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Development of Semantic Reference for Location Symbols by Bottlenose Dolphins (*Tursiops truncatus*) Using a Two-Way Communication Keyboard

Alyssa Taylor

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DEVELOPMENT OF SEMANTIC
REFERENCE FOR LOCATION SYMBOLS BY
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COMMUNICATION KEYBOARD

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DEVELOPMENT OF SEMANTIC REFERENCE FOR LOCATION
SYMBOLS BY BOTTLENOSE DOLPHINS (*TURSIOPS TRUNCATUS*)
USING A TWO-WAY COMMUNICATION KEYBOARD

by

Alyssa Nicole Taylor

A Thesis

Submitted to the Graduate School,
the College of Education and Psychology
and the Department/ School of Psychology
at The University of Southern Mississippi
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for the Degree of Master of Arts

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ABSTRACT

The ability for humans to communicate with another species has been an aspiration and well documented. One example is through training animals to make associations between a designated cue and conditioned response (Pryor, 1986). Two-way communication, however, in which both species can express wants/needs has been predominantly pursued with apes and dolphins. Studies conducted by Louis Herman demonstrated the capabilities of dolphins to comprehend complex semantic and syntactic commands in an artificial language system (Herman, Richards, & Wolz, 1984). Researchers working with primates have used American Sign Language, a computer keyboard system with discrete lexigrams, and a portable lexigram keyboard (Gardner & Gardner, 1969; Rumbaugh, 1977; Savage-Rumbaugh, 1986). Savage-Rumbaugh decided to take a different approach to learning after one individual demonstrated the ability to use the keyboard without structured training, rather humans would model by using the symbols during daily interactions.

The following study aimed to follow a similar approach, to determine if dolphins demonstrate comparable success in demonstrating comprehension and production utilizing a keyboard, specifically for location symbols. The dolphins demonstrated the ability to learn to use the keyboard and were able to make associations between location symbol and referent. Dolphins showed greater than chance levels of visiting a correct location first after key activation. Overall, there was a significant decrease in the amount of time between key activation and dolphin arrival time to the location. The results suggest the dolphins did develop an understanding of a location symbol, and its referent, the location in the enclosure.

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TABLE OF CONTENTS

ABSTRACT	ii
ACKNOWLEDGMENTS	iii
LIST OF TABLES	vi
LIST OF ILLUSTRATIONS	vii
CHAPTER I - INTRODUCTION	1
Research in Animal Communication	1
Current Study	16
CHAPTER II - METHODS	18
Subjects and Facility	18
Keyboard Diagram	19
Data Collection	21
Data Analysis and Statistical Approach	22
Reliability	25
CHAPTER III - RESULTS	26
Keyboard Events	26
Keyboard Location Events Captured on Video	34
Reliability	34
Location Key Activations	35
Key Activation and Dolphin Arrival Time	38

Concordance Between Key Activation, Human Vector, and Next Location Visited by a Dolphin.....	40
Locations Left in Human Vector	41
CHAPTER IV – DISCUSSION.....	46
Keyboard Events.....	46
Keyboard Location Events Captured on Video	48
Location Key Activations	48
Percentage of Correct Events, Speaker Events, and Human Followed Events Across Study	49
Keypress Activation and Dolphin Arrival Time.....	51
Concordance Between Keypress, Human Vector, and Next Location Visited by a Dolphin	51
Limitations and Future Directions	52
REFERENCES	55

LIST OF TABLES

Table 1 Individual symbol keys and classified categories.....	20
Table 2 Summary of recorded video data.	22
Table 3 Total key activations by category.	27
Table 4 Total frequency of location key activations during the study.....	30
Table 5 Bob location key activations captured on video.	35
Table 6 Toby location key activations captured on video.	35
Table 7 Frequencies of relating key, human vector, and next location visited events.	41
Table 8 First location visited after key activation (events completely captured on video).	45

LIST OF ILLUSTRATIONS

Figure 1. Diagram of dolphin enclosure at Disney’s The Living Seas. 19

Figure 2. Underwater keyboard communication system with dolphin and human. 20

Figure 3. Total key activations during the study..... 26

Figure 4. Human key activations by category. 28

Figure 5. Bob key activations by category..... 29

Figure 6. Toby key activations by category..... 29

Figure 7. Human location key activations during the study. 31

Figure 8. Bob location key activations during the study. 32

Figure 9. Toby location key activations during the study..... 32

Figure 10. Average frequency of location key activations during a session when objects were present at the location..... 33

Figure 11. Total food key activations during the study. 34

Figure 12. Percentage of events for correct location visited, as a speaker, and when the human followed Bob throughout the study..... 37

Figure 13. Percentage of events for correct location visited, as a speaker, and when the human followed Toby throughout the study..... 38

Figure 14. Average time difference between location keypress activation and dolphin’s arrival time to the first location visited (correct location). 40

Figure 15. Average number of locations in the human vector when dolphin reached location..... 43

Figure 16. Map of the enclosure with arrows indicating typical routes to each location. 44

CHAPTER I - INTRODUCTION

Research in Animal Communication

Communication is an important aspect of life that is present and utilized in nearly every living organism. There are a variety of types of communication, including visual, auditory, chemical, olfactory, and touch, commonly two or more of these types are used to relay a message. These different types of communication occur in both humans and nonhuman animals. However, each of these types of communication serves a purpose, to exchange information between participants for the mutual advantage of both (Klopfer & Hatch, 1968). Communication occurs when a signaler sends information to the receiver, the receiver then interprets the signal and adjusts their behavior accordingly (Bright, 1985; Rogers & Kaplan, 2000). The signal may have a variety of meanings depending on how the signal is sent and received. For example, Vervet monkeys (*Cercopithecus aethiops*) can express different alarm calls based on a nearby predator approaching, leading to different responses by the receivers, such as looking up or down for a bird or a snake (Seyfarth, Cheney & Marler, 1980). Many species of birds will use their colorful feather plumage and or song to attract females while also defending their territory against other competing males (Catchpole & Slater, 1995). Grooming in many monkey and primate species is a form of tactile communication that improves social bonding and often signals reassurance (Rogers & Kaplan, 2000). Lastly, honeybees (*Apis mellifera*) can communicate the direction and distance of flowers with nectar and water sources by completing a “waggle dance” to inform other members of the colony (Von Frisch, 1974).

Bottlenose dolphins similarly use several types of communication. For instance, Wood (1953) was one of the first scientists to note the varying sounds emitted by

bottlenose dolphins during different situations. He further described communicative intent on what the different sounds may indicate. Specifically, a jaw clap produced by the dominant male during feeding times appeared to function as a threat or warning to fellow tank mates. In addition, whistles and clicks are the most noticeable (to humans) of auditory communication by dolphins. Measured initially by Lilly and Miller (1961) with spectrographs, the sounds were produced in a variety of contexts, such as during play, excitement, curiosity, aggression, individual recognition, and mother-calf interactions (Herzing, 1996; Reynolds, Wells, & Eide, 2000; Wood, 1953). Likewise, physical contact is an important form of communication between dolphins. For example, pectoral fin rubbing, or “petting”, between conspecifics can serve as a form of social bonding and may help maintain social relationships (Dudzinski, Gregg, Ribic, & Kuczaj, 2009; Dudzinski, Gregg, Paulos, & Kuczaj, 2010).

An additional form of communication that dolphins use is echolocation. Echolocation allows them to navigate and forage by sending out sound wave clicks and listening to the echoes as they return from hitting an object. Echolocation can be shared between dolphins. For example, Xitco and Roitblat (1996) demonstrated that dolphins were capable of eavesdropping on a conspecific’s echolocation clicks and echoes to correctly complete a match-to-sample task when they themselves did not have access to the object.

The research described above has been focused on intraspecific species communication, or members of the same species communicating with one another. Yet, interspecific species communication has been of high interest for many decades.

Predator-prey interactions are an instance of communication between two different species as shown by the interaction between a cleaner fish and a coral reef fish. Parrotfish, the client, will swim to a cleaning station on a coral reef and signal to a cleaner fish, a wrasse for example, by displaying such behaviors as opening its mouth and spreading out its fins (Grutter, 1999). The wrasse will then proceed to remove parasites and mucus from their clients. Occasionally, these mutualistic communication signals can be taken advantage of; a cleaner fish may cheat and take more than parasites from their clients, e.g., blood, or inversely a client may eat the cleaner fish (Bshary & Grutter, 2002; Francini-Filho, Moura, & Sazima, 2000).

Outside of a predator-prey context, the ability for humans to communicate with other species has long been desired and humans have continuously worked towards this goal. One demonstration is through training domesticated animals to make associations between a designated cue and conditioned response. For example, Border Collies (*Canis lupus familiaris*) can be selectively trained by their owner's when, and when not to herd the sheep based on whistle cues (McConnell & Baylis, 1985). In addition, several species of animals in zoos and aquariums are trained with positive reinforcement techniques to voluntarily perform specific behaviors (Pryor, 1986). For instance, husbandry behaviors are of particular importance because they allow veterinarians to complete health and wellness exams without restraint or discomfort for the animal. The keeper or trainer cues the behavior with a discriminative stimulus, for example, using a verbal command "down" and then "wait" to ask a sea lion to lay down, be still, and allow a blood sample to be taken. Similar training techniques on experimental tasks have facilitated investigations on dolphin vision (e.g., Spong & White, 1971; Dral, 1972), echolocation

abilities (e.g., Au, Floyd, Penner, & Murchison, 1974; Au, Floyd, & Haun, 1978), memory capacities (e.g., Herman & Gordon, 1974; Bruck, 2013), language comprehension and production (e.g., Herman & Forestell, 1985; Herman, 1986), symbol and object representation (e.g., Herman, Morrel-Samuels, & Pack, 1990; Herman, Matus, Herman, Ivancic, & Pack, 2001), and more.

Interactions during training allow for humans to communicate with dolphins, but also for dolphins to communicate back, though in more limited ways. They can express frustration, such as breaching or leaving during a session to send a message. Pryor (1986) recounted an observation by Ron Schusterman in which a dolphin that had been performing well on a cognitive task suddenly made a series of incorrect responses. It was soon discovered the fish dispenser delivering reinforcement contained bad fish. When the fish was replaced, the dolphin made correct responses again. Though anecdotal, it seemed easy to interpret the dolphin's pattern of responding as communicative and purposeful.

One early study to attempt to communicate with dolphins via species-appropriate signals was conducted by the U.S. Navy by Batteau and Markey in the mid-1960s. The goal of the study was to determine if communication between man and dolphin could be achieved via electronic dolphin-like whistles (Batteau & Markey, 1967). They created two electronic instruments to translate human vocal sounds into artificial whistles that were played through a hydrophone into the dolphin tank. Initially, one male dolphin was trained using operant conditioning to respond to five different words (translated into whistles) and complete a behavioral response, such as "go through hoop" (Batteau & Markey, 1967). The dolphin demonstrated the ability to successfully discriminate between the different translated whistles and complete the corresponding behavior with

an 85% correct response rate. A second dolphin was also trained to respond correctly to the translated whistles, however, attempts to train the two dolphins to imitate the whistles met with little success.

Efforts to establish two-way interspecies communication, between humans and nonhuman animals, in which both species can express wants and needs via arbitrary symbols has primarily been pursued with apes and dolphins, through multiple paradigms. An important aspect to establish communication between species is for both speaker and listener to relate the symbols to their referents. The ability to use words or symbols to refer to specific locations, objects, or an event is called referential communication (Gauker, 1990; Savage-Rumbaugh, Murphy, Sevcik, Brakke, Williams, Rumbaugh, & Bates, 1993). Gauker (1990) proposed that multiple relations between a symbol and object exist. Therefore, when a symbol is used in different contexts, an animal can link the previous usage of the symbol with current usage and potential outcomes of using the symbol in new situations. This allows for a fuller referential representation of symbols to develop.

Studies conducted by Louis Herman and colleagues at the Kewalo Basin Marine Mammal Laboratory (Herman, Richards, & Wolz, 1984; Herman & Forestell, 1985; Herman, 1986) examined the abilities of dolphins to comprehend complex commands. Dolphins, Akeakamai and Phoenix, were taught two different artificial languages, gestural and acoustic respectively, and tested on an understanding of familiar and novel strings of commands, or sentences, produced by humans in an artificial language (Herman et al., 1984). According to Herman *et al.*, each word was an independent unit, and corresponded to objects placed in the dolphin's pool (e.g., HOOP, SURFBOARD,

FRISBEE), actions that could be performed on the objects (e.g., TOSS, jump OVER, swim UNDER), and object modifiers (e.g., LEFT and RIGHT). Each word was identified by a specific arm/hand movement from a trainer for Akeakamai, or a discrete whistle generated by a computer for Phoenix. The authors initially trained the dolphins using positive reinforcement to discriminate sounds and gestural responses to individual words. For example, following the sound or gesture BALL, the dolphins were rewarded for orienting towards the ball, but not other objects floating in their pool. Individual words were then combined to form sentences. Each sentence was formed by presenting a sequence of two to five words, and the word order, or syntax, of the sentence also conveyed meaning. For example, the correct response to LEFT HOOP RIGHT BALL FETCH was to bring the ball to the right of the dolphin (and not the ball on her left) to the hoop on the dolphin's left (and not an alternative hoop on her right).

Herman *et al.* (1984) defined comprehension as “the ability of the dolphins to utilize the semantic and syntactic information in the sentences in order to carry out the instructions, and was measured by the accuracy or appropriateness of their responses to those instructions.” During comprehension testing, Phoenix was tested on 368 different sentences, including novel and familiar sentences, and had an overall correct response rate of 85.1%; Akeakamai was tested on 308 sentences, including novel and familiar sentences, and had an overall correct response rate of 82.8% (Herman et al., 1984). Given the number of objects, actions, and potential combinations, chance performance would have been less than 5%. Based on the overall correct response rate, it is evident that the dolphins demonstrated comprehension of sentences, word units, and word order in their respective artificial languages.

While dolphins' comprehension of syntax in these studies often received top billing, the results also provided support for comprehension of the semantic component of the signals. A key aspect of comprehension shown by Akeakamai and Phoenix in their artificial languages was the semantic generalization. Herman *et al.* (1984) focused on creating generalizations from the initial stages of training. A new word for Akeakamai and Phoenix was first taught in a limited context with one object, but once learned, the new word was generalized in a planned manner. For example, HOOP was first taught with one individual octagonal hoop made from PVC pipe but was then quickly and systematically applied to hoops of different shapes, materials, hoops that would float or sink, and hoops of all different colors (Herman et al., 1984; Herman, 1986). Similarly, an action like TOSS was first trained by tossing one object but then extended to other named objects that could be tossed. Akeakamai and Phoenix generalized objects and actions, and, in addition, they experienced many different context variations, including different trainers, different and numerous objects in their tank (sometimes containing multiple exemplars of the same object), and quasi-random sentence order for unpredictability (Herman, 1986). Akeakamai and Phoenix faced a continuously increasing complexity of sentences and consistently achieved high-performance levels, indicating a great deal of generalization in objects, actions, and contexts that allowed a fuller comprehension of the words in the artificial language to develop.

Savage-Rumbaugh, Pate, Lawson, Smith, and Rosenbaum (1983) suggested that semantic reference allows an animal to use a symbol/word to refer to an object that is not present. Herman and Forestell (1985) explored whether Akeakamai could report whether an object was present or absent. During language training, occasionally an anomalous

sentence would occur in which the instruction could not take place because the named object was not present in the tank. When this occurred, sometimes the dolphin returned to her trainer without performing the action on a different object. Herman decided to introduce a NO paddle (Herman & Forestell, 1985). The NO paddle allowed the dolphin to indicate that the action could not be performed because the object was missing and this response was learned in one day. During subsequent testing, missing object trials were interspersed as probes among normal sentences that signaled commands that could be executed. Akeakamai pressed NO on the first 11 missing object sentences, and on 84 of 97 presented (Herman & Forestell, 1985). Additionally, search time decreased as the experiment progressed. A YES paddle was also successfully introduced to Akeakamai to report if a named object was in the tank following a question sign, e.g., BALL QUESTION. Further, she was subsequently able to immediately generalize her use of the YES and NO paddles from answering questions about named objects in her pool to answering questions when the same objects were shown to her but never placed in the pool. This flexibility demonstrated further depth to her understanding of the semantic character of the signs in her artificial language.

Scientists working with primates, primarily chimpanzees, have used American Sign Language (ASL) to facilitate two-way interspecies communication. A female chimpanzee named Washoe was taught ASL with a variety of training methods, including; imitation, molding of hands, and instrumental conditioning (Gardner & Gardner, 1969). During daily routines, Washoe was exposed to many activities and objects that caretakers could describe using ASL. The authors hoped that Washoe would begin to associate the signs with referents and start to use the signs herself using

imitation. Spontaneous delayed imitation of some signs was reported, suggesting she understood the sign when originally shown and taught. Other signs were explicitly conditioned in one situation in hope that it would generalize to others, for example, the sign for MORE, which was taught within a game of tickling, but then was applied to requests for food and other toy objects with prompting (Gardner & Gardner, 1969).

For a sign to be considered a part of Washoe's vocabulary, a conservative method was employed, requiring three separate caretakers to report seeing the sign followed by an appropriate and spontaneous use of the sign for a consecutive fifteen days (Gardner & Gardener, 1969). Formal testing of Washoe's vocabulary was achieved with naming objects placed in a box with a double-blind observer technique. In addition, throughout the day, a set of predetermined 10 question frames were to be asked of Washoe, such as 'Whose ball?' or 'What smell?'. Washoe correctly replied to 84% of questions asked (Gardner & Gardner, 1975). The nature of ASL allowed both humans and Washoe to interact with her caretakers in her daily activities, asking questions, requesting objects, providing a glimpse into her understanding of symbols.

In more controlled tests, Fouts (1973) also trained two male and two female chimpanzees ten signs that represented different objects. The chimpanzees were trained by molding their hands into the proper sign with the object present. Similar to Gardner and Gardner (1969), a double-blind observer experiment was conducted in which each of the objects were placed in a closed box and the chimpanzee was asked what was in the box. Three of the four chimpanzees performed at above chance levels in responding correctly to what object was placed in the box.

The use of ASL and chimpanzees with their ability to learn the language was highly debated. Gardner and Gardner with Washoe (Gardner & Gardner, 1969; Gardner & Gardner 1975), Fouts (1973), and initially Terrace (Terrace, Pettito, Sanders & Bever, 1979; Savage-Rumbaugh, 1986) with Nim Chimpsky concluded that apes have the ability to communicate effectively with ASL. However, there are inadequacies and methodological issues that arose. There are a limited number signs an ape is able to make due to the inadequate motor skill movements of their hands (Savage-Rumbaugh, 1986), not only restricting what signs they are able to make but leading to the interpretation of a sign that is considered 'close enough' to the correct form. Terrace and his colleagues revised their conclusion of an ape's ability to use language after careful review of their work with Nim. While focusing more on syntax and grammar with teaching Nim ASL, they determined that Nim's signing was primarily imitations of signs made recently by his teachers and there was no meaning or understanding on Nim's part on the signs he was producing, rather he was using the signs to satisfy a request from his teachers to get a reward (Terrace *et al.*, 1979; Savage-Rumbaugh, 1986). While Terrace *et al.* determined that apes cannot learn language based on this observation, the Gardners' and Fouts demonstrated apes are able to communicate with ASL and during formal testing of their comprehension, careful protocols ensured no cueing occurred, utilizing double-blind procedures. Due to the imprecision of ASL with chimpanzees, Rumbaugh and his colleagues were motivated to develop a method of studying ape language acquisition that could avoid the obscurity of observer over-interpretation.

To eliminate the ambiguity inherent in the apes' use of ASL hand signs, Rumbaugh (1977) and his team at the Language Research Center created a computer-

based keyboard system for their chimpanzee, Lana, with discrete, symbolic keys, or lexigrams, that varied in color and pattern. When pressed, each lexigram key, or a sequence of lexigrams, would remain illuminated until a correct sequence was created. For example, PLEASE MACHINE GIVE JUICE PERIOD would trigger an automatic dispenser to provide juice for Lana. The keyboard was mounted in Lana's home enclosure, and she used it to request necessities like food, water, and social interaction. Lana was trained using operant conditioning techniques to press a key and was rewarded with the corresponding item or activity, such as going out into the yard (Gill & Rumbaugh, 1977). She initially used 'stock' sentences on her keyboard--simply turning the keyboard on and pressing a food key would result in the machine dispensing the food. She was able to master this within two weeks (Rumbaugh & Gill, 1977). As Lana improved, she learned to start a sentence with PLEASE and end a sentence with the PERIOD lexigram to indicate to the computer the command was complete. Eventually, each word was represented by a different lexigram on the keyboard and Lana would need to press multiple keys to command the computer. Technicians and caretakers also modeled keypresses as Lana succeeded more with social contact. Though she had a strict training schedule to learn the different lexigrams and correct syntax, Lana appeared to perform better during informal sessions with caretakers. Lana learned to communicate using the keyboard and could name objects and persons, requested non-present objects so she could gain access to them, and even appeared to engage in some conversations with her caretakers (Rumbaugh & Gill, 1977). However, the referential nature of her lexigram production and comprehension may have been restricted due to the relatively limited

number of contexts that came with using the keyboard in her home enclosure, and the relatively finite number of items the machine dispensed.

After Lana, Savage-Rumbaugh started working with chimpanzees named Sherman and Austin. Like that of Lana, they used a keyboard to communicate with their caretakers, however, their teaching was slightly different. Different rote trainings were developed for each chimpanzee to make the associations between lexigrams and foods. Sherman was able to press a symbol and receive that food item, whereas Austin would see a food item held by a caretaker and had to press the correct symbol in order to receive the food item (Savage-Rumbaugh, 1986). Sherman demonstrated rapid associations between lexigram and food items much quicker than Austin, Savage-Rumbaugh suggested the faster association was linked with the reception of a desirable item when the lexigram was produced, rather than through a third party.

Although Sherman and Austin learned to make associations between symbols and items or actions, when formal testing was presented, their performances were not as expected. For example, during one study in which a caretaker would ask WHAT THIS? Of a food item, the chimpanzee needed to pick the correct lexigram, however, they were not given that food item as a reward if correct, but rather a different food reward (Savage-Rumbaugh, 1986). This seemed to confuse the chimpanzees and their performance greatly decreased on the number of correct responses, yet increased rapidly again when the method was changed to give them the food item the caretaker was asking about. While being able to request foods and name them, Sherman and Austin were unable to understand a symbol and its referent for anything other than edible objects. Savage-Rumbaugh (1986) explained that the chimpanzees did not understand when the teacher

would select a lexigram and pointed to an object that the two were associated unless there were additional context-dependent cues. For instance, when asking for a blanket when making up a bed, Sherman and Austin understood the symbol BLANKET and would retrieve one (Savage-Rumbaugh, 1986). Although Sherman and Austin's keyboard communication was highly request oriented and they had difficulty during formal testing tasks, they demonstrated the ability to communicate their own desires with the lexigram productions.

Many early studies emphasized the use of structured training techniques over immersion learning. In addition, most early ape-language projects focused on the production of language, with the ape required to produce a symbol, be it a hand sign or lexigram, and assumed that comprehension and referential understanding would automatically follow (Savage-Rumbaugh, Rumbaugh, & McDonald, 1986; Savage-Rumbaugh et al., 1993). Savage-Rumbaugh (1981), showed simple associations like that of see a ball and make the sign for ball limited the symbol use of apes however, this brought into question their ability to comprehend that the symbol for ball truly represented a ball, possibly due to the lack of using the symbol in a variety of contexts (Savage-Rumbaugh et al., 1993).

In contrast, young children learn language through observation and interaction with caregivers who model language use in diverse contexts and routines. Consequently, Savage-Rumbaugh and her colleagues decided to take a different approach to language learning with a pygmy chimpanzee (*Pan paniscus*), or bonobo, after one individual demonstrated the ability to use a lexigram keyboard without structured training.

After years of formal training, an adult female bonobo Matata demonstrated very little comprehension and production utilizing a portable lexigram keyboard (Savage-Rumbaugh et al., 1986). However, her young son, Kanzi, did, even though he was not the focus of the training. Savage-Rumbaugh *et al.* (1986) reported that at around two and a half years of age, Kanzi was separated from his mother when she was placed into a breeding environment. Kanzi became very attached to his human companions, as someone was with him 24 hours a day, seven days a week. They were surprised to see Kanzi using the keyboard in an appropriate manner, selectively pressing specific keys, rather than just pressing random keys when his mother was present. For example, he started to use lexigrams to ask for specific foods by name and, if presented with multiple food choices, he would pick the one he had requested. It was clear that Kanzi had learned through observation. As a result, Savage-Rumbaugh decided to not use the traditional training technique to teach Kanzi but to take a different approach. Kanzi's human companions would model and encourage him to communicate, like parents with a young child, by using the symbols around him during daily interactions and activities, with no requirement for Kanzi to learn specific symbols. Rather, he could choose which symbols he wanted to learn by observing the way his human companions used them (Savage-Rumbaugh, 1986).

To provide the optimal environment to foster and develop his communicative abilities, his food was dispersed at different living areas and other named locations within 55 acres of land that surrounded the Language Research Center. This kept Kanzi highly motivated to communicate with his companions, picking locations he wanted to visit and facing potential problems, such as finding a snake while in the forest (Savage-Rumbaugh,

1986). He could observe his companion as they solved problems and communicated to Kanzi their actions and intentions. Kanzi could choose a location to go to by selecting a lexigram, or even the food item that was placed at that location. Sometimes he selected lexigrams for multiple locations at the start of a day, and his companions took him to visit all of them (Savage-Rumbaugh, 1986).

Every lexigram used by Kanzi was recorded, whether automatically on the indoor keyboard computer, or entered later into a log when the portable keyboard was used. Each lexigram was classified as correct or incorrect, and either spontaneous, structured, or prompted. Spontaneous use was defined as symbols used without elicitation by Kanzi's companions. Structured use was noted for lexigrams selected as responses to questions or requests from companions. Prompted responses were noted when Kanzi used lexigrams that had just been used by his companion's (Savage-Rumbaugh, 1986). A lexigram was considered part of Kanzi's vocabulary when behavioral concordance between the lexigram and its corresponding referent were observed (Savage-Rumbaugh, 1986). For example, if Kanzi were to request a ball by selecting the BALL lexigram, and no ball was present, his companion could reply verbally 'yes, can you find your ball?', rather than getting a ball for Kanzi. Behavioral concordance was recorded if Kanzi searched and retrieved a ball, demonstrating a correspondence between his productive use of the symbol BALL and his subsequent retrieval of a concordant referent. In addition, the symbol needed to occur spontaneously, and be used in the appropriate context with the concordant referent nine out of ten consecutive times.

More results from Savage-Rumbaugh *et al.* (1986) suggested a more fully developed referential character in Kanzi's understanding of his lexigram symbols

(Savage-Rumbaugh et al., 1983). Within the first week after his mother left, Kanzi was using lexigrams for eight different food items correctly—something that had taken almost a year for his mother to learn. Savage-Rumbaugh reported that with no special training Kanzi asked for things, named items for his companions, responded when others used these lexigrams, could select a requested item from a group of items, or a picture of the item from a group of pictures, and give it to a companion, and use his keyboard to reference places and objects not present. The nature of learning for Kanzi paralleled that of a parent and young child as the child learns a language. This approach, while different than all previous studies with apes showed great success in the development of referential understanding. The following study aims to follow a similar approach, to determine if bottlenose dolphins demonstrate comparable success in demonstrating comprehension and production utilizing a keyboard.

Current Study

Dolphins have demonstrated the ability to comprehend semantics and syntax in artificial language systems and to produce simple responses (e.g., Herman et al., 1984; Herman & Forestell, 1985). The subsequent effort aimed to demonstrate the referential use of symbols by bottlenose dolphins in both comprehension and production, while attempting to emulate the approach used by Savage-Rumbaugh with Kanzi. A large keyboard was designed that could be submerged underwater at Disney's The Living Seas. Two male bottlenose dolphins began the project in 1992 and interacted with their trainers and the keyboard for approximately eight years. The keyboard had different symbol keys for actions, agents, foods, grammatical terms, modifiers, objects, tools, tool sites, and locations. No explicit training of the underwater keyboard took place, rather, human

divers modeled the use of the underwater keyboard in daily activities with the dolphins. The first goal of the study was to determine if the dolphins could learn to use the keyboard using this model approach, rather than discrete trials of positive reinforcement paradigms used in previous studies (e.g., Akeakamai/Phoenix and Sherman/Austin). The second goal of the current analysis was to investigate the development of semantic reference for the location symbols that were used more often by the two dolphins than any of the other keys. The following hypotheses were addressed: 1) The dolphins will learn to activate and utilize the keyboard by observing the human divers model use during daily activities, 2) The dolphins will develop associations between a symbol and its referent, specifically a location symbol and its physical location in the enclosure, 3) Dolphins will make these associations without initial explicit training trials of the specific location symbols, 4) The dolphins will use the location symbols without immediate reinforcement after key activation, 5) There will be individual differences between each dolphin's utilization of the keyboard.

CHAPTER II - METHODS

Subjects and Facility

Two adult male bottlenose dolphins (Bob and Toby) were used for the duration of this study and housed at Disney's The Living Seas, located in Orlando, Florida. The dolphins were approximately 15 years of age and had been participating in various research studies for 8 years. The dolphins consumed about nine and a half kilograms of food per day, consisting of herring, capelin, mackerel, sardines, and night and silver smelt. During a session, dolphins would receive a portion of their food ration for that day, however, a dolphin would receive all food rations regardless of their participation in a session. The dolphins' participation in the study was approved by Disney's Animal Care and Use Committee.

The circular enclosure was 61 meters in diameter, 8 meters deep, and held 22 million liters of water. Consisting of artificial coral structures, the aquarium simulated a natural Caribbean reef environment. In addition to the dolphins, the aquarium housed approximately 1,000 animals including stingrays, sharks, sea turtles, and many different species of fish. A central underwater viewing window allowed guests to see the environment and research that was being conducted. A diagram of the enclosure where sessions were conducted, along with the nine named locations within the environment is displayed in Figure 1.

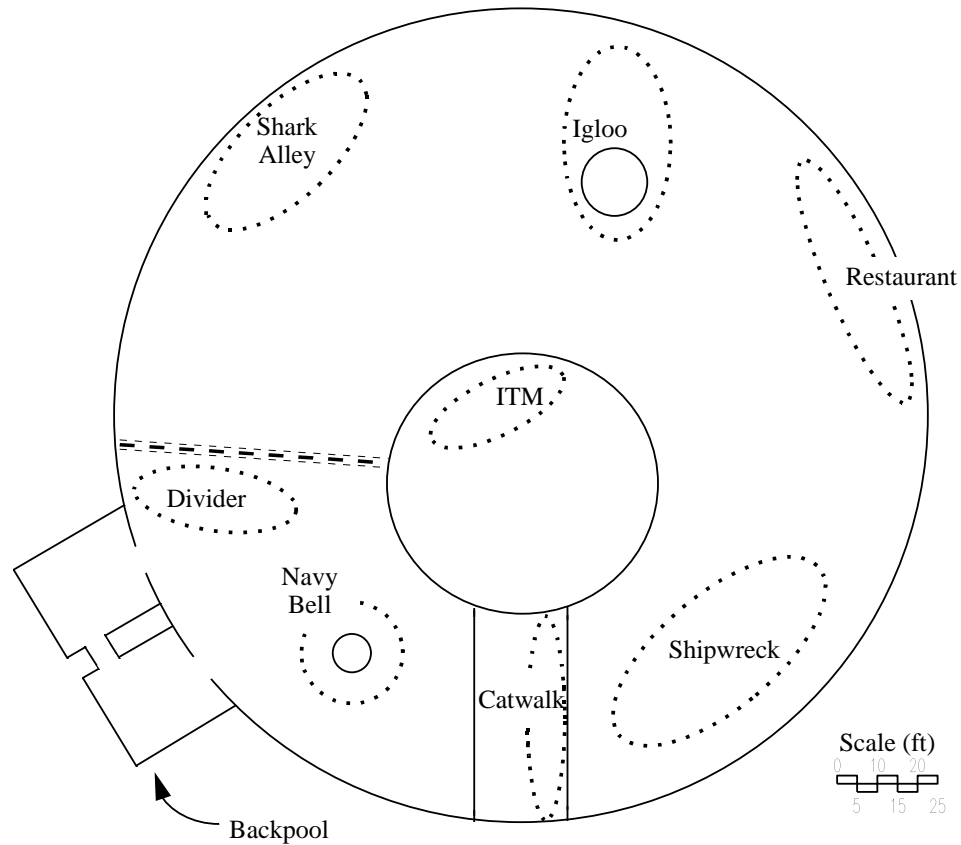


Figure 1. Diagram of dolphin enclosure at Disney's The Living Seas.

Keyboard Diagram

The underwater keyboard consisted of four panels, each panel containing up to 15 individual keys. The keyboard apparatus is displayed in Figure 2. The different keys were composed of a hollow tube that contained a unique three-dimensional object. The objects differed in shape, material, and size. Additionally, an infrared beam was focused across the opening of each key. To activate the symbol key, the infrared beam was broken, followed by an auditory response, where an English word for the activated key was played on an underwater speaker that was attached to the keyboard. For a list of

individual symbol keys on the keyboard and their respective classified categories for the present study, see Table 1.

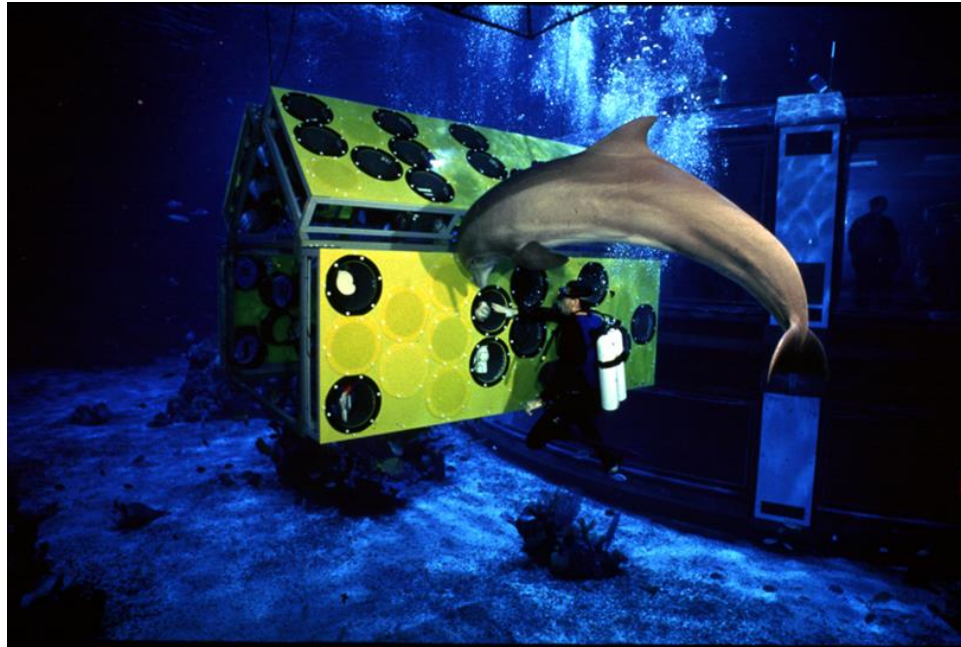


Figure 2. Underwater keyboard communication system with dolphin and human.

Table 1 *Individual symbol keys and classified categories.*

Key Classification	Keys
Actions	CHASE, FIND, GIVE, GET, GO, HAVE, OPEN, PLACE, PLAY, SEARCH, TOUCH, WATCH
Agents	BOB, TOBY, PERSON, SPEAKER, NINA, NORIKO, WE
Foods	FOOD, HERRING, MACKEREL, SARDINE, SMELT, WHITEBAIT
Grammatical	AND, OR, AT, PAST, NO, YES, QUESTION, SAME, WHICH, WHAT, WITH, WHO, WHERE
Locations	BACK-POOL, CATWALK, DIVIDER, IGLOO, ITM, NAVYBELL, RESTAURANT, SHARK-ALLEY, SHIPWRECK
Modifiers	BIG, SMALL, NEAR, FAR

Table 1 (continued).

Objects	BALL, BUMPER, BUOY, CONE, HOOP, SNAKE, CANNON, CONTAINER, SURPRISE
Tools	FLOAT, STICK, WEIGHT
Tool Sites	FLOAT CATCHER, STICK PLUNGER, WEIGHT RECEPTACLE

Data Collection

A total of 2,174 sessions were conducted using the underwater keyboard between July 28, 1992 and September 5, 2000. Each session lasted between 10 and 40 minutes with humans, in SCUBA, and dolphins interacting at the keyboard. As stated above, the dolphins did not receive any explicit training with the keyboard or specific keys. Typically, one human interacted with one dolphin, modeling use of the keyboard, and then a second human interacted with the other dolphin. Video recordings of sessions were obtained with a Sony V801 Hi8 mm camcorder that was placed in an Amphibico underwater housing container. Videotaped sessions of the first 33 sessions were recorded. Thereafter randomly selected sessions between October 1992 and July 1998 were recorded. Table 2 documents the video data collected during the study.

In addition, the computer that controlled the acoustic feedback also recorded a log of all keypresses during sessions. Every keypress was recorded and time coded. Additionally, a human observer in snorkel or SCUBA positioned directly above the keyboard recorded written notes about events occurring during the sessions, such as the identity of who pressed the key (i.e., the speaker), the identity of whom the keypress was

directed to (i.e., the listener), and additional contextual information. These written notes were added to the logs of activated keys after each session.

Table 2 *Summary of recorded video data.*

Year	Number of Sessions with Video	Minutes of Video	Total Number of Keyboard Sessions
1992	32	814	39
1993	53	1367	190
1994	69	1371	355
1995	15	318	342
1996	14	258	332
1997	14	234	281
1998	18	305	241
1999	N/A	N/A	309
2000	N/A	N/A	85

Data Analysis and Statistical Approach

The keypress log was used to identify all instances of location key use by dolphins and humans. In addition to the identity of the speaker and listener(s), and the contextual information in the log, the timestamp was used to identify activations of location keys that were captured on video. The video record was analyzed before and after location key activation to determine: 1) the human response to a dolphin key activation; was there a key activation in response, did the human gesture, did the human start to travel, or no response from the human and 2) concordance with the physical location next visited. The location visited by a dolphin directly after a key activation was further coded for 1) the location visited, 2) the humans' role in visiting the location (e.g., human followed the dolphin to the location), 3) was the dolphin cued by the human

immediately after key activation (dolphin activations only), 4) the time at which the dolphin arrived at the location, and 5) whether the first location visited was correct (i.e. it matched the location key activated, or was incorrect).

Location key activations captured on video were also analyzed to measure the orientation and vector of humans relative to the dolphin and the named locations. For example, with the keyboard positioned between Shark Alley and the ITM, a human's orientation at the keyboard could be immediately mapped to either Shark Alley or the ITM, since they were located 180 degrees from each other (See Figure 1). But both the Divider and Navy Bell locations were in one direction, while the Igloo, Restaurant, and Shipwreck were in the other direction. On a different occasion, with the keyboard positioned near the Shipwreck, all of the other locations besides the Catwalk were initially located in the same direction. Therefore, whenever location key activations were captured on video, all named locations concordant with the humans' orientation and vector were recorded and subsequently eliminated as the human approached the location concordant with the key activated. For example, RESTAURANT was activated at 11:02:31, the locations of Backpool, Divider, Navy Bell, Shark Alley, and Itm were eliminated by the human vector at 11:02:32 as they started to swim in the opposite direction. As the human passed the Igloo location, it too was eliminated at 11:02:43. When the human reached the destination location of Restaurant at 11:02:52, the recording was ceased and all other locations were considered eliminated at 11:02:52 (in this case, Shipwreck and Catwalk). The number of locations still considered "in play" when the final destination was reached was recorded (i.e. in the previous example the number was 2). Measuring these vectors allowed for comparison of the predictive value of concordant

key activations relative to other cues associated with the orientation and movement of humans in the environment.

Furthermore, each location key activation was categorized relating the key activated, the human vector, and the next location visited by a dolphin. Categories were as follows: KVN, the *key* activated was concordant with the human *vector* as the dolphin arrived at the *next* location (e.g., IGLOO activated, human vector towards Igloo, dolphin visited Igloo as next location); KV-N, the key activated was concordant with the human vector as the dolphin arrived at a location that was not concordant with either (e.g., RESTAURANT activated, human swam in that direction, and dolphin visited the Igloo); KN-V, the key activated was concordant with the next location the dolphin visited, however, the human vector was not concordant with either (e.g., SHARK ALLEY activated, dolphin visited Shark Alley, while human vector was toward Divider/Navy Bell); K-VN, the human vector was concordant with the next location the dolphin arrived at, however, the key activated was not concordant with either (e.g., Dolphin arrived at Igloo and human's vector was directed at Igloo, however, the key activated was SHIPWRECK); K-V-N, the key activated was not concordant with the human vector as the dolphin arrived at the next location, which was also not concordant with either (e.g., ITM activated, human vector towards Divider/Navy Bell and dolphin visited the Igloo). These recordings and the previously discussed time eliminations by the human vector were then examined to determine if key presses were better predictors of the dolphins' next location visited than cues associated with the human's orientation and vector.

Given that the data set covered the dolphins' behavior over a period of seven years, analyses were run to test for changes in all measures over time, splitting the data

into year subsets. Analyses included the examination of the total frequency of key activations, the frequency of key activations by category (See Table 1) and frequency of different location key activations. Further, chi-square analyses included whether the dolphin was led by the human to the location or the human followed the dolphin to the location, whether the dolphin was the speaker (activated key) or the listener (human activated key) and the number of locations visited by the dolphin before the location matched the key activated, the “correct” location. Additionally, the difference between the dolphin’s arrival time at a location and the time stamp of key activation was compared across years. Furthermore, a comparison of the concordance categories (between keys activated, human vectors, and next locations visited by the dolphins) and the locations left in the human vector when a location was reached were analyzed against that expected by chance.

Reliability

Inter-coder reliability was assessed between two coders, author and naïve rater, using approximately 10% of videoed sessions, with sessions randomly selected from each year of the study. A Cohen’s kappa was calculated to measure the agreement between coders for the human’s role in the location visited after a location key activation, the number of locations visited until the correct location was reached, and the relationship between key activated, human vector, and next location visited by a dolphin. In addition, the agreement between the dolphin arrival time to the location was compared.

CHAPTER III - RESULTS

Keyboard Events

The frequency of total key activations is shown in Figure 3. The frequency was calculated from the keypress log and includes every key activated by a Human, Bob, or Toby, as a function of year. Overall, Humans showed an abrupt increase in frequency between 1993 and 1994, followed by a decrease from 1994 to 1997, and an increase to prior levels from 1997 to 1999. After activating just a few keys in 1992, Bob and Toby also abruptly increased key activations in 1993, and then showed a similar U-shaped pattern of key activations from 1994 to 1999. It should be noted that sessions were conducted for only partial years in 1992 (July-October) and 2000 (January-May).

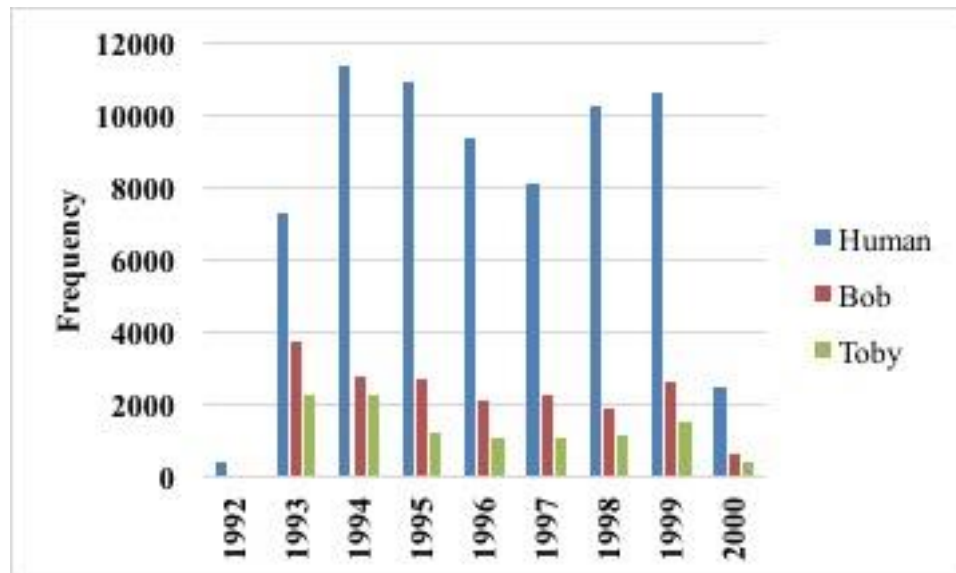


Figure 3. Total key activations during the study.

Further, the total frequency of key activations was divided into key categories (see Table 1 for a description of the categories). The frequencies of key activations by

category by year for Human, Bob, and Toby are shown in Table 3. A chi-square analysis was performed comparing frequency of key activations in each category between Human, Bob, and Toby, and an overall significant difference was found, $\chi^2(16, N = 100,184) = 21,852.596, p < .05, V = .330$, indicating the distribution of frequencies of key activations for humans, Bob, and Toby were not the same. Unsurprisingly, humans activated keys with much higher frequencies than the dolphins. Bob consistently activated more keys than Toby. There were significant differences in the frequency of activations between a Human and the dolphins, and a significant difference between activations for Bob and Toby, for the key categories of action, agent, food, grammatical, location, and object. Exceptions included a non-significant difference between Human and Bob in the category of Modifier and non-significant differences between Bob and Toby in the categories of Tools and Tool Sites.

Table 3 *Total key activations by category.*

Category	Human	Bob	Toby
Action	19055 (13759)	244 (3690)	323 (2173)
Agent	2715 (2079)	107 (558)	143 (328)
Food	6939 (8480)	3395 (2274)	1760 (1339)
Grammatical	10417 (8017)	300 (2150)	716 (1266)
Location	22554 (31403)	14327 (8422)	7904 (4960)
Modifier	676 ^a (660)	200 ^a (177)	65 (104)
Object	1626 (1299)	124 (349)	103 (205)
Tool Sites	595 (442)	17 ^b (119)	18 ^b (70)
Tools	5672 (4110)	126 ^b (1102)	63 ^b (649)
<i>Total</i>	<i>70249</i>	<i>18840</i>	<i>11095</i>

Note: Parentheses represent expected frequencies.

^a No significant difference between Human and Bob

^b No significant difference between Bob and Toby

The frequency of different categories during each year for a Human, Bob, and Toby are shown in Figures 4, 5, and 6 respectively. Humans demonstrated a greater diversity of use of key categories, mainly using keys in the categories of location, action, and grammatical throughout the study. Bob and Toby demonstrated a more limited use of key categories and most frequently activated location and food key categories. Toby activated more keys in more diverse categories than Bob in 1993 and 1994, predominantly due to his persistent activations of a single grammatical key, AT. By 1995, both dolphins came to activate location keys almost exclusively.

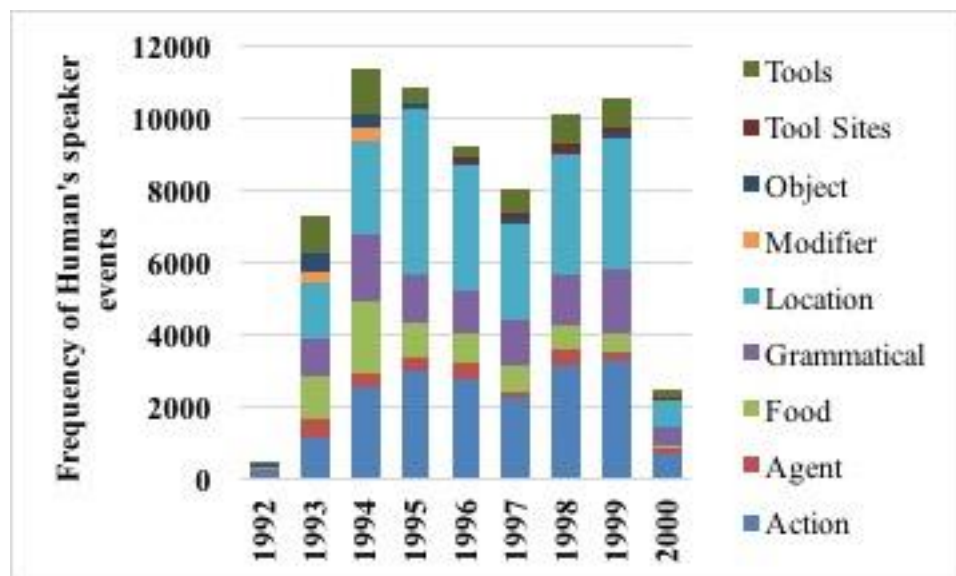


Figure 4. Human key activations by category.

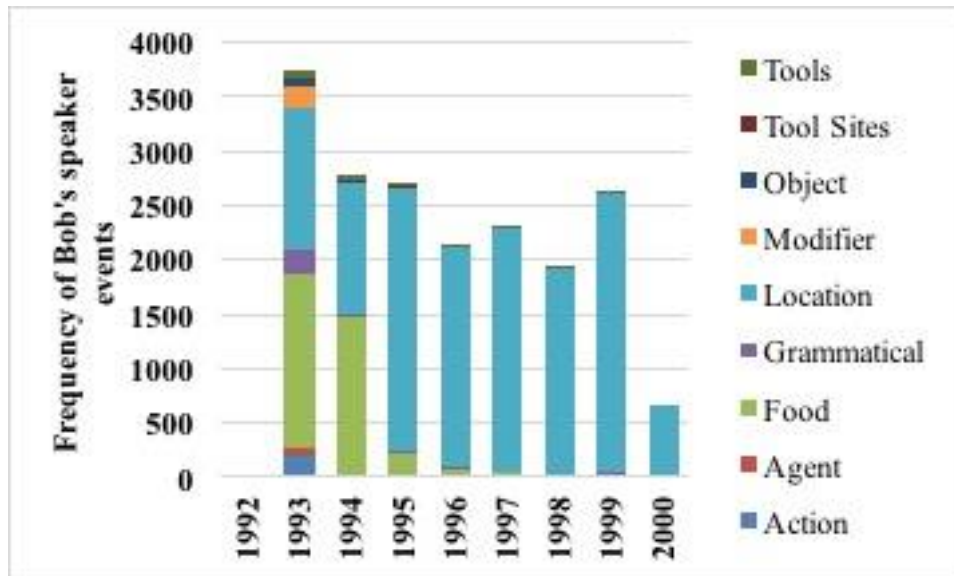


Figure 5. Bob key activations by category.

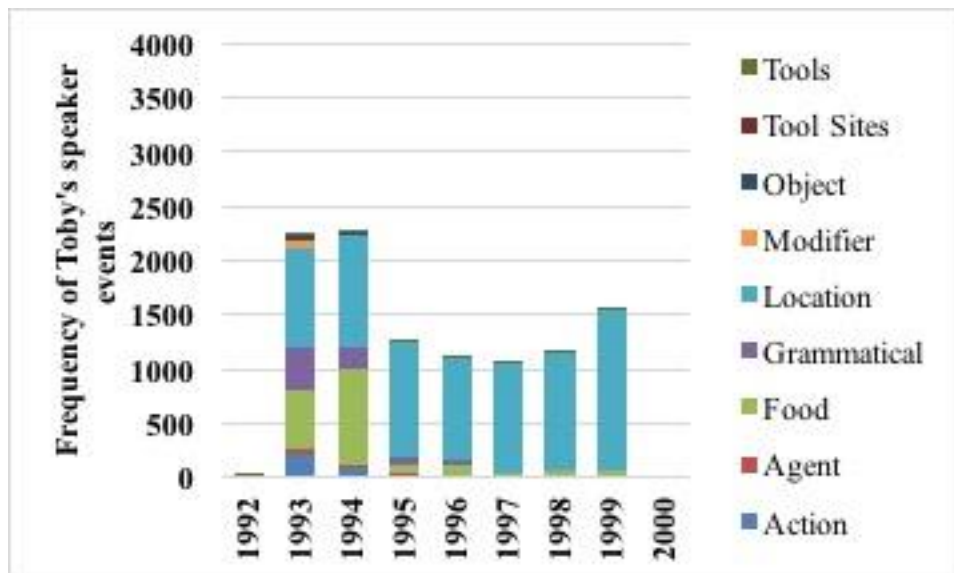


Figure 6. Toby key activations by category.

The frequencies of activation for each location key by Human, Bob, and Toby are shown in Table 4. A chi-square analysis was performed comparing the frequency of location key activations between Human, Bob, and Toby, and an overall significant

difference was found, $\chi^2(16, N = 44,691) = 11,673.822, p < .05, V = .361$, indicating the distribution of frequencies of location key activations by a Human, Bob, and Toby were not the same. Cramer's V showed a medium effect size. Although Bob and Toby did not use the location keys as much as the Human, there was a significant difference in the frequency of location key activations between a Human and dolphin for all locations. Furthermore, there was a significant difference between location key activations between Bob and Toby for all locations except RESTAURANT.

Table 4 *Total frequency of location key activations during the study.*

Location	Human	Bob	Toby
Backpool	158 (91)	2 (58)	21 (32)
Navy Bell	2160 (1873)	1137 (1195)	429 (659)
Divider	2850 (2744)	2579 (1750)	31 (966)
ITM	4381 (3492)	2532 (2228)	36 (1229)
Shark Alley	2201 (1921)	1595 (1225)	26 (676)
Igloo	2526 (4078)	2290 (2601)	3298 (1435)
Restaurant	3255 (2578)	1174 ^a (1645)	701 ^a (907)
Shipwreck	3107 (3887)	1277 (2479)	3350 (1368)
Catwalk	1822 (1797)	1741 (1146)	12 (632)
<i>Total</i>	<i>22460</i>	<i>14327</i>	<i>7904</i>

Note: Parentheses represent expected frequencies

^aNo significant difference between Bob and Toby

The frequency of location key activations during each year for a Human, Bob, and Toby are shown in Figures 7, 8, and 9 respectively. Each speaker demonstrated the use of every location key throughout the study (as seen in Table 4). Humans used the full diversity of location keys roughly the same during each year of the study, with the exception of BACKPOOL. Keyboard sessions often began with the dolphins entering the main aquarium from the Backpool, and ended with them returning to it. Backpool was infrequently visited in the middle of a session. Similar to the humans, Bob demonstrated

the use of every location key during each year of the study, with different location keys being activated most frequent during different years (e.g., in 1995, ITM was the most frequent location key activated; in 1997, SHARK ALLEY was his most activated location key; and in 1999, CATWALK was his most frequent location key activation). In contrast, Toby typically activated only four of the nine location keys during each year of the study, with IGLOO and SHIPWRECK making up the greatest frequency per year. It should be noted that the grammatical key AT that Toby continued to activate with some frequency in 1993 and 1994 was located adjacent to the IGLOO key.

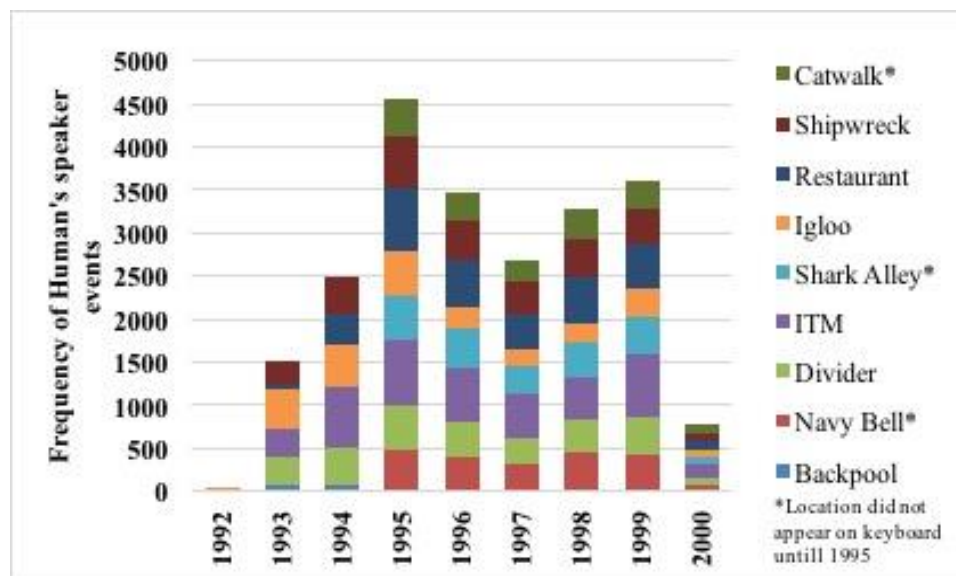


Figure 7. Human location key activations during the study.

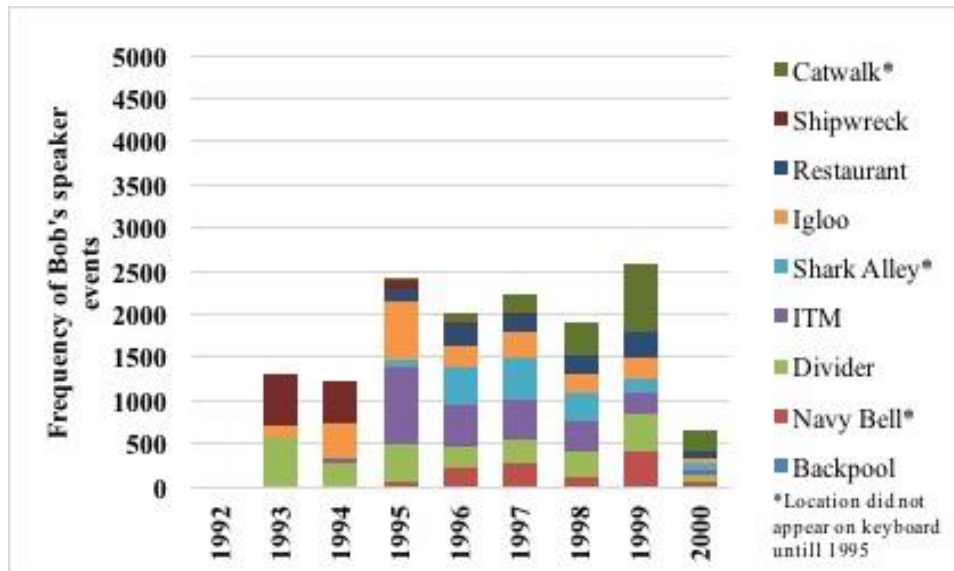


Figure 8. Bob location key activations during the study.

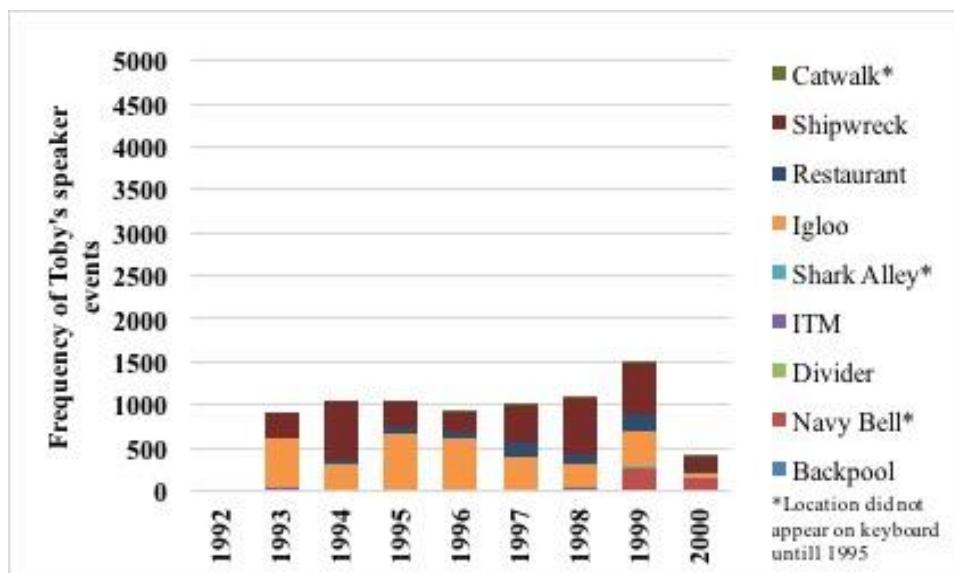


Figure 9. Toby location key activations during the study.

Additional analysis compared the average frequency of location key activations during a session when there was an object present at a location (see Figure 10). When herring or mackerel were at a location, Bob activated the location key with these food

items present more frequently during a session, and Toby activated a location key more frequently when smelt or herring were present. This coincides with their preferences of different food types (see Figure 11). The greatest frequency of food key activations for Bob were HERRING and MACKEREL, and for Toby, they were HERRING and SMELT throughout the study.

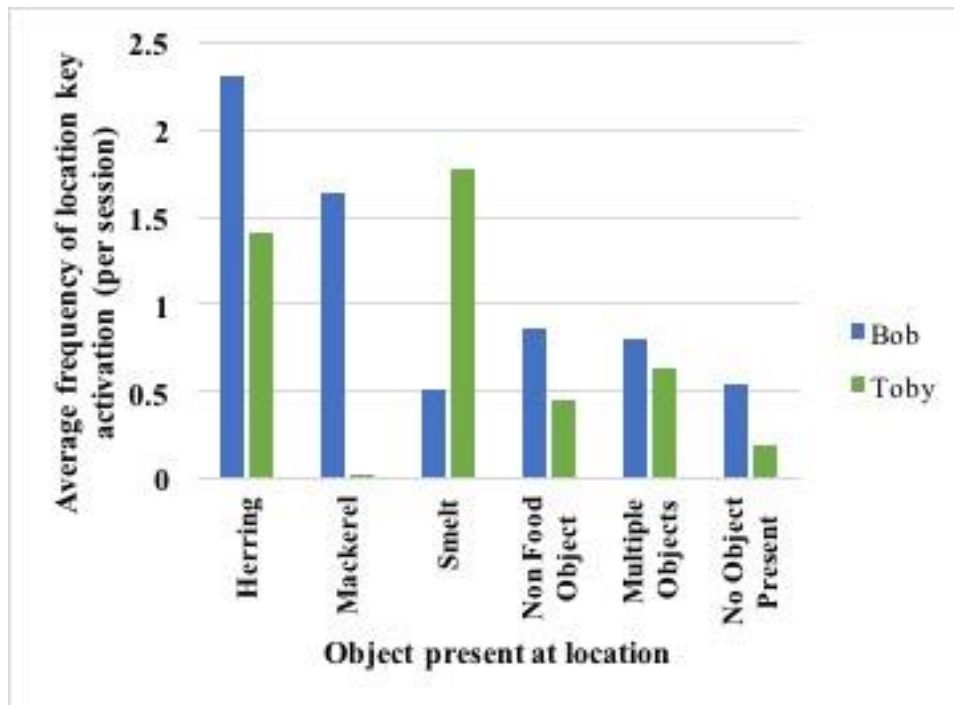


Figure 10. Average frequency of location key activations during a session when objects were present at the location.

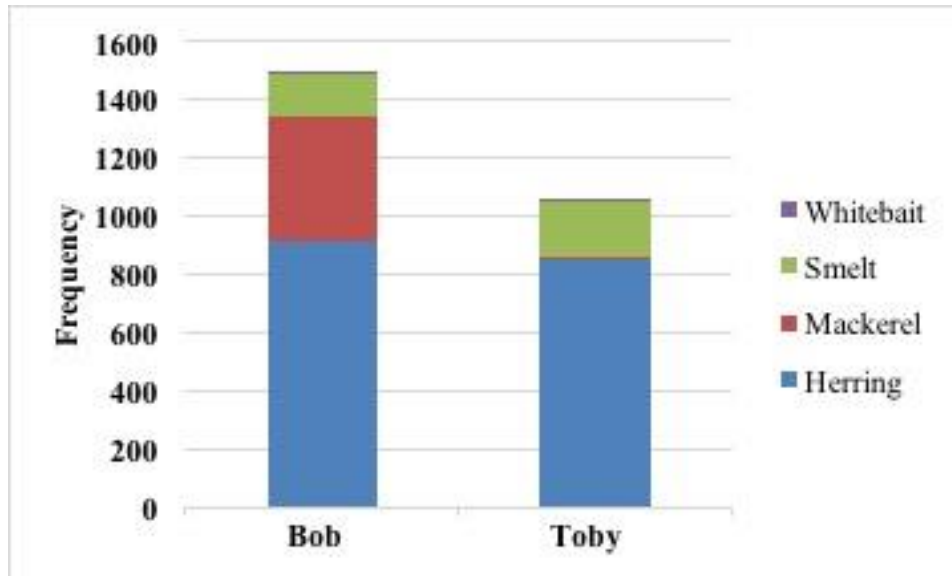


Figure 11. Total food key activations during the study.

Keyboard Location Events Captured on Video

Reliability

Inter-coder reliability was assessed using Cohen’s kappa and measurement of agreement. For the human’s role after a location key activation, the agreement between coders was 80% with a kappa of 0.70 and considered “good” agreement. The number of locations visited before the correct location was reached and the relationship between keypress activated, human vector, and the next location visited by a dolphin (i.e. KVN) had agreements of 86% with a corresponding kappa of 0.74, both considered a “good” agreement. In addition, the measurement of agreement of the dolphin arrival time to the location was found to be 82%. To determine agreement for the dolphin arrival time, the number of seconds for each coder was examined, if they were in within 5 seconds of one another for an event, it was considered agreement, and greater than 5 seconds was considered a disagreement.

Location Key Activations

The frequency of location key activations captured on video for further analysis is shown in Table 5 (Bob) and in Table 6 (Toby). Location key activation events are shown as a function of dolphin (Bob or Toby), their role in the event (Speaker or Listener), and the role of the human during the event (Led the dolphin or Followed the dolphin to a location). The frequencies are further subdivided depending if the first location visited by the dolphin after a location key activation was correct or incorrect (i.e. the first location visited by the dolphin matched the location key activated).

Table 5 *Bob location key activations captured on video.*

<i>Correct location visited</i>	Bob Speaker	Bob Listener	Total
Human Led	54 (59)	95 (90)	149
Human Followed	50 (45)	63 (68)	113
Total	104	158	262
<hr/>			
<i>Incorrect location visited</i>	Bob Speaker	Bob Listener	
Human Led	6 (9)	19 (16)	25
Human Followed	6 (3)	3 (6)	9
Total	12	22	34
<i>Total</i>	<i>116</i>	<i>180</i>	<i>296</i>

Note: Parentheses represent expected frequencies

Table 6 *Toby location key activations captured on video.*

<i>Correct location visited</i>	Toby Speaker	Toby Listener	Total
Human led	40 (41)	81 (80)	121
Human followed	19 (18)	33 (34)	52
Total	59	114	173
<hr/>			

Table 6 (continued).

<i>Incorrect location visited</i>	Toby Speaker	Toby Listener	
Human led	7 (8)	23 (22)	30
Human followed	2 (1)	3 (4)	5
Total	9	26	35
<i>Total</i>	68	140	208

Note: Parentheses represent expected frequencies

Chi-square analyses were conducted to discover any significant differences between speaker/listener, human led/human followed, and correct/incorrect events for Bob. There were no significant differences when Bob visited a correct location, comparing a speaker vs. listener event and a human led vs. human followed event, $\chi^2(1, N = 262) = 1.721, p = 0.190, V = .081$. There was a significant difference when Bob first visited an incorrect location, comparing speaker vs. listener event and a human led vs. human followed event, $\chi^2(1, N = 34) = 5.275, p < .05, V = .394$. Cramer's V indicates a medium effect. When the first location Bob visited was incorrect and a human led him to the location, Bob was significantly more often the listener than the speaker. The inverse was true when the human followed Bob. Bob was significantly more often the speaker.

There were no statistically significant differences between these variables when Bob visited a correct location. Figure 12 shows that the throughout the years of the study, there was a high percentage (greater than chance levels) of visiting a correct location first. Furthermore, the percentage of events when Bob was the speaker showed a U-shaped pattern of key activations, similar to that of his total key activation frequencies in Figure 3, and showed a moderate positive relationship across the years of study, $r(5) = .559, p < .05$. Lastly, a trend of increasing events of a human following Bob to a location

was observed throughout the study, showing a strong positive relationship $r(5) = .932, p < .05$, indicating his tendency to swim off to a location before the human could lead him in the right direction.

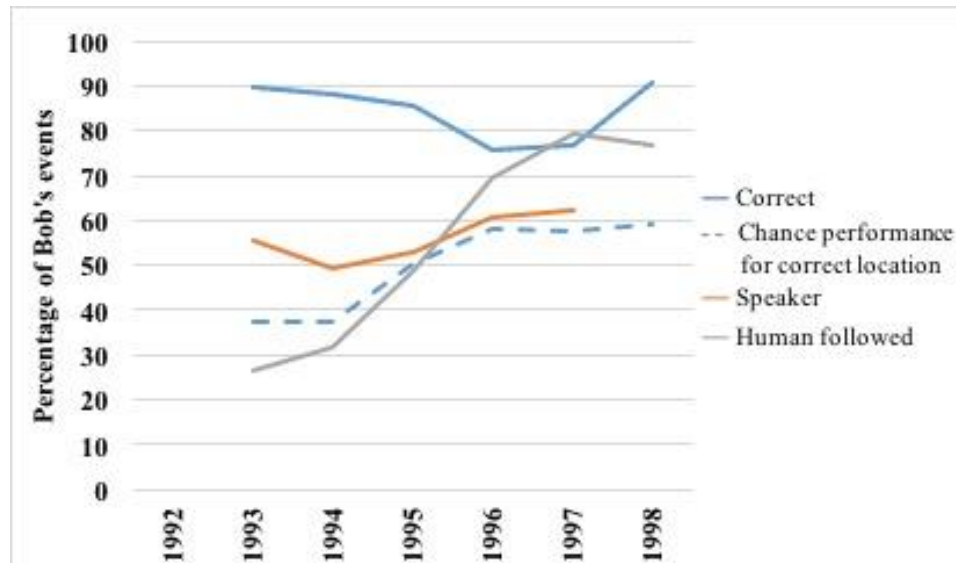


Figure 12. Percentage of events for correct location visited, as a speaker, and when the human followed Bob throughout the study.

Chi-square analyses were conducted to discover any significant differences between speaker/listener, human led/human followed, and correct/incorrect events for Toby. However, there were no significant differences when Toby visited a correct location or incorrect location, comparing a speaker vs. listener event and a human led vs. human followed event; correct location: $\chi^2(1, N = 173) = .196, p = 0.658, V = .034$; incorrect location: $\chi^2(1, N = 35) = .623, p = 0.430, V = .133$.

Figure 13 shows that Toby first visited the correct location greater than chance levels, although that declined over the years of the study, as did the percentage of events

for Toby as the speaker (a strong negative relationship, $r(5) = -.864, p < .05$), which appeared different from Bob. However, similar to Bob, there was an increasing trend of humans following Toby to a location after a location key activation, showing a strong positive relationship $r(5) = .933, p < .05$, rather than Toby waiting for the humans.

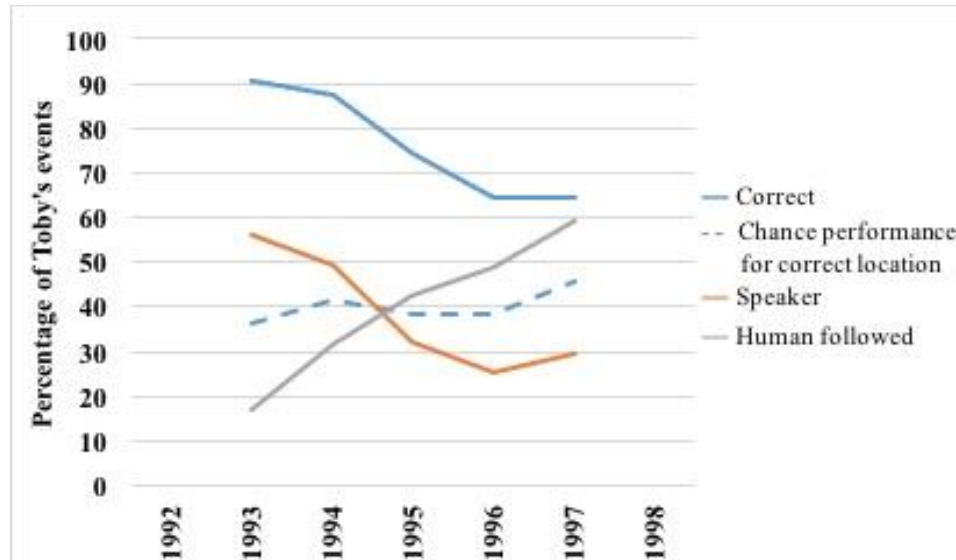


Figure 13. Percentage of events for correct location visited, as a speaker, and when the human followed Toby throughout the study.

Key Activation and Dolphin Arrival Time

The average time between location key activation and the arrival of the dolphin at the Next location visited is shown in Figure 14. A box and whisker plot was used to show the distribution of time differences and their variability. The time differences were collapsed across locations and divided by years. The lower whisker indicates the shortest time difference between a location key activation and the dolphin arrival time to the location, with the upper whisker indicates the greatest time difference. The average time

difference to arrive at a location after a key activation is represented by a green dot, with the green line demonstrating the trend of average time differences as the study progressed. Only events in which the first location visited was considered correct were used in the calculation. A log transformation was performed on the data due to a large positively skewed distribution, skewness value of 1.548 ($SE = 0.560$). In order to adjust for the skewed distribution, statistical analysis was conducted using the log transformed data; 1992 ($M = 1.378$, $SD = 0.163$) and 1998 ($M = 1.084$, $SD = 0.152$); $t(51) = 6.326$, $p < .05$, $d = 1.866$. Overall, there was a steady, significant decrease in the average amount of time between keypress activation and the dolphin arrival time to the location between 1992 and 1998. The original data is presented in Figure 14 to better observe the decreasing time difference across the study, while the statistical test was conducted with the transformed data for proper analysis.

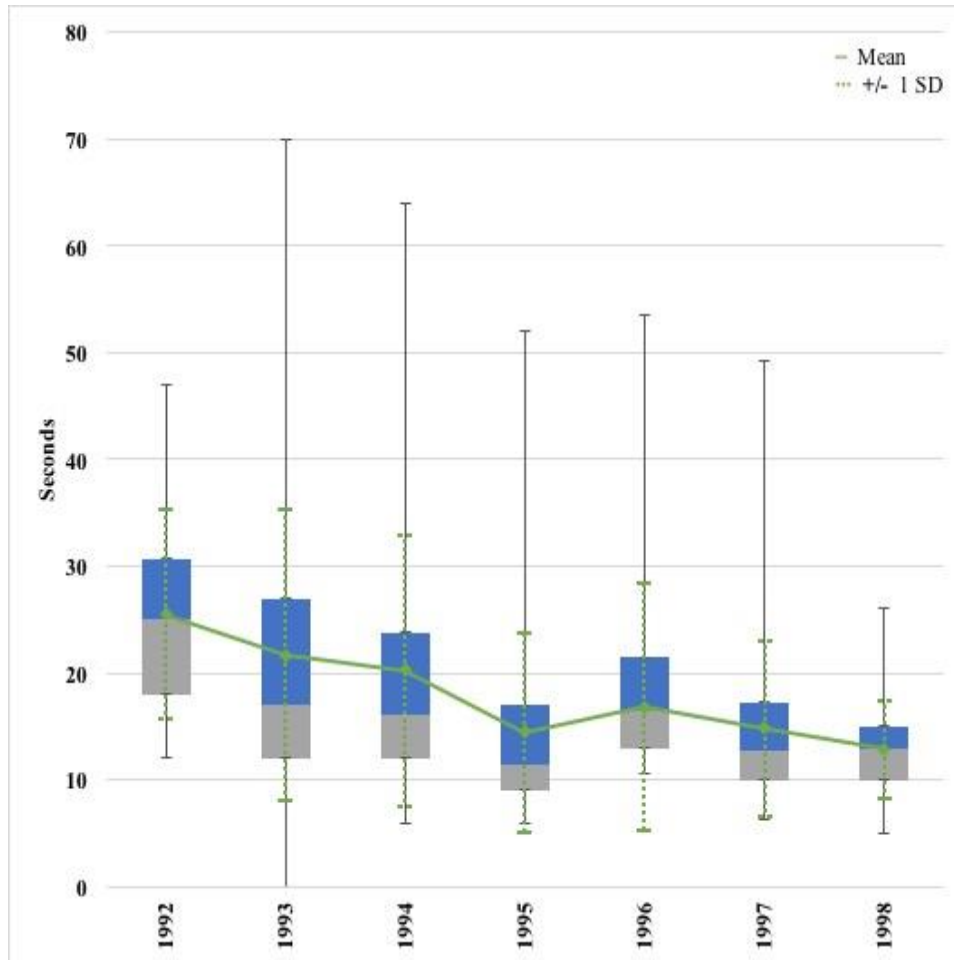


Figure 14. Average time difference between location keypress activation and dolphin's arrival time to the first location visited (correct location).

Concordance Between Key Activation, Human Vector, and Next Location Visited by a Dolphin

An attempt was made for every location key event captured on video to relate the Key activated, the human Vector when swimming to the location, and the Next location visited by the dolphin. Frequencies relating each type of event is shown in Table 7. The two most frequently occurring events were KVN, meaning concordance between the Key, the human Vector, and the Next location visited by the dolphin, and KV-N, meaning

the Key and the human Vector were concordant, however, the Next location visited by a dolphin was not concordant with either. There were not enough occurrences of K-VN, KN-V, or K-V-N to be analyzed. A chi-square analysis was conducted to compare frequencies of KVN vs. KV-N events for Bob and Toby. A significant difference was found between the KVN and KV-N events for both Bob and Toby, $\chi^2(1, N = 591) = 6.828, p < .05, V = .107$. Cramer's V indicates a small effect. This was likely due to the higher frequency of KV-N events for Toby (i.e. a higher frequency of incorrect locations, relative to Bob). Many events could not be scored (coded "N/A" below) because the human's vector was not captured. For all but four of the remaining events, the Key activated and human Vector were always concordant. There was, therefore, no opportunity to directly evaluate the independent contributions of the Key activated and the human's Vector to the Next location visited.

Table 7 *Frequencies of relating key, human vector, and next location visited events.*

Event	Bob	Toby
KVN	307 (296)	197 (208)
KV-N	40 (51)	47 (36)
K-VN	0	1
K-V-N	2	1
KN-V	0	0
N/A	253	100

Note: Parentheses represent expected frequencies

Locations Left in Human Vector

The average number of locations that were still in the human vector when a location was reached is shown in Figure 15. After a location key was activated, human and dolphin would start to swim in the direction of the location activated, as the human

got closer to the location activated, other locations were eliminated as the possible destination based on the human vector. For example, if DIVDER was activated, Igloo, Restaurant, Shipwreck, and Catwalk were almost immediately eliminated from the human's vector as they swam in the opposite direction (see Figure 16 below). As the human got closer to the Divider, Itm and Shark Alley would also be eliminated, and when the human approached the destination of Divider, there were still 3 locations consistent with the human's vector, Divider, Navy Bell, and Backpool. A map of the enclosure with arrows indicating the typical routes of a human is shown in Figure 16 with the keyboard placed in its most typical position.

Locations of Divider and Igloo had the greatest average of locations left in the human vector with just over 3 locations each. The location of Shipwreck had on average of two locations left in the human vector when it was reached, Shipwreck and Catwalk. The location of Navy Bell had an average of almost two locations left in the vector when it was reached, consisting of Navy Bell and Backpool. Backpool, Restaurant, and Catwalk were the last locations left in a human vector when swimming to the appropriate location. Due to the random placement of the keyboard throughout the course of the study, Itm and Shark Alley could possibly have one or two locations left in the human vector. In the keyboard's most typical position (displayed on the map), Itm and Shark Alley would only have one location left in a human's vector as they are the only locations in the vector. In contrast, when on occasion the keyboard was placed next to the Shipwreck, there was the possibility of more locations, e.g., for Shark Alley, Igloo would now be consistent with the human's vector.

Although there were nine locations, and eight were used regularly, it would be inappropriate to posit chance performance as 1/9 or 1/8, because, in addition to the key activated, the human vector was an available cue for the dolphins. To create a more conservative estimate of chance performance for the percent correct next location, a weighted average for each dolphin was calculated by multiplying the reciprocal of the average number of locations consistent with the human vector when the human arrived (e.g., for Shipwreck, 1/2.299) by the frequency of the key activations for that location that year (e.g., for Bob, SHIPWRECK, in 1993 was 592), then summing these values for each location, and dividing by the total frequency of location keys per year. In this way, chance performance was calculated to vary between 37.3% to 59.1% for Bob, and 36.5% to 45.7% for Toby.

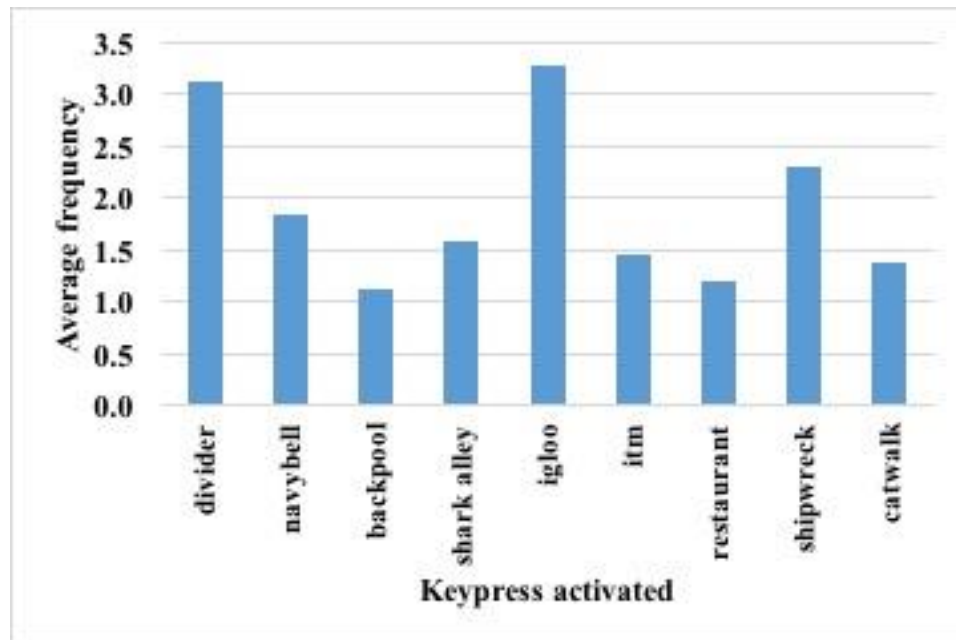


Figure 15. Average number of locations in the human vector when dolphin reached location.

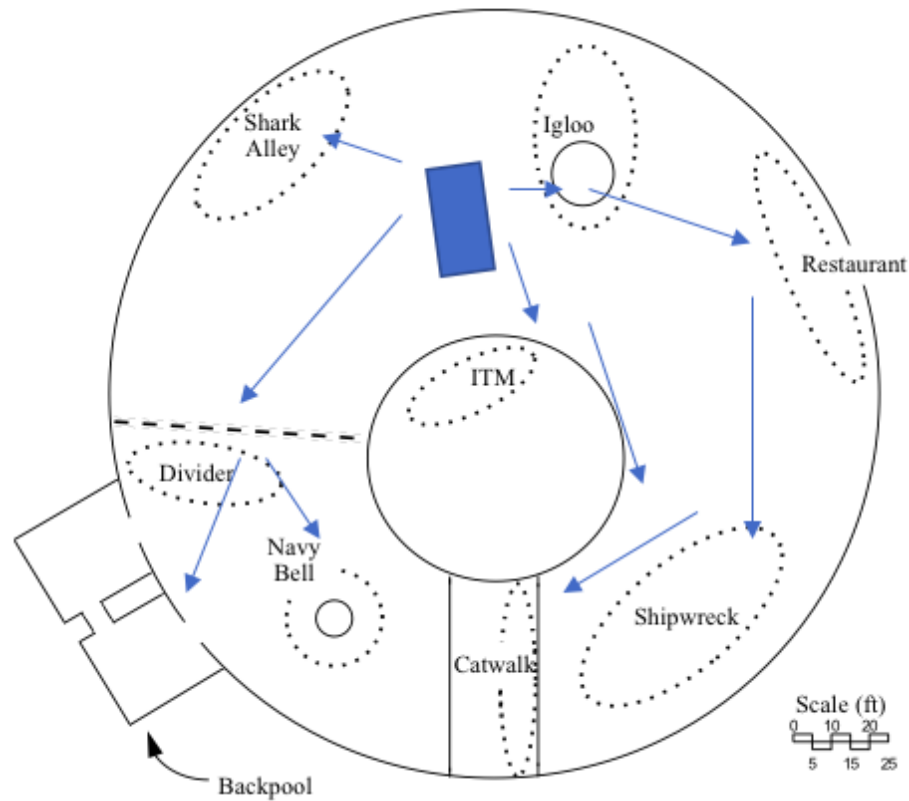


Figure 16. Map of the enclosure with arrows indicating typical routes to each location.

Further analysis of the first location a dolphin visited is shown in Table 8. Frequencies are shown for correct locations along the diagonal, while frequencies for incorrect locations are shown in adjacent cells. The locations are ordered in the table such that adjacent locations, which were, therefore, more often consistent with the same human vector, are closer to each other. The totals do not include events not completed captured on video (i.e., no “N/A” events), nor do they include completed events when the first location was “unknown” (i.e. the camera did not capture this on video due to camera not fast enough to follow), which was total of 12 events. For example, when the location keypress activated was NAVY BELL or BACKPOOL, Divider was incorrectly visited

first by the dolphin a total of 18 times (4 Backpool, 14 Navy Bell), which were all in the same vector. In general, higher frequencies of incorrect locations cluster closer to the diagonal than farther from it.

Table 8 *First location visited after key activation (events completely captured on video).*

<i>First location, keypress</i>	<i>backpool instead of</i>	<i>navy bell instead of</i>	<i>divider instead of</i>	<i>shark alley instead of</i>	<i>igloo instead of</i>	<i>itm instead of</i>	<i>restaurant instead of</i>	<i>shipwreck instead of</i>	<i>catwalk instead of</i>
backpool	3	1	4	0	0	0	0	0	0
navy bell	0	6	14	0	0	0	0	0	0
divider	4	1	105	0	1	2	0	0	0
shark alley	0	0	0	24	0	0	0	0	0
igloo	0	0	1	1	148	2	1	2	0
itm	0	0	1	0	1	108	1	1	0
restaurant	0	0	0	0	7	2	36	0	0
shipwreck	0	0	0	0	8	6	6	73	2
catwalk	0	0	0	0	0	2	2	1	4
Total	7	8	125	25	165	122	46	77	8

CHAPTER IV – DISCUSSION

The goals of this study were to 1) determine if dolphins could learn to use an underwater keyboard without explicit training but by observing model human divers utilizing the keyboard and 2) investigate the development of semantic reference for location symbols by bottlenose dolphins in both comprehension and production. Many of the predicted hypotheses were supported by the results of this study. The dolphins demonstrated the ability to learn to use the keyboard simply by observing a human activate symbols. The evidence supports the dolphins were able to make associations between location symbol and referent utilizing a different approach than discrete trial by trial training, but rather a more opportunistic paradigm. In addition, dolphins were not immediately reinforced when activating a location key, rather, once they reached the location. Furthermore, there was not always a reinforcement at the location for the dolphin. During each session, different food items and objects (i.e. the reinforcement) could be placed at a location to be obtained by the dolphin, however, not every location would contain a food item or object. This resulted in a variety of outcomes for a dolphin after a location key was activated, yet the following results suggest the dolphins, and especially the dolphin Bob, did develop an understanding of a location symbol on the keyboard, and its referent, the actual location in the enclosure.

Keyboard Events

The total frequency of key activations for humans was far greater than that of either dolphin, however, there were increased key activations at the beginning and near the end of the study, with decreased key activations at the center point of the study. The

years of 1992 and 2000 consisted of the lowest frequency counts for each speaker, due to sessions only being run for part of the year.

Further analysis examined the frequency of key activations in each category (see Table 1 for a description of the categories). A significant difference was found between the distribution of frequencies of key activations in each category comparing the speaker of the event. Unsurprisingly, humans, who understood all of the keys as symbols to start, used the categories of keys differently from the dolphins. After an initial period of activating a diverse assortment of keys, Bob and Toby primarily activated location and food keys and as the study progressed, activated the location keys almost exclusively (see Figure 4, 5, and 6). This suggests that Bob and Toby could communicate their wants and needs by simply activating a food or location key, and eventually just the location keys. Perhaps in response to the interaction shaped by the dolphins, humans also came to use the location keys with greater frequency than any other category of keys.

Like the humans, Bob came to utilize all the location keys available, with the exception of Backpool (see Figure 7 and 8). Backpool was primarily used to initiate a session and rarely used as a destination location. Bob appeared to learn the associations between the location keys and the physical locations during keyboard interactions, perhaps similar to how a child might learn through observation and imitation when learning a word (Brown, 2000). Toby's use of the location keys was similar but more limited than Bob's. Toby predominantly used only four of the nine different location keys during each year of the study (see Figure 9). In other ways, Toby's development trailed that of Bob's. He adopted a more passive approach and continued to follow humans from one location to the next throughout the study. Since humans interacted with both

dolphins in a similar manner, it suggests that Bob's more active approach with activating keys and leading humans was not the result of human direction, but of individual differences in learning.

Further support of Bob and Toby's development of the association between location key and its referent are demonstrated by the concordance between the frequency of key activations of preferred food items and pressing a location key where a preferred food item was located. This suggests, that Bob and Toby activated a specific location key more when that location was baited with their preferred food

Keyboard Location Events Captured on Video

Location Key Activations

The frequency of location key activations captured on video was analyzed for Bob and Toby. Chi-square analysis demonstrated no significant differences between frequencies of speaker or listener events or frequencies of human led or human followed events when Bob visited the correct location first. However, there was a significant difference when Bob visited the incorrect location first, comparing speaker vs. listener events for both human led and human followed events. When Bob visited an incorrect location, he was most often the listener and led by the human. Perhaps his accuracy declined when he was in a more passive role.

A chi-square analysis indicated there were no significant differences between when Toby visited a correct location first or incorrect location first, comparing if it was a speaker or listener event and if it was a human led or human followed event. This could be explained by the low sample size of Toby's location key events.

Percentage of Correct Events, Speaker Events, and Human Followed Events Across Study

The percentage of correct first locations was greater than the percentage of incorrect first locations during the course of the study for both Bob and Toby (see Figure 10 and 11). Herman and his colleagues worked with Akeakamai and Phoenix to examine dolphins' ability to comprehend semantics and syntax of sentences. As stated above, he defined comprehension as "the ability of the dolphins to utilize the semantic and syntactic information in the sentences in order to carry out the instructions, and was measured by the accuracy or appropriateness of their response to those instructions" (Herman & Forestell, 1985; Herman et al., 1984). Akeakamai and Phoenix's overall correct response rates (82.8% and 85.1%, respectively) provided evidence of their comprehension of the complex sentences they were tested on. When a location key was activated, the accuracy of Bob and Toby's response was measured as correct or incorrect based on the first location visited; Bob's percentage of going to the correct location first remained above 75% throughout the entire study and Toby's remained above 65% (see Figure 10 and 11), each greater than expected by chance. This suggests that the dolphins in the current study also developed some aspects of semantic reference for the location symbols as their accuracy improved in going to the correct location first.

A speaker event indicates who activated the location key. For Bob, his speaker events initially decreased at the beginning of the study but then continually increased for the later years of the study, this pattern is similar to his total key activations. It suggests, that initially Bob was pressing keys somewhat randomly and as he learned to distinguish between the different location keys, his speaker events decreased. As he developed

confidence in his understanding of the semantic reference between location key and its referent, his speaker events started to increase. Alternatively, Toby demonstrated a decreasing percentage of speaker events while the listener events increased over time. Perhaps Toby also learned that random key activations were unproductive, but was slower than Bob to learn the associations between each location key and its referent. That the dolphins were likely to visit the correct next location whether they were the speaker or listener suggests both the development of some aspects of referential understanding in both production and comprehension (Savage-Rumbaugh et al., 1993).

More often than not the dolphin would swim ahead of the human, however, the determination of a “human led” vs. “human followed” event occurred within seconds after the location keypress activation. If a dolphin had to wait for the human to start swimming in the direction of the location to be visited, it was considered a “human led” event, whereas when dolphin simply started to swim towards a location after a keypress, it was considered a “human followed” event. Bob had an increase in the percentage of human followed events every year observed during the study, indicating a decrease in the percentage of human led events every year (see Figure 10). Due to the low frequency of events for Toby in 1998, those years were excluded from the analysis, however, the same general trend of increasing human followed events were observed throughout the study (see Figure 11). This would indicate that as the dolphins began to develop an understanding of the location keys and their corresponding locations in the enclosure while utilizing the keyboard, the human no longer needed to lead them to the location, rather they took initiative to swim towards a location and a human followed the dolphin to the location.

Keypress Activation and Dolphin Arrival Time

The average time difference between a location key activation and the dolphin arrival time at the correct location significantly decreased across the course of the study (see Figure 12). This further suggests the dolphins were becoming more confident in the relationship between the key activated and the physical location.

Concordance Between Keypress, Human Vector, and Next Location Visited by a Dolphin

The relationship between the location keypress activated, the human vector while swimming to a location, and the next location visited by a dolphin after a keypress was recorded, with the goal of determining the independent contributions of the key activated and the vector of human as cues for the dolphin. However, in the natural flow of keyboard session, the key activated and the human vector were almost always the same and thus determining the influence of the key activated or the human in visiting a location was not currently possible with this data set.

In conclusion, this study is preliminary and the evidence suggests the development of some aspects of semantic reference for the location symbols in the dolphins, especially Bob. Utilizing an approach similar to that of Savage-Rumbaugh and Kanzi, Bob and Toby were not explicitly trained to use the keyboard or learn specific symbols, rather human divers modeled the use of keyboard and its symbols in daily interactions and Bob and Toby could choose which symbols they wanted to explore (Savage-Rumbaugh, 1986). This different approach to two-way communication between different species met with great success for Kanzi in the development of his symbol representation of symbols and their referents (Savage-Rumbaugh et al., 1983; Savage-Rumbaugh et al., 1993) and showed promise for Bob and Toby.

Limitations and Future Directions

The swimming speeds of the human divers compared to the dolphins revealed to be a considerable limitation during a session and may have prevented further evidence to support the development of semantic reference in the dolphins. Not only the human divers interacting with the dolphins but those videotaping the sessions were not always able to follow a dolphin close enough to capture the result of the dolphin using the keyboard. In future studies, multiple video cameras, perhaps placed in specific locations around the enclosure to capture all angles could eliminate the events not being captured. Comparatively, the keyboard was not able to move during a session, but rather, only between sessions. Therefore, a more portable keyboard design could allow for interactions to take place continuously between human and dolphin and without the wait and possible distractions between the keyboard interactions.

The current study limited to examining the keyboard events in which a location symbol was used because of them being the most frequently used category of symbols by a dolphin. This suggests the dolphins were able to communicate an intent by only using a location symbol, but perhaps it was because the location symbols were the most consistent and direct in order to obtain the result the dolphin was looking for. The keyboard didn't move during a session, but the locations always remained the same, and it was typically at a location that some sort of activity would occur. It may be the increased use of location symbols were because of a more straightforward association between the symbol and referent than the other symbols on the keyboard. Future studies of this data set could include examining additional symbols on the keyboard that the dolphins used, such as Food symbols, their second most used category of keys.

In examining the videotaped sessions, it was hopeful to determine whether a dolphin was influenced more by the information of the key activated or the human vector and orientation to the location. This did not occur due to the more opportunistic style of a keyboard session and thus a limited number of events in which the key activated did not match the human vector of the location. Future studies should include more structured test trials, perhaps at a low density, but throughout the acquisition, to help disambiguate between the dolphins' association of the location symbol and its referent as a result of the development of the understanding of reference or relying on contextual information provided by the human's vector and orientation. Test trials, in which the humans did not turn away from the keyboard and waited for the dolphin to swim in a direction or humans purposely turned and swam in the opposite direction of the location that matched the key activated would have made it possible to evaluate the dolphin's reliance on information in the key rather than the human's orientation and vector.

An additional and different approach to test the dolphins on their development of the association between location symbol and referent could be done in separate discrete trials. Savage-Rumbaugh, McDonald, Sevcik, Hopkins, and Rubert (1986) tested Kanzi on his ability to be shown a picture of an object and match it with its lexigram (and vice versa), and asked a question about an object in English and pick its corresponding photo or lexigram. Kanzi demonstrated his associations between various referents and lexigrams and that they could be bidirectional. The location symbols on the keyboard each had a 3D object in their designated key slots. Future studies could consist of test trials to ask the dolphin to go to a location by showing them the 3D symbol outside of the keyboard. Once the destination is reached, the dolphin is signaled it is correct/incorrect

and can return to the human. Furthermore, a human could ask “where is X?” (additional associations between object symbols, such as Hoop or Snake, and their referents need first be developed), and have the dolphin respond by selecting the correct location 3D symbol out of a sample, the dolphin may need to search the enclosure for the object, but the response must be selecting the 3D symbol for the location. This could provide further evidence in the dolphin’s ability to comprehend a symbol and its referent in a variety of contexts.

These are just a few of the future studies and ideas that can be done with this data set to examine the comprehension and production of using symbols and understanding their referents. Additional studies with a more portable keyboard and structured tests could be done to provide further evidence of their development of semantic reference.

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