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Responses of Human-Habituated Wild Atlantic Spotted Dolphins to Play Behaviors Using a Two-Way Human/Dolphin Interface

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Since 1985, a well-studied community of free ranging Atlantic spotted dolphins, *Stenella frontalis*, and bottlenose dolphins, *Tursiops truncatus*, has been observed underwater in the Bahamas. Over this period, the dolphins have become habituated to human swimmers. Long-term underwater observations revealed that some of these dolphins engaged in play behavior using man-made and natural objects in the presence of humans, and allowed humans to interact with them during play. We investigated the dolphins' play behaviors in response to a more formal two-way communication interface from 1997-2000. Spotted dolphins were exposed to an underwater keyboard in which visual and acoustic symbols represented the objects the dolphins were observed playing with. Objects could be obtained and played with by indicating the appropriate associated symbol. Pointing and triadic gaze between human participants was used to model the system in the presence of dolphins. Our results indicated that human use of the system encouraged the dolphins to attend to activity at the keyboard. Female juveniles, especially six main individuals, were the main players. Dolphins increased their normal levels of associations with certain conspecifics during exposure sessions and also took dominant roles during sessions in the presence of certain conspecifics. Dolphin age class, sex, and levels of synchronization with humans all contributed to the success and level of engagement during exposure sessions between humans and dolphins.

The idea of humans developing a better understanding of a non-human species' wild behavior and cognition by communicating with them in their natural habitat, through some sort of mutually understood symbolic communication system, is intriguing and has merit. Laboratory-based language research with non-human animals has demonstrated its broad application to the understanding of a species' cognition including its cognitive skills and processes, representational abilities, concept formation, theory of mind, and intelligence (e.g., Herman, 2006; Herman, Pack, & Morrel-Samuels, 1993; Pepperberg, 1993; Savage-Rumbaugh, 1986). An advantage of studying communication abilities like language in the laboratory is the precise control researchers have over subjects, stimuli, and variables. However, laboratory studies sometimes leave open questions about external validity of findings, and limit the examination of the breadth and depth of

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communication abilities in a broader environmental and social context (Pack, 2010). Field observations of several species have revealed evidence of limited within-species referential communication regarding predators and food using natural symbols (e.g., vervet monkeys, *Chlorocebus pygerythrus*, Cheney & Seyfarth, 1990; chickens (*Gallus gallus domesticus*): Evans & Evans, 1999; Gunnison's prairie dogs (*Cynomys gunnisoni*): Kiriazis & Slobodchikoff, 2006; Belding's ground squirrels (*Spermophilus beldingi*): Mateo, 1996). Dolphins have also been the subjects of intense scrutiny in the wild to examine for evidence of referential communication, especially given the strong demonstrations of this ability in the laboratory (Herman, 1986; Herman & Forestell, 1985; Herman, Kuzcaj, & Holder, 1993; Herman et al., 1993; Herman, Richards, & Wolz, 1984). Substantial support has been provided that in the wild (as well as in the laboratory) dolphins use "signature whistles" (unique whistle associated with the identity of self or a close associate) in referential exchanges with other dolphins (summarized in Pack, 2010). The present study examined whether dolphins in the wild could learn to use their referential communication skills to understand and produce symbols in communicative interactions with humans within the context of play (Bekoff & Allen, 1998).

Referential communication is a triadic transaction that involves the management of joint attention between an informant and a receiver towards an object, place, or event of interest (see Pack & Herman, 2006). The informant directs the attention of the receiver either through gazing, pointing, or a symbol towards something of interest. During communicative actions, the informant may gaze back and forth between the object and the receiver to check on their attention. Likewise, if the receiver does not find anything of interest in the direction of the informant's gaze or point cue, the receiver may check back to verify the direction of the informant's cue. In humans, deictic gazing and pointing typically precede referential symbolic competence involving words (Savage-Rumbaugh, 1986).

Previous studies of referential communication between dolphins and humans have investigated the ability of dolphins to comprehend and produce pointing behavior, and the ability of dolphins to comprehend and produce abstract symbols associated with objects, actions, and relationships. For example, Tschudin, Call, Dunbar, Harris, and van der Elst (2001) demonstrated that naïve dolphins spontaneously responded accurately to human gazing and pointing to distally placed objects. Pack and Herman (2004) showed that dolphins are one of the few species that spontaneously understand gazing and pointing cues presented statically (i.e., without movement of the informant) and their referential character (Pack & Herman, 2007). Dolphins have also shown excellent comprehension of human points substituted for object gestures within an artificial language system (Herman et al., 1999; Herman & Uyeyama, 1999). With regard to production, Xitco, Gory, and Kuczaj (2001) showed that dolphins could (i.e., without specific training) produce indicative cues by pointing the rostrum while keeping the body aligned toward an object of interest to direct human attention to that object. Importantly, the dolphin in these studies "checked back" towards the human receivers when the humans were distantly located. An additional study showed that the dolphin pointed most often when a human's attention was available (i.e., when the human was present and face forward towards the dolphin, Xitco, Gory, &

Kuczaj, 2004).

Herman and colleagues demonstrated that dolphins could understand the semantic and syntactic components of symbolic sequences within an artificial language system in which either gestures of a trainer's arms and hands or computer-generated sounds were associated with objects, actions, agents, and relationships (summarized in Herman, 1986; Herman et al., 1984; Herman et al., 1993). Taking a different tack, Reiss and McCowan (1993) focused on production of symbols by dolphins. They developed a communication system in which keys on a keyboard represented different objects or actions. Activation of a key by a dolphin resulted in a unique sound associated with that key being played, and then a human presenting the corresponding object or action to the dolphin. Two of four dolphins used the keyboard initially and then spontaneously began producing acoustic facsimiles of the sounds associated with a few of the objects in appropriate contexts (e.g., when playing with the object). Importantly, Reiss and McCowan (1993) took advantage of the natural tendency of dolphins to engage in play with objects. However, no tests of comprehension of symbols were conducted (*cf.* Herman et al., 1984).

Finally, Xitco et al. (2001) using an acoustic/visual symbol keyboard interface demonstrated that two dolphins were able to understand the symbols when produced by a human companion inasmuch as the dolphins when seeing a symbol activated would often proceed ahead of the human to the object associated with that symbol. The dolphins also demonstrated the spontaneous emergence of symbol production after observing humans using a symbolic system to achieve particular goals (Xitco et al., 2001). However, few details were presented on specific tests to examine the validity that produced symbols were understood referentially.

Overall, these laboratory-based artificial language projects demonstrated the dolphin's ability for semantic and syntactic comprehension (Herman, 1986), and for production of symbols in meaningful contexts (Reiss & McCowan, 1993; Xitco et al., 2001). However, the laboratory settings in which the studies were performed limited the types and diversity of environments, activities, and objects that could be represented by symbols or symbolic sequences. One of the advantages of the captive bonobo (*Pan paniscus*) language studies of Savage-Rumbaugh and colleagues (Savage-Rumbaugh, McDonald, Sevcik, Hopkins, & Rupert, 1986) was access to a 55-acre natural forest within which to develop, model, and use their symbolic communication system. The forest allowed for a diverse and extensive vocabulary to be developed as well as diverse functional routines during which food, agents, actions, relationships, and places could be referred to and later tested for comprehension in the more controlled laboratory (Savage-Rumbaugh et al., 1993). Additionally, functional object use and play were often involved in these activities that encouraged bonobo requests for objects beyond different foods. Play, whether social or object oriented, may serve a critical developmental and evolutionary function in young animals (Bekoff, 1984; Bekoff & Allen, 1998).

In the Bahamas, we have studied a resident group of individually identified Atlantic spotted dolphins and bottlenose dolphins since 1985. The clarity of the water in this site makes it an ideal location for studying underwater dolphin behavior and social interactions. Life history (Herzing, 1997), correlations of vocalizations and behavior (Herzing, 1996, 2000, 2006), and interspecific interactions between dolphin species (Herzing & Johnson, 1997) have all been described. Recently, Bender, Herzing, and Bjorklund (2008) reported on specific teaching mechanisms, involving both observation and instruction between foraging dolphin mothers and calves that appear to involve directed attention through triadic transactions. Additional mechanisms and direction of information transfer have also been proposed (e.g., oblique transmission, imitation and stimulus enhancement in Herzing, 2005).

Although interactions with lone wild dolphins have been reported in many parts of the world (Lockyer, 1990), and some examples of cooperative fishing between dolphins and humans have been reported (Pryor & Lindbergh, 1990), regular play interactions between a wild dolphin "society" and human researchers in the Bahamas provided an opportunity to explore this unique interspecies interaction. We considered this resident community of spotted dolphins a good candidate for exposure of an interactive human-dolphin communicative interface for several reasons. First, Atlantic spotted dolphins are genetically closely related to bottlenose dolphins, the subjects in all of the laboratory studies on referential communication reviewed earlier. Second, the spotted dolphins in this community have a natural propensity to interact with both bottlenose dolphins, a sympatric species in the study area, and humans. Third, the life histories and maternal relationships of most of these dolphins were known for several generations. Finally, the Bahamas field site, with its variable environment offers objects and activities that are functionally important to the dolphins and could potentially serve as the basis for communicative interchanges. For example, over years of study we have witnessed the dolphins often engaged in loose "play" activities with humans that revolved around the back and forth exchange of natural objects (e.g., seaweed). These already existing "windows of opportunity" between humans and dolphins provided a context for interactive work. Many animals use play in social contexts to solidify bonds and gain knowledge about their conspecifics (Bekoff, 1984; Fagen, 1981). In theory, if access to a desired play object required the assistance of a human (e.g., they were housed in a transparent container that could only be opened by a human, *cf.* Xitco et al., 2001), this could provide motivation for a dolphin to use a symbolic system to communicate with a human to gain access to the object.

Our goal was to develop an interface in the wild and observe spontaneous features that emerged during interspecies interaction. This involved providing opportunities for regular exposure to symbol use and production, developing environments and activities in which interspecies communication would be functional, engaging and sustaining the interest of individuals of the species and exploring mechanisms (like joint attention and referential comprehension) during symbol use. We chose the *social-rivalry* framework because of the previous success with other species utilizing similar features during the exploration of an interspecies interface with humans. The *social-rivalry* theory of modeling a communication system has been successfully used during two – way work with African grey parrots (Pepperberg, 1993), and with dolphins (see also Xitco et al., 2001 for human-human modeling of using a symbolic keyboard in the presence of a dolphin). Inasmuch as the dolphins in this location are not provided with food by humans (*cf*. Connor & Smolker, 1985; Samuels & Bejder, 2004), we focused on symbols associated with play behaviors and objects used in play.

The objectives of the study were two-fold: 1) to design an exposure protocol and an interface conducive towards two-way communication between dolphins and humans in the wild, and 2) to document the process of exposure, social modeling, and emergent features during this interactive work.

Here, we report on the initial exposures and reactions of the dolphins to humans modeling the use of an underwater keyboard to obtain items as well as engaging in communicative acts using pointing and gazing. We report age classes, activity of individual dolphins, and exposure to and change over time, in the use and interaction with this two-way interface.

Materials and Method

Since 1985, over 220 individual Atlantic spotted dolphins in an approximately 480 km^2 area of Little Bahama Bank have been identified using photographs and video of dorsal fins, flukes and constellations of spots. These dolphins were sexed via direct observation of the genital area, and categorized into age classes by their degree of spotting and color phase, and repeatedly observed over the twenty-year period (Herzing, 1997). The result of this long-term research program was the generation of long-term individual life histories (Herzing, 1997) that were updated every summer from research conducted annually during summer months.

The current project capitalized on the accessibility of this dolphin community to underwater observation and interaction with humans (Herzing, 1996) and life history information available for individual dolphins in this community that have been tracked through photo identification since 1985 (Herzing, 1997). Coefficients of association (COA), scored as the presence of an individual during any given encounter, were calculated using the half-weighted index (Cairns & Schwager, 1987) through the four-year period. To measure possible changes in association during the interactive work from regular observational dolphin encounters, we compared all COA every year between every encounter, exposure work, and non-exposure work.

Subjects. We worked with a subset of the free ranging Atlantic spotted dolphins community described above from 1997-2000. Table 1 lists the amount of effort during interface work over a four-year period. Many spotted dolphins in the Bahamas are habituated to the presence of humans in the water. Over the course of the longer-term research program, most of these dolphins have been observed to have direct interactions with humans including “playing games” with seaweed and other objects. During these interactions we have observed to some degree the dolphins and humans mutually modifying their behavior (e.g., the dolphins slowing down while in the presence of humans, dropping an object they were carrying in front of humans, allowing humans to remove the object from a dolphin’s appendage). In other activities we have documented the dolphins observing humans during behavioral activities and changing their movement patterns, or engaging in spontaneous behavioral mimicry of humans (*cf.* Herman, 2002, see also mimicry of synthetic sounds by bottlenose dolphins, e.g., Reiss & McCowan, 1993; Richards, Wolz, & Herman, 1984). These informal object exchanging games, instances of interspecies mimicry and other social interactions between dolphins and humans provided a potential opportunity for developing the two-way communication system.

Table 1
Amount of effort, by year, for exposure sessions between dolphins and humans in the Bahamas (1997-2000)

Year	**1997**	**1998**	**1999**	**2000**	**Totals**
Days of effort at sea	40	65	50	60	215
Days of exposures	38	23	19	10	90
Duration - Minutes	947	780	465	249	2441
Duration - Hours	16	13	8	4	41
Avg. Duration (min)	25	34	24	25	27

1997 Pilot Study

In 1997 a prototype device was designed to playback artificially created tones and rhythms. The human team coordinator Denise Herzing (DH) had an Ocean Technology System (OTS) underwater ear that allowed one-way verbal communication to the human team at the beginning, or cessation of sessions with the dolphins (Figure 1A). Each human participant wore an underwater ear for reception only. The prototype was 12.7 cm x 6.35 cm x 5.08 cm and weighed approximately 170 grams. Each sound could be initiated by depressing one of the twelve keys on the keypad (Figure 1B). Because of the human subject's inabilities to recognize, real-time, subtle differences in whistles, artificial tones in a variety of sequences were synthesized. Each sound was composed of one or more tone bursts, defined by duration and frequency and presented at uniform amplitude, and associated with human activity in the water (Figure 1C). Human participants practiced recognizing and coordinating their human actions in a swimming pool, and in the field site, when no dolphins were present. Dolphins were then exposed to combinations of tone sequences and human action. Although the dolphins paid attention and observed human-associated activities of this acoustic system we decided to add some visual elements to this system to further engage the dolphin's visual modality for the 1998 season.

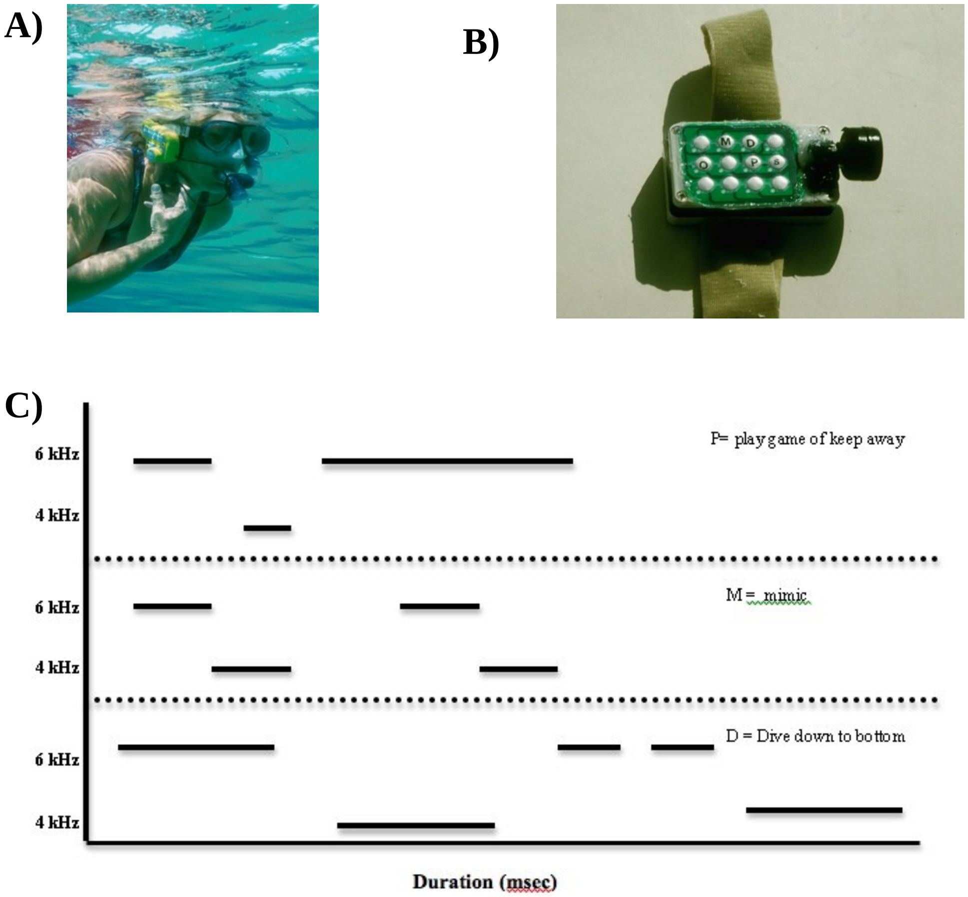

Figure 1. Equipment used during exposure sessions. **A)** Ocean Technology System earpiece, **B)** wristband keyboard, **C)** diagrammatic of tone sequences generated

1998 –2000 –Visual and Acoustic Symbols and Keyboard Interface

Because "play" activities with humans revolved around the back and forth exchange of natural and non-natural objects, we labeled some of these objects with arbitrary visual and acoustic symbols and incorporated these labeled objects into the interface. We hypothesized that the dolphin, through exposure to the modeled referential communication between humans, would discover the function of referential communication and would spontaneously begin to request objects, or to comment on objects within this system. During interactive sessions we tracked 1) the individual dolphins present (identification, sex, age classes), 2) the level of attention by dolphins to the system (scale of synchrony and eye contact with humans), 3) the level of participation by individual dolphins in social interactions and object use (scale of D1 (greatest)-D4 (least participatory) measure by the amount of time interacting with the object or human during one exposure session), and 4) the dolphin's developing comprehension of the elements involved in referential communication.

Four differently shaped non-iconic visual symbols were developed as "names" for the following objects: scarf, rope, sargassum, and bow ride. Each symbol was associated with a unique acoustic signal that could be activated by an attending human, when a request was made by either a dolphin or human (Figure 2A-C). The visual symbols were approximately 25 x 25 cm in size, made of white PVC starboard that contrasted the black background of the waterproof box. Each visual symbol was attached to a small watertight box containing a Sony MZ-E40 portable mini disc player that was triggered externally to play the single acoustic signal associated with that symbol and its represented object. Each symbol/box unit was placed on an aluminum bar to allow a keyboard "operator" to transport the keyboard in the water as needed to work with the dolphins, and to trigger a symbol's associated acoustic sound by pushing a toggle switch located on each separate symbol/box when appropriate requests occurred. The sounds associated with each symbol were synthetic, human-designed, frequency modulated whistles, outside the dolphin's normal repertoire (Figure 2C).

System Initiation. Humans practiced using the keyboard in various ways when the dolphins were not present. When we did encounter dolphins, we first assessed sea surface and current conditions (i.e., they needed to be calm), and also whether the dolphins were engaged in any activities that we did not want to interrupt (e.g., foraging, reproductive activity, etc.). If sea state was favorable, and if the dolphins were not engaged in non-interruptible activities, we placed the keyboard in the water. When entering the water, humans carried the labeled toy objects (scarf, seaweed) in order to engage the dolphins in play. Also, replicas of the objects were placed in locations (jars) anchored to the anchor line, allowing the dolphins to explore the objects in a second location other than on the human in the water.

Prior to interactive encounters each member of the human interactive team was assigned one of the following roles: a) interacting human (1-3 participants), b) keyboard operator, c) videographer, d) photographer. The team coordinator (DH) wore the OTS modified underwater ear to verbally coordinate other team members wearing listening OTS ears (Figure 1A). The videographer documented every session and all keyboard activity and human-dolphin as well as dolphin-dolphin activities with a Sony PC110 model with hydrophone input. The photographer obtained images of each dolphin for identification verification using a Sony Cybershot camera but typically the dolphins were well known and easily identified individuals during these sessions. After the session ended, a data form was filled out onboard the research vessel including individual dolphins present, sex, age class, level of engagement with humans and the system (D1-D4), and the presence and activation of specific symbols (acoustic and/or visual) used in the water during that session at least once. The occurrence of eye contact and slow/synchronized swimming with a human was also scored, as a potential predictor of engagement.

The *social-rivalry* modeling system allowed dolphin participants to observe the communication system with humans, and the rewards produced (such as reception of an object, or engagement in intra or interspecific play). Dolphins could both compete and engage as a rival in the use of the system. During these exposure sessions, humans attended to possible communication from the dolphins (Figure 2C) including body-orienting points to the symbols or the use of sound or other movements. The frequency of each type of interaction depended on the specific group of dolphins and their experience and exposure to the system. This included:

- One human looking at another human, insuring that they had that human's attention and then pointing at (with the hand and extended arm) an object of interest. The second human would retrieve the object that was pointed to and present it to the first human who could engage in a form of play behavior with the object (e.g., the exchange game described above that will include the dolphins).
- One human looking at another human, insuring that they had that human's attention and then activating an abstract visual/acoustic symbol associated with a particular object of interest. The second human would retrieve the object and present it to the first human who could engage in a form of play behavior with the object (e.g., the exchange game described above that will include the dolphins).
- One human activating an abstract visual/acoustic symbol as a "comment" while another human is engaged in play with an object associated with the symbol. The frequency of each type of human-modeled communicative act depended on the specific group of dolphins and their experience and exposure to the system.

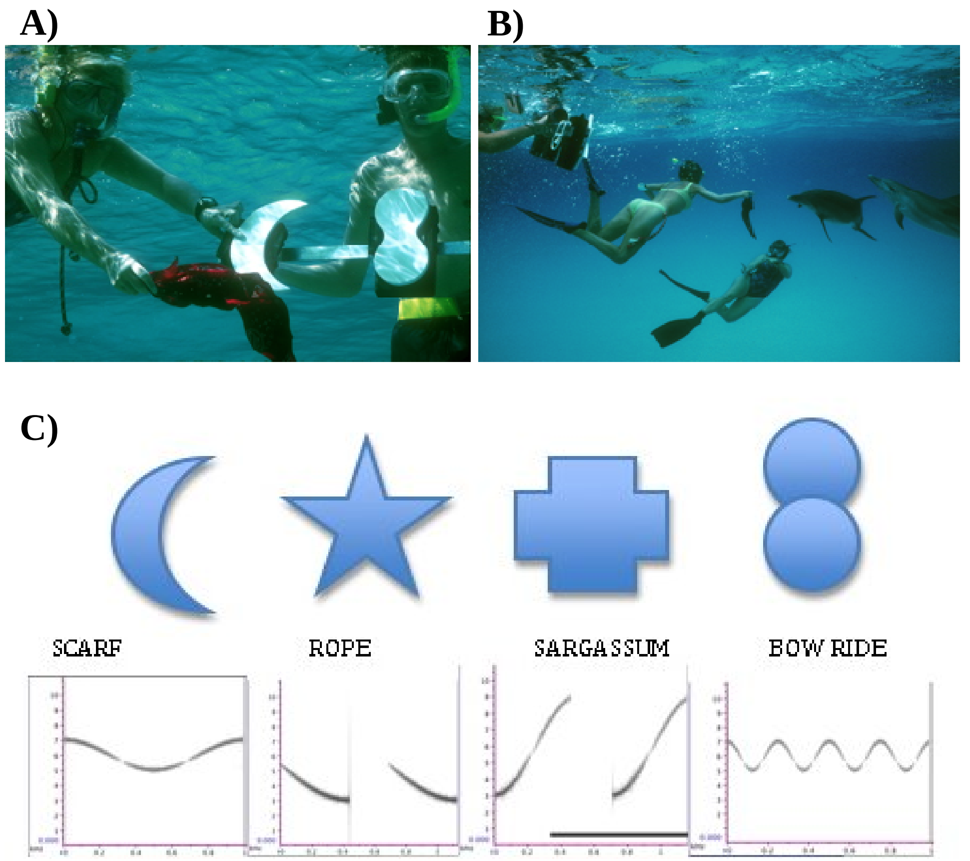

Figure 2. Equipment used during exposure sessions, **A)** Mobile keyboard with visual and acoustic symbols, **B)** Spotted dolphin working with humans with underwater keyboard, **C)** Visual and acoustic symbols used.

Dolphin to Human Interactions and Use of the Keyboard

Aside from joining in the object exchange game after a request for an object was modeled between humans (described above), there were two other situations in which dolphins could obtain objects, one involving the keyboard and the second involving the dolphin's use of pointing and gazing to an object hidden in a container that required a human's assistance to open. Each situation is described below.

One passive human (A) carried the keyboard in the water, composed of three different abstract figures (symbols). Another passive human carried the underwater video camera (B). (A) manually activated the audio signal when the dolphin had correctly displayed a solicitation for an object or activity by pointing to the symbol with its rostrum or when a human pointed at the symbol. The distance between the symbols (40 mm) allowed the keyboard operator to clearly distinguish which symbol the dolphin pointed to. Three other active humans (C, D, and E) simultaneously carried the objects to play with.

The following were the most common scenarios that occurred during sessions:

Situation 1: Humans modeled a request: all the objects were hidden in the vicinity of dolphins showing interest in swimmers (long lasting visual interest, postural solicitation). One of the humans went to the keyboard and asked for a particular object by pointing to a symbol with his/her hand. The human who had the object in possession responded by giving it to the requestor, initiating play. Humans often initiated play activities with each other while the dolphins observed.

Situation 2: Dolphins initiated a request or explored the communication system: all the objects to play with were hidden on humans C, D and E. To obtain an object the dolphin had to position itself close to the apparatus and point with its rostrum to the visual symbol. The active human (for example C) who had the object quickly went to the dolphin, brought out the requested object and engaged in play. During these sessions active humans could also request an object using the keyboard from another human, while the dolphins observed or attempted to engage in play. During a session, objects could be switched by the human in possession of the object or by a change by request at the keyboard by either a human or dolphin.

Situation 3: Dolphins explored objects in other locations: the desired objects were placed in closed but transparent plastic jars that were suspended in the water column by attaching them to an anchor line. In order to obtain an object, the dolphins needed a human to open the jar. To communicate this, the dolphin was required to either point its rostrum to the jar or position its body adjacent to the jar. If one or both of these actions occurred, the human would open the jar, present the dolphin with the object, and be prepared to engage in a game of exchange as initiated by the dolphin. Dolphins showed interest in orienting, or allowed themselves to be led to the jar while they observed the action of the human retrieving the object.

Following each session, video taped footage was carefully reviewed and analyzed for occurrences of the situations described and for components within these situations (i.e., only portions of a situation might be present). We hypothesized that a dolphin, through exposure to the modeled referential communication between humans, would learn that this type of communication can be used to achieve goals, and thus would spontaneously begin to use the system to request objects.

To measure whether exposure sessions varied from "normal" sessions (i.e., those involving passive documentation of dolphin behavior without the presence of the keyboard or any communicative acts of joint attention initiated by humans), and were communicatively productive, both intra and interspecifically, we addressed the following questions:

1. Was there a sex-based difference, or group size difference during normal interactions and the exposure sessions?
2. Did the dolphins alter their associations or behavioral interactions with each other during exposure sessions?
3. What features emerged that might lead to additional design features or other exposure protocols more conducive towards two-way communication?

Results – 1998 through 2000

Sex and Group Size

The average numbers of male and female dolphins in normal encounters vs. exposure sessions from 1998 to 2000 showed a significant difference (KW= 68.14 corrected for ties, $p < 0.0001$). Dunn's comparison test showed that females had a greater presence than males during both normal and exposure work with males dropping out slightly during the exposure sessions. There were no significant differences of mean group size during normal encounters ($M = 8.83$, $SD = 7.11$) vs. exposure encounters ($M = 9.06$ $SD = 5.27$) 1998-2000 or within (Mann –Whitney test not significant, two-tailed P value 0.42).

Exposures and Dynamics between Individual Dolphins

Table 2 shows the total number of exposures of individual dolphins to the system, and the duration and type of exposure (1998-2000). The total numbers of years exposed, numbers of actual encounters, and duration of exposure was large (500-741 min) for a small number of individuals, especially juvenile females (e.g., Caroh, LittleHali, Mitsu, Tink) that were interactive for two or more sequential years. The types of modalities that dolphins were exposed to also varied and were high for these same individuals.

Figure 3A-C shows the level of interaction of individual dolphins (D1-D4) during exposure sessions (1998-2000). Individuals showed both a varied and dynamic tendency to interact with the system. While some individuals were consistent as dominant players i.e., D1 or D2 during interactions over multiple years (see boxed area Caroh, Mitsu 1998-1999, and Tink 1998-2000), other individuals that were observed with lower levels of interaction early in a given field season, or in an earlier year, sometimes became more interactive within a season, or in the following years (see boxed area LittleHali 1998 D1 once increasing in 1999 to D1 four times).

Normal association patterns (COA) between dolphin dyads during all exposure work, combined exposure/regular, and regular encounters/year were compared 1998-2000 (Figure 4A-C). Most dyads showed a trend of greater association during exposure sessions as compared to combined types of encounters or normal encounters, and some dyads (e.g., Caroh/Tink, Caroh/LittleHali, Tink/LittleHali) showed extreme increases in association (> 0.20 COA change) during exposure work.

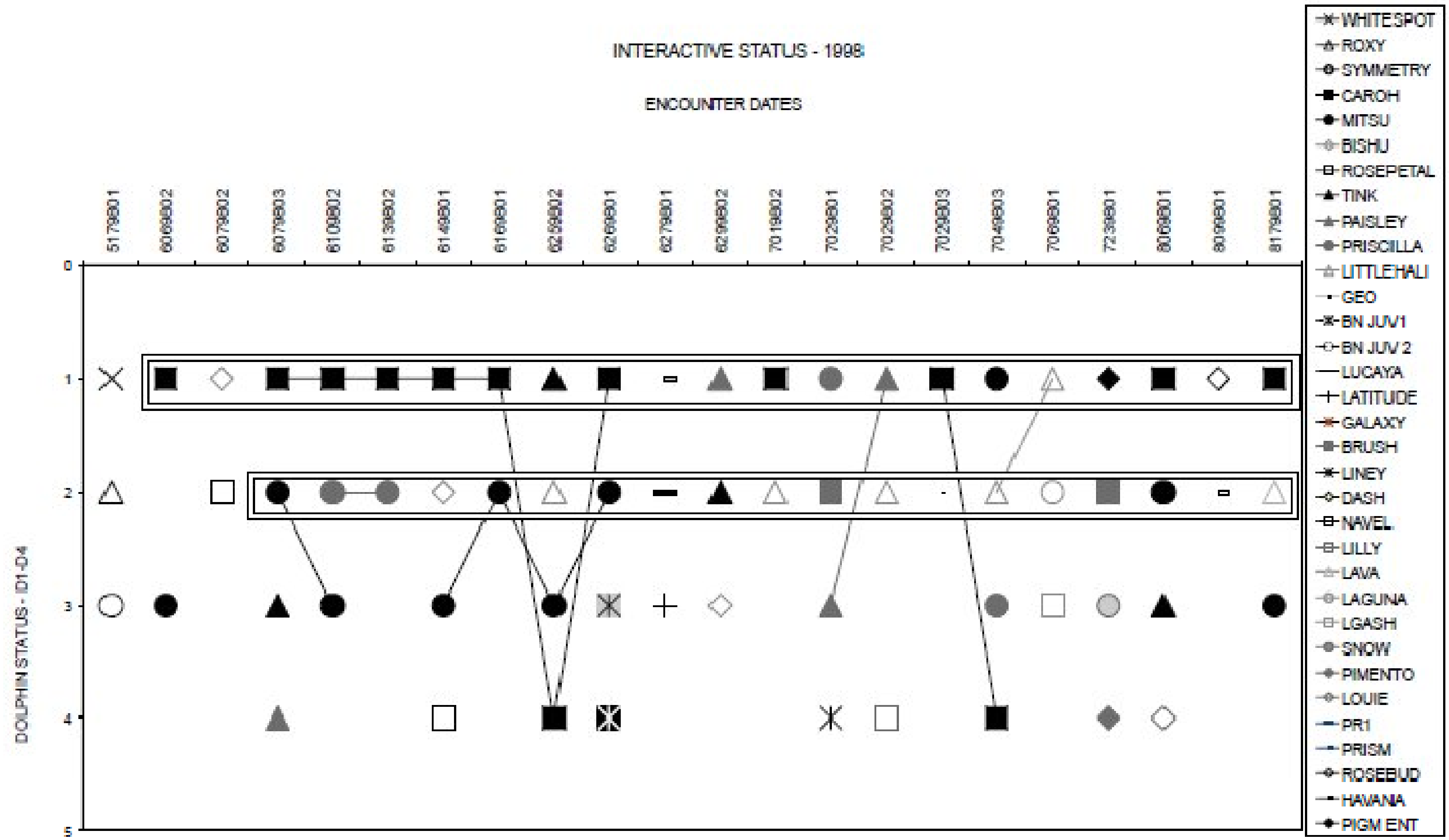

Figure 3A. Dominant interaction by individual dolphin in 1998.

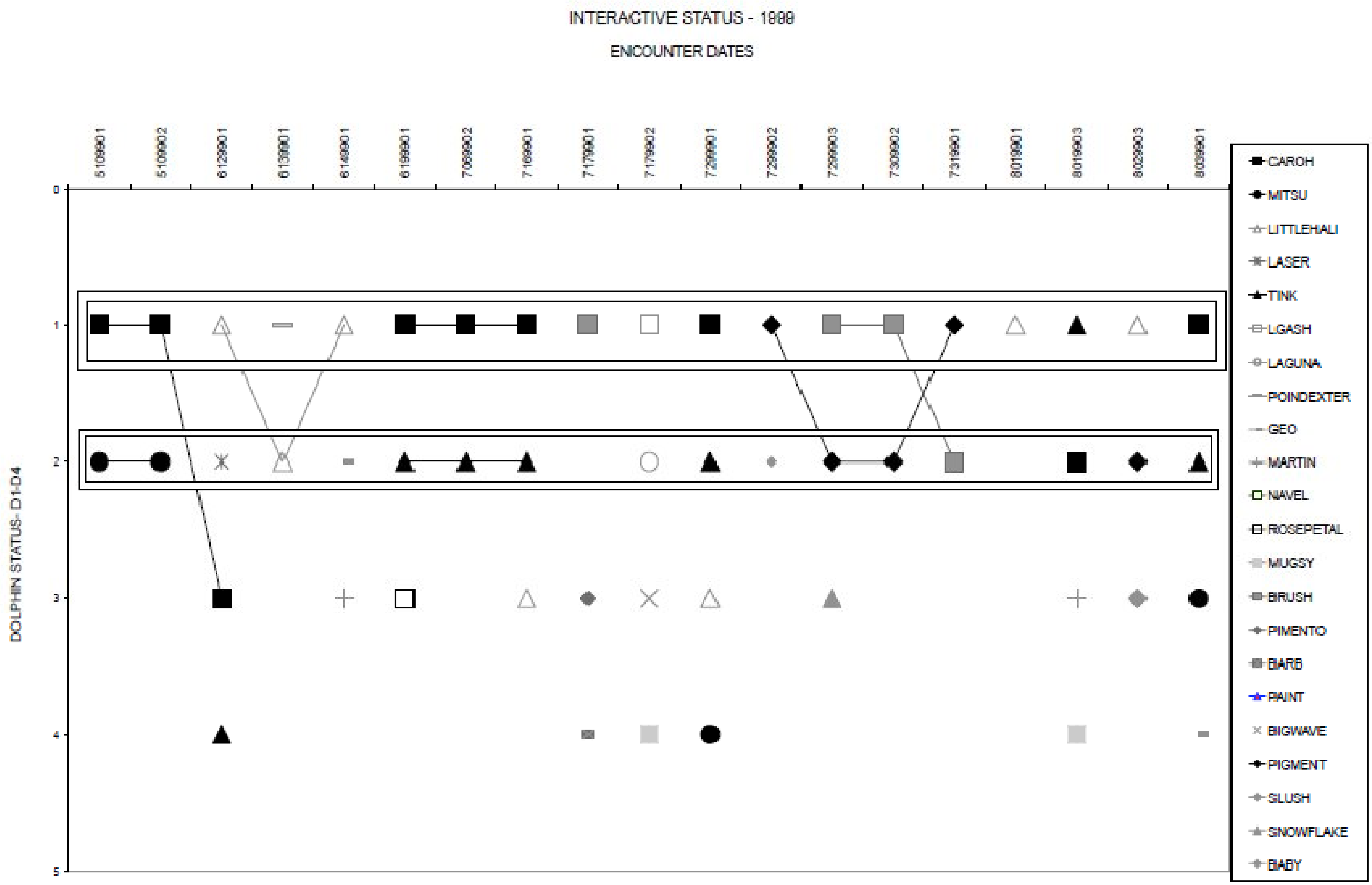

Figure 3B. Dominant interaction by individual dolphin in 1999.

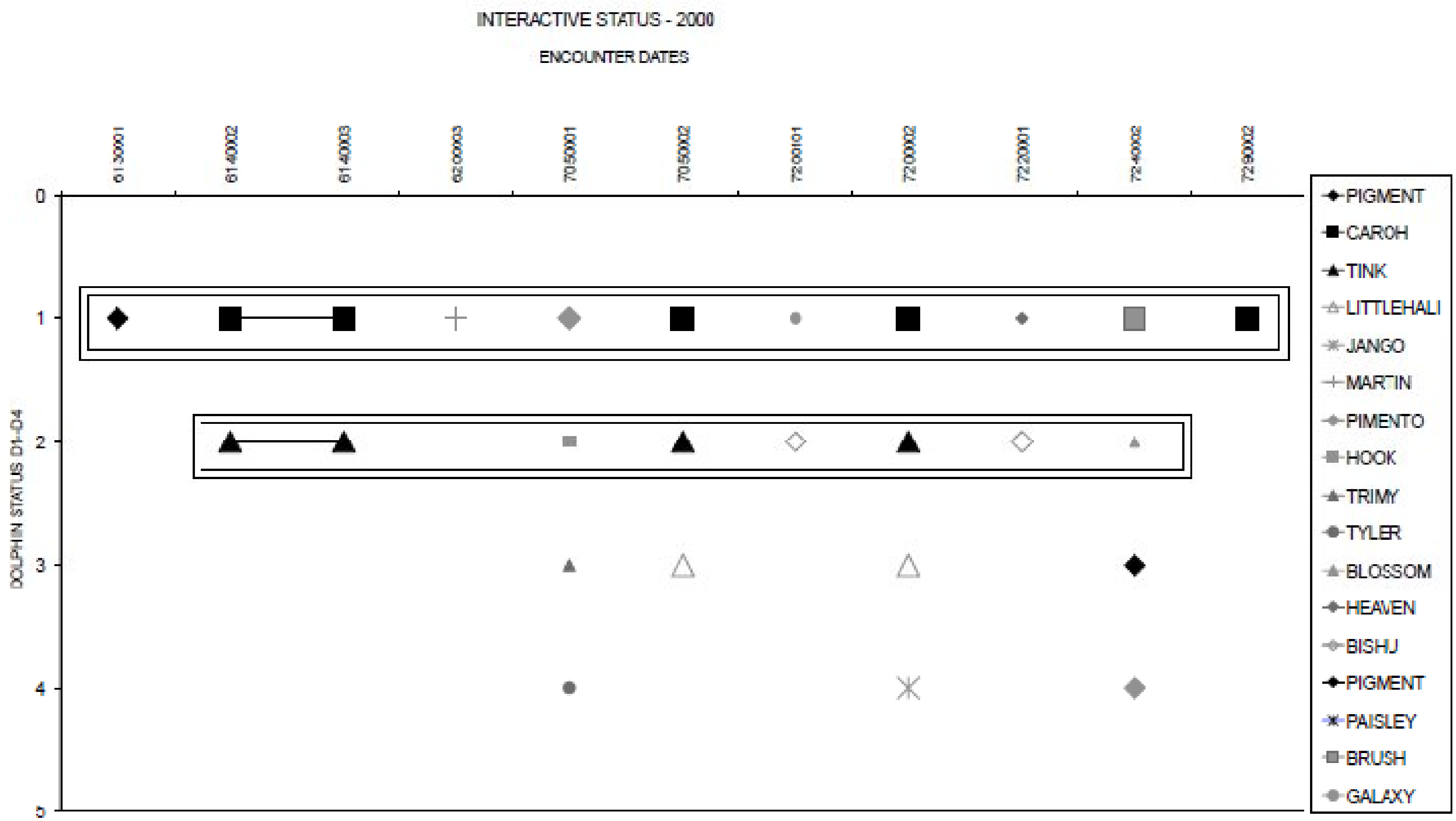

Figure 3C. Dominant interaction by individual dolphin in 2000.

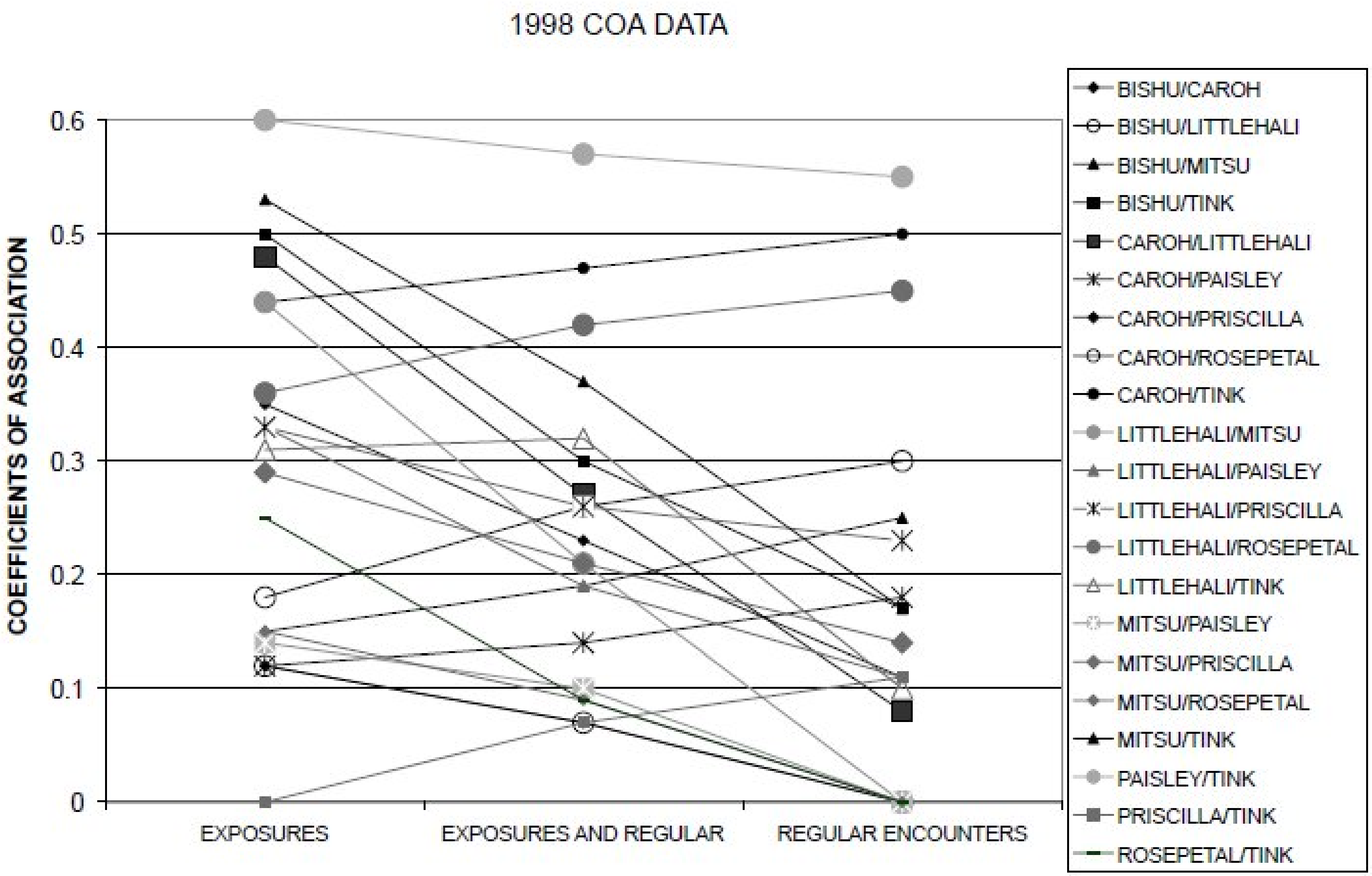

Figure 4A. Normal associations (COA) of individual dolphin during exposures, combined and regular encounters in 1998

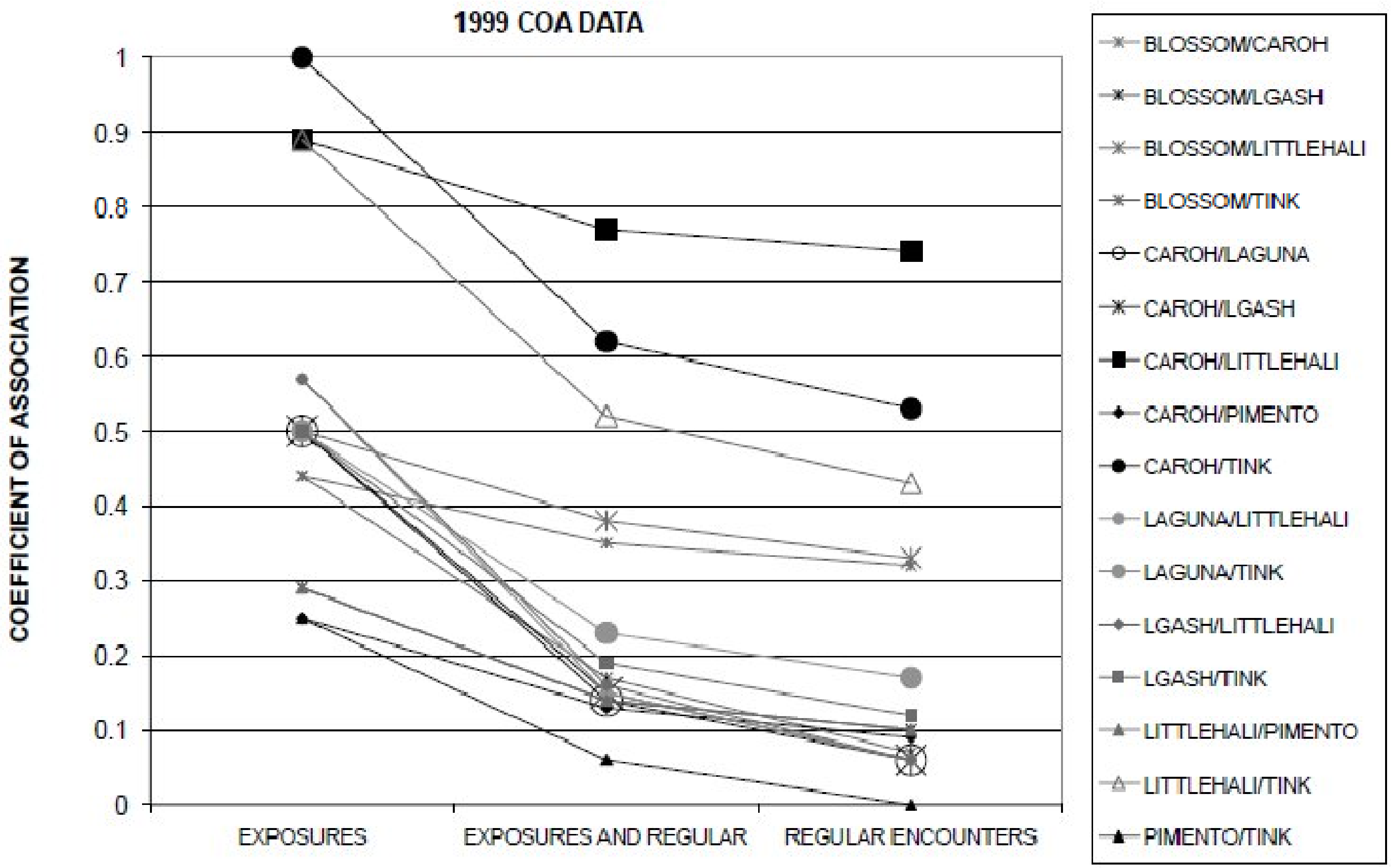

Figure 4B. Normal associations (COA) of individual dolphin during exposures, combined, and regular encounters in 1999.

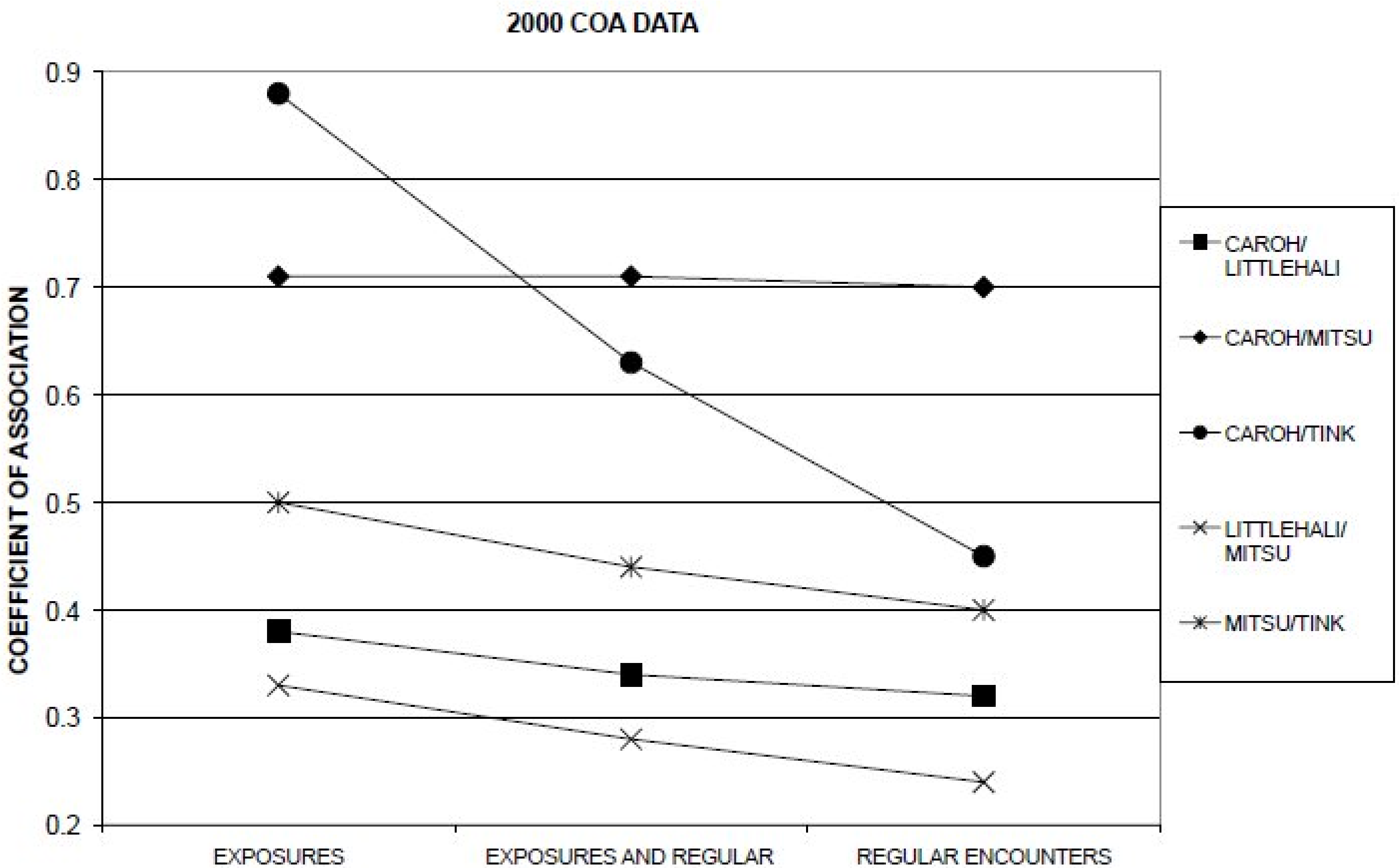

Figure 4C. Normal associations (COA) of individual dolphin during exposures, combined, and regular encounters in 2000.

Table 2
Total duration (min) of exposure by modality and per individual dolphin for keyboard exposure (1998-2000)

DOLPHINS	**Acoustic 1998**	**Acoustic 1999**	**Visual 1998**	**Acoustic & visual 1998**	**Objects & jars 1998**	**Acoustic & visual 1999**	**Objects & jars 1999**	**Acoustic & visual 2000**	**Objects & jars 2000**	**Total**
BARB	0	0	0	0	0	25	0	40	0	65
BLOSSOM	0	0	0	0	0	0	0	40	0	40
BISHU	0	0	0	0	65	0	0	10	0	75
BRUSH	0	0	0	15	60	15	15	15	0	120
CAROH	10	45	10	45	315	145	0	146	25	741
GEO	0	0	0	10	100	90	0	0	0	200
HAVANA	0	0	0	0	35	0	0	0	0	35
HEAVEN	0	0	0	0	0	0	0	10	0	10
LAGUNA	0	0	0	0	15	30	0	60	0	105
LAVA	0	0	0	35	0	0	0	0	0	35
LILLY	0	0	0	10	0	0	0	0	0	10
LGASH	0	0	0	0	15	30	0	60	0	105
LITTLEHALI	0	0	0	20	135	250	0	105	0	510
MARTIN	0	0	0	0	0	100	0	18	0	118
MITSU	0	0	0	45	320	135	0	0	0	500
NAVEL	0	0	0	15	0	70	0	0	0	85
PAINT	0	0	0	0	0	25	0	0	0	25
PAISLEY	0	0	0	25	50	0	0	0	0	75
PIGMENT	0	0	0	0	60	30	5	15	0	110
PIMENTO	0	0	0	0	60	25	0	40	0	125
POINDEXTER	0	0	0	0	0	80	0	0	0	80
PRISCILLA	0	0	0	10	80	0	0	0	0	90
ROSEBUD	0	0	0	0	35	0	0	0	0	35
ROSEPETAL	0	0	0	0	35	40	0	0	0	75
SNOW	0	0	0	0	60	0	0	0	0	60
SNOWFLAKE	0	0	0	0	0	5	0	0	0	5
TINK	0	45	0	0	250	220	0	141	25	681
TRIMY	0	0	0	0	0	25	0	25	0	50
WHITESPOT	0	0	0	0	150	0	0	0	0	150

Dynamics of Individual Dolphins During Interface Use: Individual Cases

The following events are presented to describe unique evidence of a developing use/understanding of the keyboard interface and the use of joint attention mechanisms (like pointing) as effective means of communication from dolphins to humans.

Case 1 & 2: Pointing and Triadic Gaze

During two summer sessions, we engaged in pointing behavior and triadic gaze between humans to explore whether dolphins attended to human points or used the process of triadic gaze with humans.

Demonstration of pointing between humans. On July 19th, 1997 at 1931 an exposure session occurred with three spotted juvenile dolphins, Caroh, LittleHali, and Slush, lasting 75 min. "These three dolphins came right to our anchored boat. Humans AP (Adam Pack) and DH got in the water and took turns pointing to the scarf that we had taken to the bottom and brought back up. AP and DH engaged in joint attention with each other by gazing back at the other human after pointing to check that the human was paying attention. We also pointed at a whelk in the sand. The dolphins were attentive and oriented and pointed with their rostrums towards the human action while actively tracking human movement. At one point DH dove with the scarf and was directing a point at AP, glancing back and forth between him and the scarf, now floating in the water column. Caroh, who was right next to DH, but out of DH's vision, was also orienting with her rostrum and body aligned toward to the scarf, glancing up at DH, and then back to the scarf. Caroh then proceeded to grab the scarf and swim away."

Demonstration of pointing to remotely located object. On July 26th, 1997 at 1121 we had an exposure session with three juvenile female dolphins, Caroh, LittleHali, and Uno, that lasted 20 minutes. "These three dolphins came to our anchored boat. On the anchor line was a jar containing seaweed. Caroh engaged AP with some seaweed exchange. AP swam over to the jar, approximately 10 meters from the boat to set himself at the pre-determined location. DH engaged Caroh in a seaweed exchange next to the boat and began pointing towards AP at the location of the jar, while simultaneously swimming towards the location. Caroh swam slowly next to DH while approaching the jar location. In a proximity of 3-4 m, Caroh left DH to orient to AP and his activity at the jar. Caroh observed AP and then swam away."

Case 3: Bottlenose Dolphins Engaging in Scarf Play While with Spotted Dolphins

Over four years, individual spotted dolphins repeatedly returned and engaged in exposure sessions, showing that repeated exposure to individual dolphins in the wild is possible. Particularly striking was an instance of interaction between juvenile bottlenose dolphins and juvenile spotted dolphins. At 1150 on June 26th, 1998, a 40 min exposure session occurred, involving both spotted dolphin and bottlenose dolphin juveniles. This was the tenth out of 23 exposure sessions in 1998. "A large group of bottlenose dolphins swam by our boat while we were interacting with the spotted dolphins. Upon encountering the spotted dolphins and swimming away together, two of the juvenile bottlenose dolphins suddenly returned to the boat with Caroh and Mitsu (juvenile female spotted dolphins), two of our most regular individuals during the exposure work. AP offered Mitsu the scarf, and not only did Mitsu play with it, but the two bottlenose dolphins were grabbing the scarf, as if already familiar with the game and/or object. We engaged Caroh and Mitsu in interactive scarf play during which time the bottlenose dolphin juveniles (both female) became involved in the play activity. Although the actual keyboard system was not in the water, the objects of play were involved in a free-form session. We engaged in pointing and exchanges between humans and dolphins of both species. After some aggressive behavior broke out between the spotted juveniles and bottlenose juveniles, the spotted dolphins drifted away, and the bottlenose juveniles remained in the area, playing on the bottom and with a different object (seaweed)." It should be noted that, to our knowledge, bottlenose dolphin had never engaged in scarf play with humans. Although potentially a case of simple stimulus enhancement or mimicry, historically, bottlenose dolphins have been rather shy of human interaction and had been observed for a decade on the periphery of human/spotted dolphin interaction without joining in. Normally, spotted and bottlenose dolphins enjoy a regular and intimate social relationships which includes interspecies babysitting, traveling and play, and interspecific aggression.

Case 4: First Successful Human Request to the Dolphins for an Object in Play, Utilizing Keyboard Symbols and Sounds

By 1999 there was a large amount of exposure time to the interface system, and symbols on the keyboard, with a small subset of dolphins. A first indication of potential comprehension and use of a symbol on the keyboard, by the dolphins, with a human request was noted. On July 29th, at 1050 a 90 min exposure session occurred. "The underwater keyboard was in the water and four dolphins Caroh, Mitsu, Tink and LittleHali were present. All four dolphins had focused attention on the humans and the keyboard in the water (i.e., they were oriented rostrum forward towards the humans and tracking their actions). Various exchanges of objects (scarf, rope) and keyboard pointing by humans between each other occurred over the 90 minutes. At one point, Tink had a rope toy on the bottom (15 m) where human observers were unable to access the toy. DH swam to the keyboard and requested the toy from the dolphin by activating the symbol/sound for the rope. Immediately, Tink returned from the bottom to the surface with the toy and dropped it in front of the humans at the keyboard." This was our first human generated request for an object in possession of a dolphin utilizing the keyboard. (i.e., humans requested a toy from the dolphins using the appropriate symbol). At no other time in the session did the dolphins drop the rope in front of the humans. The scarf toy was present on humans but not in the water or available to the dolphins during this request. Therefore an alternative explanation could be made that the dolphins simply responded to "a" sound from the keyboard. Previous to this request from humans at the keyboard the dolphins had been exposed to humans requesting specific toys from each other using the keyboard. Further analysis would be required to investigate if the dolphins had learned to discriminate between two symbols and sound choices (scarf and rope) available to them with this type of protocol. The question remains: after all this modeling and exposure to the keyboard and its use, did the dolphins provide clear evidence of triadic gaze, pointing, or symbol comprehension?

Case 1 slow motion analysis of pointing and triadic gaze revealed that the dolphin (Caroh) did follow the movement of the object (scarf) while glancing at the human's point, and back to the object. However this was the only clear instance of their use of triadic gaze.

Case 2 revealed no attention to the human and object as triadic gaze, although an alternative possibility is that the difficulty in documenting and recording subtle movements and gazes was too great to provide clear evidence.

Case 3 showed the potential for either active engagement of one species by another or the potential of transmission between species via mimicry. This represented the first time bottlenose dolphins had been observed playing with a "scarf" and even more revealing was the female spotted dolphins present were the main interactive individuals in the keyboard work.

Case 4 is probably the most intriguing and telling of all the observations. Because of the rudimentary keyboard technology the dolphin's orientation to the visual symbols were "taken" as a request or interest in that symbol/object that the human then provided. These wild dolphins do not readily touch foreign objects and therefore did not "activate" the key other than by pointing to it with their rostrums. Therefore, whether they had comprehended the association of the object to the symbol when they oriented to the symbol or whether they were just exploring the system remains unanswered. Future microanalysis of the video may reveal additional subtleties to these sessions.

However, even the exploration of such a tool in the wild has intriguing possibilities such as the study of an understanding of cause-effect relations (e.g., Limongelli, Visalberghi, & Boysen, 1995). Although our results were minimal and sometimes less than clear there appeared to be instances where components of interspecies communication initiated by the dolphins were present.

The extended duration of interactive encounters, up to 2.5 hrs and the case examples of the keyboard work do go beyond the classic exchange games that occur in normal situations with this community of dolphins over decades of observations. This suggests that at least some subset of these dolphins were interested in participating in an interactive system with humans (Figure 5).

Figure 5. Dolphin interacting in close proximity with humans at underwater keyboard. Object in play is the scarf, represented by half moon symbol far left on the keyboard.

Discussion

Although there were no significant differences in group size between normal encounters and exposure sessions, the results indicated that both sex and age-class were key factors in dolphin interactions with humans. Juvenile females were the primary subjects actively engaging in exposure sessions. This may represent a social propensity that is natural since juvenile dolphins have less societal responsibility than adults (Herzing, 1996). Six specific individuals including Caroh, Tink, and LittleHali, were regular participants and increased their inter-individual interaction when engaging in the exposure sessions. This could be due to different personalities as documented with dolphins in captivity (Kuczaj, Makecha, Trone, Paulos, & Ramos, 2006). Females in this community also have a larger social network than males suggesting they have a greater capacity for socializing in the dolphin community. Individual styles of language learning and problem-solving by chimpanzees have also been described (Savage-Rumbaugh, 1986). Different problem-solving strategies by individuals may be a factor to consider during exposure interactive work with dolphins (Delfour, 2000). Preferentially preferred items, such as a favorite food or toy, have occurred with other species during human initiated interactions (Westergaard, Liv, Rocca, Cleveland, & Sunomi, 2003).

Certain individuals were exposed to the interface system for long periods of time and over multiple years moved from D2 to D1 or interacted more over time with repeated exposures. This suggests a level of exposure and learning, including influencing factors of conspecific presence, age class interaction abilities, and personality variation. As is the case in captive work, specific dolphins in the wild may be more interested than others in attending to and engaging in certain types of interactive behaviors with humans, (*cf*. Xitco et al., 2001, 2004). Individuality in non-human societies can be a key factor ranging from larger information exchange within the society (Lusseau & Newman, 2004) to specific personalities issues (Highfill & Kuczaj, 2007) suggesting that such diversity may be the norm and necessary in fulfilling the social roles in complex group life. Personality factors may also contribute to individual engagement levels both intraspecifically and between humans and dolphins as they have been noted in other studies (Highfill & Kuczaj, 2007). In addition to the influence of personality, age-class appears to be a key factor in engagement with sexually immature animals participating more frequently and more actively than adults. Together the dolphin's interest in engaging in "play" with humans (Kuczaj et al., 2006) and in observing human responses to their behavior provide some key features which may provide the foundation upon which to build a two-way interface system between humans and dolphins. In addition to the influence of personality, age-class appears to be a key factor in engagement with sexually immature animals participating more frequently and more actively than adults.

In this natural setting, the dolphin's natural requirements (e.g., feeding, mating, etc.) took priority and also determined our decision whether or not to initiate or continue an exposure session. However, when initiated, both humans and dolphins were able to engage each other for focused and extensive interactions. Female dolphins engaged in the exposure sessions together, sometimes coming to the boat multiple times in one day as a small group to work. The extreme dynamic between some of the individuals (Caroh, LittleHali, and Tink) who had higher than normal dyad COA (i.e., they were present with each other more often during keyboard work than during normal encounters on other days), over a three year period, suggested that either 1) There was abnormal competition between these females during exposure session participation, 2) These specific individual associates were preferred during the exposure sessions and had a tendency to cooperate during the operation of the system, or 3) Their personalities were unique and these individuals were driven to engage in the exposure work together, despite their previous lower levels of associations. Caldwell and Whiten (2002) note that subordinate individuals may perform less proficiently in the presence of dominant individuals. The dynamic of individuals over time demonstrated the complex and changing preferences of individually participating dolphins.

Pointing, joint visual attention (JVA), and referential communication are all potential elements in the use of interspecies interfaces. The potential use of JVA should be explored during the use of communicative interfaces since JVA has been reported in other species (Morissette, Ricard, & Decarie, 1995; Scaife & Bruner, 1975). Studies of alarm calls in wild vervet monkeys (Seyfarth & Cheney, 1993), ground squirrels (Robinson, 1981), and prairie dogs (Slobodchikoff, Kirazis, Fischer, & Creff, 1991) have revealed elements of symbolic referential communication and competence. Similarly, laboratory studies of intra- and interspecies referential communication and competence have revealed both semantic and syntactic understanding in common and pygmy chimpanzees (*Pan panicus*) (Savage-Rumbaugh, 1986; Savage-Rumbaugh et al., 1986, 1993) and bottlenose dolphins (*Tursiops truncatus*) (Herman & Forestell, 1985; Herman, Kuczaj, & Holder, 1993; Herman et al., 1984,).

It was our general impression that when these dolphins were introduced to novel objects, sounds, or activities, they became quiet, attentive, and observant. This often included slow, but tight, swimming and circling in close proximity of the activity. These were good indicators of interest and likely participation. Levels of synchrony or eye contact with a particular human in the water often determined whether we had the dolphins attention, or not, and also influenced the success or failure of an exposure session. Sometimes engaging too heavily with the keyboard or objects, and not paying enough attention to the dolphins, resulted in a dolphin-terminated session, and they swam away.

Interactions between wild dolphins and humans have been reported in many parts of the world (Lockyer, 1990). Also, wild non-human interspecies interactions occur between many species and in complex behavioral and acoustic detail (Frantzis & Herzing, 2002; Herzing, 1996; Herzing & Johnson, 1997; May-Collado, 2010; Psarakos, Herzing, & Marten, 2003). This suggests that dolphins are capable of maintaining their own group-specific identity while being exposed to a wide range of behaviors from other species. There is also a possibility that this community of wild dolphins, or certain individuals within the society, have been desensitized and familiarized to human behavior and have the advantage of years of exposure to humans in the water. Human influence and complete immersion/enculturation has been an issue in dynamics of human interactive work with other species (Bering, 2004; Bjorklund, Yunger, Bering, & Ragan, 2002; Tomasello & Call, 2004).

Although the two-way interface system could not be experimentally controlled, some interesting processes and events occurred. First, over a period of four years many of the dolphins that interacted with the interface were return candidates and showed renewed interest levels. Although there were changes over the years by individual dolphin participants and their engagement levels, it was clear that a few individuals were the main participants and had the highest interest level. Even though many of these candidates had extensive exposure time to the interface system over the years, for the most part their natural cycles of life history and daily activities remained normal, including the propensity of juvenile female dolphins to engage socially with humans. Secondly, in the last year of experiments at least one case of potential functional use of the interface, by the dolphins, was observed. Finally, the inclusion by the spotted dolphins of another species of dolphin, into the exposure sessions is remarkable, even given their sympatric and socially complex relationship (Herzing & Johnson, 1997). There were clearly changes in the encounter dynamics during the incorporation of the two-way work.

Future Directions

Developing an interface system between dolphins and humans in a natural setting poses unique challenges. First, the dolphins are free to come and go as they please. Visits to the research boat and the duration of their stay were at the dolphin's discretion. The researchers had variable time with each dolphin during which he/she can expose them to an interface. Secondly, the dolphins are not fed by humans and therefore, learning and teaching took place without fish rewards. Some of the dolphins had already participated in human interactions playing with natural and synthetic objects prior to the interface. Once these additional mechanisms were introduced, the dolphins seemed to learn about them through observational learning. Of course, engaging in interactions with the play "toys" was in and of itself reinforcing. Thirdly, the interface itself, technologically and design-wise, should be improved to make a more dolphin friendly system. Without rapid signal exchange and the abilities to test specific signals in the dolphin's time frames, humans are inadequately equipped to respond and interact, both physically and acoustically. The dolphins need technologically and acoustically advanced tools both for their initiations and interactions, and humans need a real time acoustic interface to respond quickly. An acoustically triggered keyboard has recently been developed and tested and could be a future technological interface for work in the wild (Amundin et al., 2008). Delfour and Marten (2005) also used an underwater touch-screen as an interface for bottlenose dolphins during complex tasks.

Pattern recognition techniques and wearable computers all become potential tools for this type of wild interface (Starner, Weaver, & Pentland, 1998) and are currently under development to continue this work. Increased documentation can now be captured with the use of small, wearable video cameras thus providing closer and more detailed behavioral reactions. Finally, developing challenging and varied interspecies activities, while monitoring the attrition rate of individual subjects is crucial. Developing activities that can be done together (like the play game) would foster communication between human and dolphin, especially games in which a dolphin might require a human's assistance (*cf.* Xitco, et al., 2001).

This study described the development of a human/dolphin interface that worked in the open sea and exposed a well-studied community of wild dolphins to it for over 700 min over a three-year period. A small group of juvenile females were the primary players with the system and they increased their associations with each other and their degree of interaction with the system over time. Modeled communications focused on activating symbols associated with play objects and activities. No provisioning of food occurred during this work or at this study site. Developing a better interactive interface, and non-species biased tool, would allow a more extensive exploration of cross-species communication and within species cognitive strategies and abilities.

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