimicry or exceptional sensitivity to the intention movements of the other, rather than some more abstract form of communication, it still demands an understanding of the requirements of a highly abstract task, the close monitoring and anticipation of each other's movements, and the maintaining of an inventory of most recently performed behaviours in order to satisfy the requirement for variability in response.

Dolphins are clearly the most facile vocal and motor imitators of any non-human mammal. In addition to vocal imitation of arbitrary computer generated sounds, Ake also demonstrated octave generalization, recognizing sound sequences ('tunes') that were transposed by an octave and producing sounds an octave removed from a model sound that was outside of her tonal range. Fundamentally, octave generalization of tunes further illustrates sensitivity to sequential structures, which was illustrated previously by Ake's sensitivity to the syntactic structure of her gestural language. All four dolphins demonstrated not only an ability to copy observed motor behaviours of other dolphins, but also of humans. Imitation of human motor behaviour required forming structural relationships between the dolphin's perception of the human body plan and its own body image. Analogies were formed, such as the correspondence of the human leg and the dolphin's tail. The dolphins' understanding of the television world was also forcefully illustrated by the effective copying of motor behaviours of dolphins or humans observed on a television screen.

These various findings illustrate the dolphins' acute social awareness, including sensitivity to the attentional mechanisms of others and to the nuances of their behaviours, sufficient to create replicas of those behaviours.

20.5.3 The domain of the self

The question asked was what a dolphin knows or understands about itself? Recognizing that self-awareness is a multidimensioned concept, we chose two facets of self-awareness

for study that appear not to have been formally studied previously in any animal: awareness of one's own behaviours and awareness of one's own body parts.

Phoenix demonstrated conscious awareness of her own behaviours, as illustrated by her ability to repeat her previous behaviour or to perform a different behaviour, contingent on which one of two abstract gestural instructions was given, 'repeat' or 'any' (= do not repeat). She chose behaviours from a set of five. She was able to reliably self-select each successive behaviour in sequences of four gestural instructions. The first instruction required a specific behaviour, and the remaining three each asked her to repeat or not repeat her prior act. She faithfully followed the rule embedded within each instruction.

Elele demonstrated conscious awareness and conscious control of her own body parts, as illustrated by her understanding of symbolic gestural references to those body parts and by her ability to use those body parts in four different ways as directed by gestural instructions. Some instructions called for novel (first-time) uses of a body part, and were successfully carried out by Elele.

These results illustrate aspects of self-awareness that address the multidimensionality of this concept whose study has previously been limited primarily to mirror self-recognition. Recent findings of mirror self-recognition by dolphins (Reiss and Marino 2001), together with the findings presented here, reveal what appears to be a self-concept in this species.

20.5.4 Evolutionary perspectives

Finally, what pressures might select for the evolution of the levels of intellectual flexibility and the type of innovative and rational responding demonstrated? The often-heard argument that the exceptional size and development of the dolphin brain is accounted for by the requirement for extensive auditory processing, especially echolocation, can be dismissed on at least two grounds. The first is based on comparisons with insectivorous bats, the group of bats feeding on flying insects and having the most sophisticated echolocation system among all bats. Examination of the brain and body weights of 20 species of insectivorous bats listed by Hutcheon *et al.* (2002) reveals that all 20 have EQs falling below 1.0. These bats do have relatively larger auditory processing areas (cochlear nuclei complex and superior olivary complex) than do fruit eating and nectar sipping bats, which do echolocate but rely more on vision and olfaction. Thus, using insectivorous bats as a model of a sophisticated echolocating group, it is clear that echolocation and attendant auditory capabilities can be supported through specialized areas without overall enlargement of the brain or extensive enlargement of the cerebral cortex. In contrast, the dolphin brain has obviously expanded greatly in many areas, especially the cerebral cortex, the site implicated in much of human cognitive functioning.

Second, the question of the intelligence of the dolphin, as I stated earlier, can best be resolved through the results of empirical behavioural study rather than through examination of brain structures. In our studies, those reviewed here as well as others

(see e.g. Herman *et al.* 1993), the diversity, depth, and breadth of cognitive skills demonstrated by the dolphins revealed exceptional behavioural flexibility in several different domains of intellectual functioning: declarative, procedural, social, and self. These domains encompass aspects of the physical world (knowing what things are and how they function or may be utilized), the social world ('reading' and interpreting the behaviours of others, and engaging in beneficial activities with others), and the world of self (being consciously aware of one's own physical being and one's own actions).

In many of the cases described in this chapter, the responses of the dolphins to the challenges posed appeared to require logical inferences and innovative responding, as well as adaptive responding to new or changed 'world' conditions. These capabilities seem reflective of the exceptional adaptability of the bottlenosed dolphin in its natural world. This species exhibits remarkable diversity in its natural habitats, including all of the oceans within the temperate and tropical zones, as well as inshore and offshore ranges within those habitats, and migration between the two ranges. The different habitats may each demand unique foraging, feeding, antipredator, and social strategies, suggestive of an ability of bottlenosed dolphins to adapt behaviourally to diverse worlds or to changes in world conditions, including movement from the natural world to the world of the laboratory or marine park.

Although it is difficult to cleanly isolate a single root cause for the evolution of intelligence in a species, in the case of the dolphin the major determining factor may be social pressure—the requirement for integration into a social order having an extensive communication matrix for promoting the well-being and survival of individuals. I first advocated this idea in my early discussion of the cognitive characteristics of dolphins (Herman 1980), inspired in part by Humphrey's (1976) treatise on the social basis of intellect. The idea finds much support today, as expressed, for example, in many of the chapters within the earlier and recent volumes on 'Machiavellian intelligence' (Byrne and Whiten 1988; Whiten and Byrne 1998; also see e.g. Tomasello and Call 1997). Dunbar (1992) has shown that within primate societies the ratio of neocortex to the remainder of the brain increases with increases in typical group size. Within large, complex societies, individuals benefit from assessing the physical and behavioural characteristics of others in the community, and from recruiting others into alliances or collaborative activities. Within bottlenosed dolphin societies, recognition of others through unique individual signature whistles has been reported as well as mimicry of whistles of others, as an apparent affiliative act (Janik 1997; Tyack 1999). Collaborative foraging, feeding, and predator defence occurs regularly (Reynolds *et al.* 2000) and the formation of complex alliances among male dolphins has been noted among the dolphin population of Shark Bay, Australia (Conner *et al.* 1992).³

³ Editors' note: see also Connor and Mann, this volume.

Ecological pressures may additionally select for intelligence. In particular, the advantage of learning, storing, and utilizing information about such things as prey identification and habits, feeding sites, feeding strategies, predator characteristics and defences, topographical features of the habitat (cognitive mapping), and environmental cycles can select for the type of intelligence that supports declarative and procedural knowledge and skills. Both ecological and social pressures may act to select for intelligence, not necessarily exclusively or independently but more likely in parallel or in some sequential steps. Tomasello and Call (1997) concluded that, for primates, both social and ecological pressures select for intelligence, but each influences the development of different types of cognitive skills, possibly at different periods in the evolution of the species. This analysis seems compelling for dolphins as well, particularly given the convergence of dolphins and apes in so many of their cognitive attributes and skills (see e.g. Herman and Morrel-Samuels 1990).

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