## Title

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# Cognitive Research with Dolphins (*Tursiops truncatus*) at Disney's The Seas: A Program for Enrichment, Science, Education, and Conservation

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The dolphins at Disney contribute to a cognitive research program. This program has been very successful in four main areas: enrichment, science, education, and conservation. Dolphins are large-brained, long-lived mammals with extended developmental periods, complex social lives, a large variety of foraging techniques, and intricate vocal emissions; consequently, they need to engage in cognitive tasks, and they respond well to them. Our tasks have been designed for scientifically valid data collection focused mostly on questions relating to echoic object recognition, communication, and imitation/synchrony. The results have been published in peer-reviewed research journals and are summarized here. Data collection occurs in front of the public and appears to create a connection between the visitors and the dolphins. Through this program the dolphins under Disney's care have been able to promote conservation via our publications, public education, the testing of new technologies, staff (veterinary, research, husbandry) support at in situ research sites, and direct financial contributions. The program may be a useful example for other public facilities housing dolphins.

Can dolphins in a public facility promote science initiatives that help the individual dolphins themselves, other dolphins, and science education in general? Disney has invested in a team of trainers, veterinarians, educators, administrators, and researchers to address this question at The Seas. The dolphins under Disney's care at The Seas have contributed to a cognitive research program since 1988. This program has been very successful in that it has (1) enhanced the lives of the dolphins in our facility and those at other oceanaria, (2) produced reputable science published in peer-reviewed journals, (3) offered educational opportunities to hundreds of thousands of people, and (4) promoted the welfare of wild dolphins. This article briefly outlines these four major aspects of this program in hopes that it may be a useful example for other public facilities housing dolphins.

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## Why do Cognitive Research with Dolphins?

Bottlenose dolphins (*Tursiops truncatus*) depend on learning to negotiate their lives. They are large-brained mammals (Marino, 1998) with life spans of 40 to 50 years (Connor, Wells, Mann, & Read, 2000). They have an extended developmental period; calves typically stay with their mothers for three to five years or more (Mann & Smuts, 1998; Wells, 1993). They lead complex social lives in fairly large (e.g., over 100 individuals) and stable communities in which individuals interact across time and space within a fission-fusion society (Connor et al., 2000; Wells, 1993). Individuals from some age and sex classes form close, long-term associations; for example, adult males often form lifelong pairs (Owen, Wells, & Hofmann, 2002; Smolker & Pepper, 1999). Off Australia, these pairs can form alliances with other pairs, and these second-order alliances may become part of super-alliances to meet short-term goals (Connor, Heithaus, & Barre, 1999). Dolphins produce a wealth of vocal social signals, some well studied (e.g., signature whistles) and many still mostly mysterious (Harley, 2008; Janik, 2008); they can learn new vocalizations through imitation (Richards, Wolz, & Herman, 1984), and they engage in vocal matching (Janik, 2000). Dolphins also engage in a wide variety of foraging strategies, at least some of which are learned socially (Sargeant & Mann, 2009). Overall, these characteristics suggest that wild dolphins spend a significant portion of their natural lives engaging in sophisticated information processing.

Reputable facilities caring for animals typically try to provide enrichment opportunities for their animals that are specifically designed to segue with the strengths and needs of a particular species (Shepherdson, Mellen, & Hutchins, 1998). The dolphin's natural history suggests that these needs clearly include cognitive ones. Disney's The Seas has addressed this requirement by engaging the dolphins in cognitive research in the form of problem solving tasks: matching, discrimination and categorization, imitation, behavioral planning, manipulation of tools, and two-way communicative interactions via a keyboard. The dolphins generally receive fish and special attention from their trainers for participating in these tasks, although they also will participate in these activities during periods when they will not accept fish (H.E. Harley, personal observation). Occasionally, sick dolphins who refuse fish can be enticed to eat by offering them the option of taking part in a research session (L. Larsen, personal communication, 2005). These problem-solving opportunities are useful for promoting the welfare of the dolphins housed at Disney.

Our on-going research also improves our ability to monitor the dolphins' behavior and environment. For example, to study their vocalizations both within and outside of research sessions, we usually record vocalizations above and below the water almost daily (e.g., Abbott, Clark, Harley, Fellner, & O'Brien, 2009). Through these recordings we have been able to identify unusual sounds in their environment, to reduce the intensity of sounds in their environment, and to find the quietest places to keep the dolphins during required maintenance activities. Our recording method has been so useful that we have been invited to other dolphin facilities to consult about noise impacts in their environments.

Our studies of synchronous behaviors in the dolphins (e.g., Fellner, Bauer, Stamper, Losch, & Dahood, submitted 2010; Fellner, Losch, Harley, & Bauer, 2009) have also aided our management of them; we use data on their interactions to guide housing decisions. For example, after the introduction of two new dolphins to The Seas, synchrony observations gave us detailed information about how relationships between group members were evolving. Decisions on group size and composition were formed based in part on those observations.

Beyond enriching the lives of our dolphins and contributing to their management, our cognitive research program also has provided a substantial amount of scientific data about how dolphins acquire and process information that is relevant to them. Given their adaptations to the marine environment and their reliance on learning, some of the most interesting questions about dolphins are related to their perceptual systems and cognitive processing. Methods to address these questions often require long-term access to subjects and the opportunity to train them in order to organize their responses in an interpretable way. Disney's The Seas has contributed these resources to cognitive research since 1988.

## What Have we Learned from the Dolphins at Disney?

The dolphin's physiology, cognitive power, and natural history formed the basis for our choices for specific research directions. The methods we chose were informed by our questions, the need for scientific validity, the dolphins' health and welfare, and the personalities and strengths of the individual dolphins (see Highfill & Kuczaj, 2007, on dolphin personalities) who worked on the projects. Data collection is a team effort that requires substantive administrative, financial, technical, husbandry, veterinary, educational, and research support from many people. In particular, the trainers at Disney have been integral to this effort; they are Mark Barringer, Patrick Berry, Jane Capobianco, Bobbie Cavanaugh, Lisa Davis, Dave Feuerbach, Cathy Goonen-Brantley, Leslie Larsen, Conrad Litz, Barbara Losch, Tom Morris, Mike Muraco, Kim Odell. The Seas' research has focused on echolocation in relation to object recognition, communication, and synchrony/imitation.

### *Echolocation*

Dolphins have an exquisite echolocation system, a system through which they use sound to investigate their world. To echolocate, dolphins produce clicks and receive echoes that they process (see Au, 1993, for a comprehensive review of the dolphin sonar system). Their clicks are very short (40-70 μs), loud (180-225 dB re 1 μPa at 1 m), broadband emissions produced in sinus cavities within the head and emitted in a focused beam (Au, 1993). When echolocating an object, a dolphin typically produces one click and receives the ensuing echo before producing another click. The dolphin produces these clicks in a train. Dolphins can use this system for object recognition, an ability we have studied with dolphins at Disney (for a review of echoic object recognition by dolphins, see Harley & DeLong, 2008).

In one study we investigated the capacity of the dolphin to recognize a correspondence between its visual and echoic experiences of object features (Harley, Putman, & Roitblat, 2003). An adult male dolphin, Toby, performed a cross-modal delayed matching task in which he experienced a sample object in one modality (e.g., visually in air or echoically underwater behind thin black plastic) and chose an object from an array of three objects using a second modality (echoic or visual, respectively). He was tested with eighteen 3-object sets of randomly chosen unfamiliar junk objects that varied in many ways. In most cases, the dolphin was reinforced for successfully performing an identity match: after experiencing the sample object, he received fish for choosing an object identical to the sample from a 3-object array (Object A to Object A). However, with a pair of objects in each of six of the 3-object sets, the dolphin was rewarded for choosing an arbitrary, but consistent, alternative that was different from the sample (Object A to Object B). If the dolphin was merely learning to associate his visual and echoic experiences, then he should have performed as well with the arbitrary matches as he did with the identity matches. However, if he recognized a correspondence between his visual and echoic experiences of the same object features, then his experience with identity matching should have led him to choose based on identity regardless of reinforcement contingencies. In the cross-modal conditions with the arbitrarily paired objects, the dolphin made 498/672 (74%) identity-based choices versus 90/672 (13.4%) rewarded choices. The dolphin chose the third alternative in the subset the remainder of the time. Three choices were always available, therefore, chance performance was 33%. Because the stimuli were never presented simultaneously to the two modalities, the dolphin did not have the opportunity to learn to associate his visual and echoic experiences of the same object through temporal contiguity, and his results show that reinforcement did not guide his performance. The only method by which he could have associated his visual and echoic experiences of the same object was through the recognition that the object features experienced through the two different modalities were the same. Therefore, this study confirmed that dolphins get some overlapping information from vision and echolocation, and that they recognize that, at least for some object features, the feature perceived in one modality is the same one perceived in the other.

After conducting the experiment described above, we worked with colleagues, particularly Caroline DeLong and Whitlow Au, at other institutions to study the nature of the echoes produced by our stimuli through ensonifying some of these objects with a dolphin-like click (Harley & DeLong, 2008). We discovered that the dolphin made more errors with low-target strength objects (objects that returned lower amplitude echoes) perhaps because it was more difficult to get fine-tuned object feature information from softer echoes. In addition, the pattern of changes in echoes from multiple object orientations appeared to be important; the dolphin confused objects with similar patterns of changes across orientations and did not confuse objects with distinctive patterns of changes.

Another matching study at The Seas led to a similar analysis. For this study, Toby used echolocation alone to discriminate among objects in 3-object sets in which object features varied in specific ways: shape, size, texture, material (DeLong, Au, Lemonds, Harley, & Roitblat, 2006). An examination of performance accuracy, performance errors, features of echoes generated by the objects (target strength, number of highlights in the waveform, duration, peak frequency, center frequency, rms bandwidth), and features of echoes across changes in each object's orientation (relative target strength, relative number of highlights, changes in target strength, changes in waveform highlights) suggested that the dolphin neither used a single feature to discriminate among objects nor a linear combination of multiple features. Object features did not clearly predict echo features; e.g., size, shape, and material all interacted to affect echo intensity. In most sets, the dolphin could have used echoes and echo trains that varied in several ways: the distribution of energy across frequencies (i.e., echo spectrum shape), patterns of changes in target strength across object orientations, peak frequency, and center frequency.

DeLong and colleagues also compared a dolphin's confusions in echoic tasks to the performance of humans listening to slowed echoes in order to learn more about which echo features might be important for echoic object discrimination (DeLong, Au, Harley, Roitblat, & Pytka, 2007). When the humans and the dolphin confused the same objects, they may have used the same acoustic features. Again, the pattern of changes in the echoes across different object orientations affected performance. This interplay between data from trained dolphins, humans, and analyses of sounds is a fruitful way to investigate cognitive processing related to echolocation.

In another echolocation study at Disney, we discovered that not only can a dolphin recognize objects using echoes created through its own production of clicks, but it can also use the echoes returning to an actively echolocating neighbor. In a 3-alternative matching-to-sample study a non-echolocating dolphin (Toby, the listener) listened to the echoes returning from a sample object ensonified by an echolocating dolphin (Bob, the inspector) whose rostrum (the dolphin's so-called bottlenose) was within 5 degrees of the listening dolphin (Xitco & Roitblat, 1996). Each dolphin then swam to its own 3-alternative array and was able to choose an object identical to the sample with above-chance accuracy when the objects were familiar to both dolphins. When objects were not familiar to both dolphins, the listener only chose correctly when the inspector chose correctly. Because the listener's errors were not predicted by the inspector's errors, choice accuracy was probably predicted by the quality of the returning echoes. That the listener was able to get enough information to identify an object is somewhat remarkable given the directionality of the dolphin echolocation system; echoes received 10° off-axis can have a much lower intensity (-10 dB) with substantially lower frequencies (-114 kHz peak frequency) (Au, 1993) than on-axis echoes. Determining that dolphins can eavesdrop on the echoes of neighbors required careful experimental work with captive dolphins that allowed later related work to occur through observational studies of wild dolphins (Gotz, Verfuss, & Schnitzler, 2005) as well as inspiring more theoretical work on the topic (Gregg, Dudzinski, & Smith, 2007).

Echoic object recognition studies are on-going at The Seas. We are currently studying categorization of echoes and echoic recognition of shape (Harley, Fellner, & Losch, 2009).

### *Communication*

Not only do dolphins share information through echolocation, but they also depend on whistles for a variety of purposes including group cohesion (Janik & Slater, 1998). For this function dolphins use whistles that have individually unique frequency contours, changes in frequency over time. These whistles, called signature whistles, are typically defined as the whistle contour that a specific dolphin whistles most frequently when it is isolated. Signature whistles were first identified by Caldwell and Caldwell (1965) based on their recordings of captive dolphins, and their landmark work led to decades of complementary lab and field studies (see Harley, 2008, for a review of the signature whistle literature). One of the areas in which laboratory work was particularly useful concerned whistle perception and categorization by the dolphin, the focus of a study with one of the dolphins at Disney (Harley, 2008).

In this experiment, an adult female dolphin, Nina, performed a conditional matching task in which whistles produced by six wild dolphins in Sarasota Bay were each paired with a specific object/place (the objects never moved) presented in a six-object array. Nina heard a whistle, swam to a specific object, and received a fish if that object was paired with that whistle. Nina successfully discriminated the six whistles and associated them with their surrogate producers, the objects. When she heard new exemplars of whistles produced by the same whistlers as unreinforced probes, she continued to associate them with the original producer if the contours were intact but not when they were distorted, suggesting that she relied on frequency contour for classification. Because probes were not reinforced, her performance declined across presentations of the same probe stimulus suggesting that she could discriminate among different exemplars having the same frequency contours even though she categorized them together originally; therefore, different exemplars of same-contour whistles have the possibility of carrying information beyond that of identity of a dolphin. These findings contributed to our understanding of the uses of signature whistles available to dolphins.

Dolphins at Disney have participated in other communication-oriented studies as well. In one such study, Bob and Toby and their trainers used a keyboard to negotiate their environment (Xitco, Gory, & Kuczaj, 1991). When the keyboard was introduced to the dolphins, they watched their SCUBA-equipped trainers activate the keys by breaking infrared beams and then followed the trainers to specific sites in the large (about 21 million liters) underwater exhibit (in part for safety reasons, the keyboard was only accessible to the dolphins when trainers were present to monitor the dolphins' interactions with the keyboard). After about six months, the dolphins began activating keys themselves and preceding their trainers to the sites. There were often objects of interest in the environment, notably fish within containers but also tools and toys. The hope was that the dolphins would consistently use the keyboard to refer to all of these objects and places, and they did in fact use keys designating a variety of referents, especially places. However, they also introduced a more efficient method of communication. The keyboard trainers, though admirable swimmers, were much slower than were the dolphins. Perhaps in response to the waiting times encountered during these back-and-forth trips to the keyboard, the dolphins began pointing at the fish containers and other objects.

Xitco, Gory, and Kuczaj (2001) analyzed the points of the dolphins in the keyboard project. To point, a dolphin would stop swimming and align its body such that its rostrum would be directed toward the object of interest. Often, the dolphin would then turn its head toward one of its trainers, turn it back toward the object, back to the trainer, etc. Of the 722 pointing events analyzed on videotape, 461 of them (64%) included this monitoring by the dolphin. Most points were at food (88%) but the dolphin occasionally pointed at other things like tools. To test the likelihood that the dolphin was reflexively monitoring (unlikely given that monitoring did not always occur) without regard to a human presence, the researchers evaluated points when no humans were in the water but the rest of the set-up was the same; the dolphins never pointed when humans were out of the water.

In a follow-up study, the same two dolphins received a fish if they pointed to a baited container that was presented along with an unbaited container (Xitco, Gory, & Kuczaj, 2004). Trainers either faced toward the dolphin and the containers, away from the dolphin and containers, or were hidden behind a barrier in the tank. Each dolphin pointed most when a trainer was facing him, less when the trainer had her back turned, and rarely when the trainer hid behind the barrier. The dolphins frequently swam away when the trainer turned his back and always swam away when the trainer swam away.

These findings along with the eavesdropping study contribute important information relevant to joint attention (i.e., simultaneous attention to an object with the recognition that both participants are attending to the same object) in dolphins. Joint attention is applicable to many interesting cognitive questions including those concerning intentionality, communication, and theory of mind. Because interpretation of relevant behaviors is complex, these questions often require experimental work that is much easier to conduct in captive settings. Of course, the findings have significant implications for wild dolphins and their social interactions, e.g., will a dolphin act on information it knows another dolphin has?

Work in the area of communication continues at Disney's The Seas. Current studies include the dolphin's ability to discriminate and produce different acoustic rhythms (Harley, Fellner, Odell, Larsen-Plott, & Crowell, 2005) and analyses of their spontaneous vocalizations both within and outside of research sessions (e.g., Fellner & Harley, 2006, 2008).

### *Synchrony and imitation*

Of course, not all communication occurs through sound; other behaviors transmit information too. One direct way to investigate how dolphins represent a variety of behaviors is to study their ability to imitate. In early work at The Seas, Bauer and Johnson (1994) conducted a study with Bob and Toby in which the two dolphins were trained to respond to a hand sign indicating that one dolphin should mimic the behavior of its partner. After hundreds of training trials, the dolphins were tested with familiar behaviors. Toby successfully imitated 5 of 12 of these behaviors and Bob 1 of 12; neither dolphin imitated unfamiliar behaviors. The results were somewhat surprising given the facility with imitation shown by younger, more naïve dolphins at Herman's lab in Hawaii (Harley, Xitco, Roitblat, & Herman, 1998; Xitco, 1988), however, the data contributed to our understanding of what might affect imitation in dolphins, e.g., age, training history, and social relationships. The work also inspired later work at The Seas on synchrony in dolphins.

In 1994, a dolphin calf was born at The Seas. The mother-calf pair (Noriko and Naia) were video-taped for 5 minutes at least every two hours of the 24-hour day for several months. Eventually, Fellner et al. (submitted 2010) analyzed the videotapes of the pair for synchronous behavior in terms of their relative positions, bouts of synchrony, and breaks in synchrony. The mother and calf were almost constantly synchronous (almost 98% of the time) during the first month. The mother maintained the synchrony for the earliest weeks, but the calf became active in maintaining synchrony with her mother over time. The calf also developed a new suite of behaviors over the 5 weeks of the study. Synchrony offers a clear setting within which to learn new behaviors, and this framework may be the stage on which the dolphin's ability to imitate is set (Fellner, Bauer, & Harley, 2006).

Work on synchrony is on-going at The Seas today. The current focus is on male-male synchrony (Fellner, Losch, Harley, & Bauer, 2009). The clear water and constant access to the same dolphins at The Seas makes fine-tuned analysis of its functions possible and contributes to data with wild dolphins (e.g., Connor, Smolker, & Bejder, 2006).

## What do Dolphins at Disney Teach the Public?

Just as we try to choose research questions that segue with investigations of wild dolphins but require the sorts of designs best implemented in a controlled facility, we also strive to make the most of our access to the public. At Disney, the dolphin presentations are usually research sessions during which we highlight the dolphin's intellectual abilities rather than their physical prowess, the focus of most oceanarium shows. The sessions are narrated and interpreted in real time by our staff who explain how dolphins in the wild might use these same skills. At The

Seas, this approach works. When the dolphins are engaged in a session, we have observed that our visitors spend more than four times as long watching the dolphins. During research trials, guests often cheer when the dolphin gets the answer right, and sigh when the dolphin misses. When a dolphin has been having a bad run and then self-corrects, the on-lookers cheer more loudly. Our guests are drawn in by the cerebral efforts of their fellow mammals, one reason that cognitive research is highlighted at The Seas. A study of visitor knowledge about dolphins and their conservation conducted at six dolphin facilities (including The Seas) confirmed that knowledge levels increased after watching dolphin presentations at these institutions (Miller, 2009). Over the last twenty years, more than half a million members of the public have been able to watch the dolphins at Disney engage in the methods used to investigate questions in comparative cognition while listening to on-going explanatory commentary.

Through the years we have also had many people participate in research-oriented back-stage tours of our facility. Their comments suggest a recognition that even though dolphins are different from humans, they are also intellectual beings who learn through mechanisms similar to our own. In one assessment of our visitors' experiences, we simply asked them for contact information and then left a space large enough for comments but without a solicitation for them. Therefore, all responses were completely spontaneous; we did not ask for information about informal education, research, or any other effects of the program. However, 48 of 100 people used the space to comment on their experiences. All (48/48) of the comments included positive responses to the encounter (e.g., included the words "great," "good," "enjoyed," "liked," "fantastic," "fun," or similar ones). About half (25/48) of the comments also included statements indicating that they had learned specialized information from the tour (e.g., "Very informative"; "Gained a lot of information on dolphins"; "I've learned a lot about the dolphins that I never would have known"). One might think that the public would not enjoy watching the collection of trial-by-trial data acquired using a method that allowed the data to be presented in scientific journals (in one case, every trial conducted for a manuscript appearing in the journal *Nature* occurred in the public's view), but, apparently, one would be wrong. Watching science in action can clearly be both fun and intellectually stimulating for people with a wide variety of backgrounds.

## How do Dolphins at Disney Contribute to the Welfare of Wild Dolphins?

The dolphins at Disney have provided data relevant to both their own lives and the lives of their wild counterparts. Our studies on echolocation (DeLong et al., 2006, 2007; Harley et al., 2003; Harley & DeLong, 2008; Xitco & Roitblat, 1996), communication (Harley, 2008; Xitco et al., 2001, 2004), imitation (Bauer & Johnson, 1994), and synchrony (Fellner et al., submitted 2010) have all contributed fine-tuned analyses of behaviors investigated by researchers of dolphins in the wild (e.g., Connor et al., 2006; Gotz et al., 2005; Janik, 2000, 2008). Our focus on dolphin sounds is highlighted in our educational presentations and exposes our visitors to the problems wild dolphins are facing as oceans are affected by anthropogenic noise, climate change, and acidification, all of which affect the transmission of sound in the water.

The Seas also contributes directly to in situ research in three ways. First, we test prototypes of tags and other equipment that will be used to collect data with wild dolphins. For example, the dolphins Ranier and Calvin and their trainers helped ground-truth equipment used to collect Auditory Brainstem Responses (ABR) for testing hearing in wild dolphins in Sarasota Bay (Cook, Bauer, Fellner, & Mann, in preparation). Secondly, our veterinary, husbandry, and research staff participate directly in projects with wild dolphins (e.g., Bordino, Wells, & Stamper, 2008). Thirdly, dolphins at Disney make a material contribution to dolphins in their natural habitat. Currently, net proceeds from Disney's behind-the-scenes dolphin programs go to the Disney Worldwide Conservation Fund (DWCF) which supports conservation projects around the world. DWCF has provided more than 14 million dollars in funding to 170 nonprofits in 110 countries including more than 3.7 million dollars to over 260 marine projects, 65 of which focused on marine mammals.

## Conclusion

Can dolphins in a public facility promote science initiatives that help the individual dolphins themselves, other dolphins, and science education in general? The answer is yes. Due to their natural predilection for complex learning, dolphins at Disney have regularly engaged in problem-solving opportunities structured to be both enriching for the individuals and useful for producing scientifically valid data. The data from these studies have improved our understanding of the dolphin mind, sensory systems, and behavior, and have been presented in multiple venues including scientific journals and meetings, popular media, and K-12 schools; most of these studies also have impacted our understanding of wild dolphin behavior. Our research activities typically occur in the public view thereby educating hundreds of thousands of guests. The program has led to substantial financial and technical contributions for in situ work. Although we continue to work to improve our dolphin program and to evaluate its efficacy, overall, we have found it to be successful in terms of meeting our goals related to enrichment, science, education, and conservation. We hope that this example may be useful to others with similar aspirations.

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