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Assessing Animal Vocal Communication Using the Hyperspace Analog to Language (HAL) Model

A Dissertation submitted in partial satisfaction
of the requirements for the degree of

Doctor of Philosophy

in

Neuroscience

by

Allison Beth Kaufman

June 2010

Dissertation Committee:
    Dr. Curt Burgess, Chairperson
    Dr. Khaleel Razak
    Dr. Aaron Seitz

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The Dissertation of Allison Beth Kaufman is approved:

Committee Chairperson

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To James:

You know me - I wrote 70,169 words in this document and I don’t have one I can think of to write here.

ABSTRACT OF THE DISSERTATION

Assessing Animal Vocal Communication Using the Hyperspace Analog to Language (HAL) Model

by

Allison B. Kaufman

Doctor of Philosophy, Graduate Program in Neuroscience
University of California, Riverside, June 2010
Dr. Curt Burgess, Chairperson

The Hyperspace Analog to Language (HAL) model is used to measure contextual co-occurrence in human language (Lund & Burgess, 1996). In this dissertation, the HAL model was applied to three non-human animal systems; the vocalizations of an African gray parrot, the songs of humpback whales, and the courtship songs of male mice (from both a wild-type population and a genetic model for Fragile X syndrome). In all cases, HAL found evidence of contextual co-occurrence and therefore higher order structure in the communication systems. In the case of the parrot, HAL showed contextual clusters stemming from common phrases in the repertoire, showing these phrases had been arrived at via individual word learning and substitution (as opposed to memorization of each and every phrase as a specific entity). In the humpback whale songs, HAL identified Classes of units that could be combined into patterns specific to individual regions. Changes in these patterns and the usage of the Classes may be additional support for the idea of cultural or geographic clans in these marine mammals. In the mouse song, HAL analysis found different co-occurrence Classes for the wild type and knock out (Fragile X model) mice, and established that although the Fragile X mice appear to be putting together courtship songs with the correct syntax, they may not be doing this using a global co-occurrence schema. Much of this research is preliminary and required subjective judgments, in addition to the creation of new statistical techniques. The judgments made and statistical methods developed were seen as the most reasonable options, however further experimentation is necessary in the case of all three experiments.

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CHAPTER 1: INTRODUCTION AND METHODS

BACKGROUND

Defining Language

Much recent research and debate has focused on defining language and examining its components in a comparative framework (Christiansen & Kirby, 2003). In a 2005 paper by Fitch, many of the components of the language debate are laid out, along with a review of what has been – and still needs to be – investigated. He identifies three critical areas – speech, syntax, and semantics – that must be explored in both humans and animals in order to effectively define and understand language. He also emphasizes that the study of language in animals other than primates (such as dolphins and birds) is especially important, as it is indicative of analogous evolution between distantly related species, and may show that the selection of particular traits for language is adaptive in multiple species.

In addition to this is a seeming inability to define the idea of communication among animal researchers in general (Rendall, Owren, & Ryan, 2009; Scott-Phillips, 2010; Soltis, 2009). Research is based on definitions that range from the basic premise that communication is defined as the passage of information (Owings & Morton, 1998; Shannon, 1948) to the more complex idea that communication that contains higher-level cognitive or referential meaning can be called language and equated to human speech (Savage-Rumbaugh, 1993; Zuberbuhler, Cheney, & Seyfarth, 1999). For purposes of this paper, I will use simply "an attempt to pass information" as the criterion for communication.

Recursion in Animals

Recursion has always been an important component in a language acquisition mechanism. In 2002, *Science* published a paper by Noam Chomsky and colleagues detailing their new theory on the "faculty of language" (Hauser, Chomsky, & Fitch, 2002). The paper classified human language into two components: (a) the Faculty of Language in the Narrow sense (FLN), which consists of an internal computational system for recursion, and (b) the Faculty of Language in the Broad sense (FLB), which consists of the FLN, plus sensory-motor and conceptual-intentional systems. One of the main arguments Hauser et al. make is that the FLN, which is comprised mainly of recursive abilities, is unique to humans and distinguishes human language from that of animals (recursive ability refers to the ability to embed a theoretically infinite number of phrases within sentences, for example, “John said that Mary said the boy was playing”). This idea, that recursion is solely a human ability has been specifically challenged by animal researchers.

Several studies of non-human animals have directly addressed the idea that some species may be able to understand recursive structures. Genter et al. (2006) found the ability to understand recursive structures in the European starling (*Sturnus vulgaris*), and other studies have identified similar abilities in parrots (Pepperberg, 1992). The ability to understand sequential regularities more complex than traditional Finite State Grammars[1] (FSGs) has been demonstrated in pigeons (Herbranson & Shimp, 2008)[2]. Savage-Rumbaugh et al. (1993) showed that a bonobo (*Pan paniscus*) was better able to comprehend recursive structures than a two-year-old child, and it has been demonstrated that bottlenose dolphins (*Tursiops truncates*) can comprehend conjoined sentences, an essential component in recursive construction (Herman, Richards, & Wolz, 1984).

In one of the most cited empirical studies on this topic, tamarins (*Saguinus oedipus*) and college students were tested on their ability to learn both FSGs and PSGs (Fitch & Hauser, 2004). The study, which provided *the same amount* of training on PSG and FSG to both tamarins and undergraduates, is, however, extremely flawed. For example, the investigators failed to determine if the humans in their study were actually using a context-free grammar to identify sentences rather than other plausible pattern recognition techniques (Kochanski, 2005). Recursion beyond one to two levels of embedding is virtually unintelligible to humans (for example, the sentence “The rat that the cat that the dog bit chased ate the cheese”); therefore, it makes little sense to assume that participants in the study specifically identified the

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[1] A linear grammatical structure

[2] Recursion was not specifically examined in the Herbranson and Shimp study

recursive pattern in “ba la tu li pa ka” (where ba, la, and tu are A syllables and li, pa, and ka are B syllables), as opposed to a non-recursive pattern such as “ba li la pa tu ka” (Fitch & Hauser, 2004).

Several other teams have remediated flawed methodology in studies such as Fitch and Hauser’s, only to be met with opposing results. Perruchet and Rey (2005) believed there could be alternate underlying reasons for the Fitch and Hauser results (e.g., the humans could have counted the number of transitions between the voices vocalizing A syllables and B syllables, or they could have identified phrases as having the same number of A’s and B’s). The researchers modified the experimental procedure of the original study so that participants were required to use recursive patterning to learn the sentences - and found that the human participants *did not learn*. Fitch and Hauser had used two acoustically different tones as their syllables, so Perruchet and Rey used sequences that were recursive on both syllable and tone and tested for each one separately. Participants chose the tonal patterns as the ones that followed the rule they had learned. Friederici et al (2006) used the same procedure in an fMRI study and claimed to have found different areas of activation in the brain during processing of FSG and PSG. However, when de Vries et al. (2008) altered the procedure to test a more precise set up stimuli, A3A2A1B1B2B3 vs. A3A2A1A4B2B3, A3A2A1B1B3B2 vs. A3A2A1A4B2B3, and A3A2A1B1B2B3 vs. A3A2A1B1B3B2, they found it was much more likely that the subjects had used counting rules, rather than hierarchical rules, to complete the task. Participants scored similarly on the first two conditions (which could be differentiated by counting) and at a chance level on the third (which could only be differentiated by the hierarchical structure). In surveys administered after the experiment, none of the students mentioned learning a hierarchical rule.

Most recently, a study attempting to replicate Fitch and Hauser’s results (Hochmann, Azadpour, & Mehler, 2008) showed that subjects could differentiate FSG from PSG; however, they also identified as correct (i.e., as PSG) items with uneven numbers of A’s and B’s (AAAABBB), which are not part of a PSG. The subset of participants who classified all items correctly reported counting the number of A’s and B’s – not identifying a hierarchical structure – as their technique (Hochmann et al., 2008).

Additional research in this area deals with statistical regularities in communication streams. An often cited study compares the learning of statistical dependencies by tamarins and human infants (Hauser, Newport, & Aslin, 2001; Hauser, Weiss, & Marcus, 2002; Newport, Hauser, Spaepen, & Aslin, 2004; Saffran et al., 2008). In several of these studies, tamarins have shown evidence of the ability to learn and generalize rule-based grammars and statistical dependencies (Hauser et al., 2001; Hauser, Weiss, et al., 2002; Newport et al., 2004). Even more recently (Hauser & Glynn, 2009), the ability to extract rule-based grammars was shown in free-ranging Japanese macaques (*Macaca fuscata*). This finding expanded the diversity of study subjects to Old World monkeys and to wild animals using artificially arranged patterns of natural vocalizations - rather than captive animals using artificial sounds (Hauser & Glynn, 2009). The research presented in this dissertation is closely linked to the abilities shown by these species to deal with rule based grammars, in addition to parallel abilities found in rats (Toro & Trobalon, 2005). Lastly, Feher et al. (2009) recently demonstrated that song styles in zebra finches (*Taeniopygia guttata*) could develop *de novo*, and, thus, hypothesized that this culture was created from both genetic and environmental components. The environmental component, they further claimed, is subdivided into portions both dependent on the bird's tutor (i.e. culture) and independent of it. When the tutor's song is further broken down into dependent and independent components (with reference to its own tutor), a recursive structure ensues (Fehér, et al., 2009) - which Hauser et al., (2002) claim to be impossible for a non-human species.

Very recent research using a connectionist model known as a Simple Recurrent Network (Elman, 1990) has shown that recursion can be learned via experience; it is not necessary to be innate. Work with this model revealed that it can make novel predictions (which could be confirmed via behavioral testing) about all types of embedding (Christiansen & MacDonald, 2009). This finding is specifically salient because the SRN is a memory model, and one which incorporates memory over time (Elman, 1990). Some of the earliest papers addressing recursive abilities in animals are actually not studies meant to address the idea of recursion, but studies meant to address the idea of memory (Menzel, 1973; Tinklepaugh, 1932). These studies both used experimental procedures that required chimps to remember the location of food (in some cases over an extended amount of time), and only noted tangentially (if at all) that the chimps used recursive methods to locate and collect their meals. Lastly, studies have shown that the predictive abilities of high dimensional models can be demonstrated using sensorimotor features as input (Howell, Jankowicz, & Becker, 2005), a remarkable way of elucidating the contextual nature of words, that additionally ties full circle to observations of manual recursion in animals (Byrne, Corp, & Byrne, 2001).

Approaches to the Study of Language in Animals

Reznikova (2007) lays out the three basic methodologies that have been used to study language and communication in animals – attempts at direct translation of vocalizations, attempts to teach language to animals, and attempts to quantify characteristics of communication via information theory. The research presented here covers each of these areas, although it is unified by an overarching theme of computational linguistic modeling, which finds its greatest parallels in information theory. Because of the broad and interdisciplinary nature of the approach the present study takes, background from all three perspectives on animal communication research is required.

Direct translation of vocalizations

Reznikova (2007) insightfully points out that researchers have only fully succeeded in decoding two non-human communication systems – the dance of honeybees (von Frisch, 1967) and various types of danger signaling in communally living species such as monkeys and prairie dogs (C.S. Evans & Marler, 1991; Manser, 2001; Seyfarth, Cheney, & Marler, 1980; Slobodchikoff, Kiriazis, Fischer, & Creef, 1991; Zuberbuhler, 2003).

However, researchers have successfully decoded some very important aspects of many animal communication systems. Two abilities – referential communication and combinatorial semantics – are particularly indicative of higher cognitive abilities.

Referential knowledge is the understanding that a signal, which is essentially not a tangible thing, corresponds directly to something that is tangible (for example, an object). While alarm calling is widespread in the animal kingdom (Arnold & Zuberbuhler, 2006a; Griffin, Savani, Hausmanis, &

Lefebvre, 2005; Hollen & Manser, 2006; Hollén & Radford, 2009; Randall, McCowan, Collins, Hooper, & Rogovin, 2005; Randler, 2006; Rendall, et al., 2009; Scott-Phillips, 2010; Seyfarth, et al., 1980; Soltis, 2009; Zuberbühler, Marc, Klaus, Nicola, & Vincent, 2009), semantic referential abilities were first found in Diana monkeys (*Cercopithecus diana diana*). One of the initial experiments involved the desensitization of these monkeys to alarm calls; in this particular species, male and female monkeys possess different alarm calls, and female alarm calls can be elicited by either the vocalization of a predator (eagle or leopard) or the male's alarm call. Desensitization of females to one of these signals (for example, the male eagle alarm call), also caused desensitization to the eagle vocalization itself. This finding provides evidence to support the idea that the female monkeys, upon hearing the male eagle alarm call, form a mental representation of an eagle, that they can then transfer and apply to the eagle vocalization (Zuberbuhler et al., 1999). This ability to form mental representations was later confirmed to be true in the case of visual stimuli as well (Arnold, Pohlner, & Zuberbühler, 2008). Referential calling with regard to the existence of a food source has been more enigmatic; it has only been shown conclusively (i.e., by the actual initiation of feeding behavior) in two species – the marmoset (*Callithrix geofffroyi*) and the chicken (C. S. Evans & Evans, 1999; Kitzmann & Caine, 2009). Conceptually, the idea of referential abilities in animal species is perhaps even more beneficial than it might seem at first glance. Landauer and Dumais (1997) postulate that it is possible to learn a considerable amount of language using induction - without explicit feedback. It seems that it would be extremely beneficial for the survival of any one individual monkey to recognize, for example, that a tiger is dangerous from only having experienced first hand the danger of a lion.

The ability to combine calls has also been observed in several species. Putty nosed monkeys (*Ceropithecus nictitans*) have two call types; however, they are able to arrange these calls into syntactically different combinations that, in turn, represent semantically different meanings (Arnold & Zuberbuhler, 2006b). A similar system has been found in two species of black and white colobus monkeys (*Colobus spp.*; Schel, Tranquilli, & Zuberbühler, 2009). Extending the parallel to humans even further, Campbell's monkeys (*Cercopithecus campelli campbelli*), have a communication system that involves (a) acoustic sounds serving as roots to a vocalization (akin to the "stem" in human language), and (b) sounds that can be alternatively fixed onto these stems – as with a human language morpheme (Ouattara, Lemasson, & Zuberbuehler, 2009). A system such as this is reminiscent of the recursive system held by some to be unique to humans. Lastly, white faced capuchin monkeys may encode their identity into food calls, allowing for others to make judgments on the benefit of attempting to join in a particular meal (Gros-Louis, 2008); this process combines both referential and cognitive abilities.

Teaching Language to Animals

The idea that we can teach our language to animals stems from research that has indicated that particular species possess higher cognitive abilities; thus, attempts to teach them should not be futile. Whether by cause or by effect, this means that much experimental research in this area is done with species such as primates to that humans "relate," and the most well-known experiments in animal communication are by far ones that attempted to communicate with animals via teaching them artificial language. Several of these programs have been highly successful (although at times controversial) – for example, Kanzi the bonobo (Savage-Rumbaugh & Lewin, 1994), Alex the African gray parrot (Pepperberg, 1999), and the dolphins of Kewalo Basin (Herman et al., 1984), all who have mastered the basics of human languages either in the form of actual words or symbols/gestures.

Evidence for the kind of cognitive complexity that would allow animals to learn human languages can be found in the theory of mind research (Forrester, 2008; Stuss, Gallup, & Alexander, 2001). Theory of mind, thought by some not to exist in non-human animals, is "thinking about thinking," or the awareness that a conspecific can know something about the knowledge of another conspecific. Tests of this ability have shown that primates have knowledge of both the amount of information a conspecific has, and the purpose of another's behavior (Hare, Call, Agnetta, & Tomasello, 2000; Hare, Call, & Tomasello, 2001). For example, subordinate chimpanzees will only move to obtain food when competing with an uninformed or misinformed dominant, or when the informed dominant has been replaced by a naïve animal (Hare, et al., 2000). Additionally, several species of non-human animals – bonobos, chimpanzees, elephants, dolphins, orangutans, and possibly gorillas – have passed the "mirror self recognition" (MSR) test (Inoue-

Nakamura, 1997; McCowan & Reiss, 2001; Patterson & Cohn, 1994; Plotnik, de Waal, & Reiss, 2006; Povinelli, et al., 1997; Stuss, et al., 2001; Westergaard & Hyatt, 1994). MSR involves understanding that a mirror reflection is specifically a reflection of the individual, and is thus used as an indicator of self-awareness (Gallup, 1970). The animals credited with this ability have all been (in most cases, quite obviously) observed engaging in self-directed behaviors while looking in a mirror.

Quantifying communication using information theory

A variety of techniques rooted in information theory (the quantification of information; Shannon, 1948) and other mathematical concepts (such as entropies, neural networks, and statistical regularities) have been shown to provide much insight into animal communication. In fact, experimental procedures as early as the 1970s attempted to understand how animals communicated via information theory (e.g., Menzel, 1973). These procedures assigned tasks or provided information to one member of a population; in order to complete the task or obtain a reward, it was necessary for the knowledgeable individual to pass this information on to others in the population. This technique has even been used to measure information transfer in ants. One elegant experiment showed the transfer of bits of information (turns in a maze along a path to get food, where one turn was equal to one bit of information), from scout ants to worker ants, to be reliable in the actual finding of the food by the workers (Reznikova, 2007).

Additionally, computer modeling has come to the forefront of research, with recent efforts to quantitatively detect, segment, and classify vocalizations in species including bottlenose dolphins (Buck & Tyack, 1993; Janik, 1999; McCowan, 1995), killer whales (*Orcinus orca*; Brown, Hodgins-Davis, & Miller, 2006; Deecke, Ford, & Spong, 1999), humpback whales (*Megaptera novaeangliae*; Suzuki, Buck, & Tyack, 2006), bats (*Microchiroptera spp*.; Skowronski & Harris, 2006), prairie dogs (*Cynomys gunnisoni;* Placer, Slobodchikoff, Burns, Placer, & Middleton, 2006), beaked whales (*Mesoplodon spp.*; Mellinger, 2008), and songbirds (Siegal & Varley, 2006).

The Role of Animal Models in Examining the Evolution of Language

Despite the fallacy that humans "evolved from" animals, there is merit in an evolutionarily comparative approach to the study of language – particularly one with a neuroscience perspective (Kuczaj & Kirkpatrick, 1993). The comparative approach gives, among other things, insight into the evolutionary pressures that have shaped our own cognitive processes.

It is well known that the human brain is lateralized for certain tasks. Some hypothesize that this lateralization evolved because the ability to process two "tasks" at once was extremely advantageous. For example, normal chicks are able to use their one eye in a foraging task, while simultaneously using their other eye to monitor their surroundings for predators (Hunsaker, Rogers, & Kesner, 2007). Chicks whose lateralization is disrupted during development by incubation in the dark are unable to carry out these tasks simultaneously (Hunsaker et al., 2007).

Studies have also shown that the asymmetry for language possessed by humans may also be present in other primates. Positron Emission Tomography (PET) has shown activity in the areas of the brain associated with conceptual representation and recognition of conspecifics in humans to also be present in the brains of awake rhesus macaques when they hear vocalizations from other macaques (Gil-Da-Costa, et al., 2004). This hemispheric asymmetry is also present in another species, the vervet monkey (*Cercopithecus aethiops*); however, the advantage is in the opposite hemisphere (left ear/right hemisphere, as opposed to right ear/left hemisphere). This finding supports the idea that asymmetry may have been advantageous for survival, adaptation, and evolution; however, the "details," for example, the particular side which houses the asymmetry, may be less important (Gil-Da-Costa & Hauser, 2006).

The mirror system hypothesis (Rizzolatti & Arbib, 1998) states that spoken language evolved from gesture (Arbib, 2005). Much of this theory is based on the primate homolog to Broca's area in humans, the F5 region. In this region are found mirror neurons, that are activated both when executing a movement and seeing another execute the same movement (Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). As these are motor neurons, in a scenario such as this, the most likely precursor to the language area in the human brain would have been responsible for motor control. More recently, a similar class of neurons has been identified in birds that is activated both during singing and during audition, particularly when note sequences are within (or similar to) a songbird's repertoire (Prather, Peters, Nowicki, & Mooney, 2008).

Regardless of the developmental path, vocalizations of both humans and animals may respond to environmental pressures in a similar manner. The alarm calling behavior in Campbell's monkeys, discussed above, is established to be acoustically variant and semantically combinable across situations; in addition, it appears to respond to the direct needs of a particular population. When free living monkeys are compared to ones in captivity, the same rapidly rising, pulsed, call elements are used by both populations to create different alarm calls. Whereas free living individuals used these call elements to produce multiple, predator-specific alarm calls, captive individuals did not. The captive monkeys studied possessed one call, composed of these same acoustic elements - an alarm call for humans (Ouattara, Zuberbühler, N'Goran, Gombert, & Lemasson, 2009). While this discovery is, of course, additional evidence for referential signaling in this species, it also shows developmental plasticity of acoustic communication signals, a characteristic much studied in humans. It appears that despite different branches from our common ancestor, the ability to adapt acoustics to what is needed in a particular situation or lifestyle has been conserved in monkeys.

Finally, the FOXP2 gene was first identified in a family with a severe speech disorder and is often referred to as the "language gene," due to its suspected crucial role in the normal development of language (Lai, Fisher, Hurst, Vargha-Khadem, & Monaco, 2001). FOXP2 is present both in animals that vocalize and those that do not, and is also involved in motor coordination (including the muscles in the face responsible for vocal communication). Recent work on similarities between human and chimpanzee FOXP2 shows a difference in expression and regulation of several target genes (Konopka, et al., 2009). This work shows separate but parallel path for the development of FOXP2 and its targets; and in combination with information about language differences between humans and chimpanzees, will help in the exploration of congenital language deficits.

Implications for the Study of Human Language, Cognition, and Evolution

A similarity or consistency of language between humans and non-human animals would have many implications for evolutionary theory. The ability to compare languages across species would (a) allow the examination of cognitive and mechanical traits in language that are conserved across homologous species (such as humans and non-human primates) (Fitch, 2005; Zuberbuhler, 2005), and (b) permit testing of ideas that our linguistic abilities are modifications of a shared homologous trait, as opposed to novel occurrences (Lloyd, 2004). Perhaps more interesting, because of the lack of a common ancestor, is that linguistic similarities between humans and non-primates would indicate analogous situations in that language evolved in multiple phylogenetic lines (Fitch, 2005). From this we could hypothesize situations for which the trait of language ability would be selected. For example, a finding that marine mammals use semantics and a syntactic structure in their communications would provide evidence that at some point in the evolution of both humans and marine mammals, the environment supported the development of complex communication. It might then be possible to compare the evolutionary history of both species to determine what these conditions were and the mechanisms by which language developed. This comparison would speak to the importance of communication as a survival tactic, just as the analogous evolution of flight in birds, insects, and bats (mammals) speaks to the advantage of the development of flight. This is one of the strongest arguments for communication research involving species such as marine mammals, which is currently less abundant than that which deals with primates.

Language (or language-like) abilities in non-human animal species would, perhaps retrospectively, provide evidence for advanced cognitive mechanisms in these species. Researchers have provided evidence for hemispheric lateralization in animals with respect to several different cognitive abilities – a situation analogous to that of the human brain (for more information, see Kilian, Fersen, & Gunturkun, 2005; Ridgway, 2002; von Fersen, Schall, & Gunturkun, 2000; Yaman, Fersen, Denhardt, & Gunturkun, 2003), that in turn may be evidence indicative of complex cognition and development because of the increased substrate available for functional use. Investigations into the lateralization of communication in marine mammals would also be intriguing in light of Ridgway's (2002) evidence for the existence of unihemispheric sleep in dolphins, for which the implications for communication have not yet been examined. For example, if aspects of dolphin brain function are strictly lateralized, does one hemisphere compensate for the processes that would normally be occurring in the "sleeping" hemisphere? If so, how is this done and can this compensation be induced in impaired humans? These possibilities further indicate the necessity for evolution of advanced anatomical and physiological features to support complexity in animal brains; it is very likely that this cognitive complexity could provide the framework for language (perhaps as an evolutionary spandrel, as per Gould and Lewontin, 1979), or, at the very least, an increased propensity for language development. As pointed out by Lloyd (2004), "none of the capacities that Kanzi [the bonobo used in many of Savage-Rumbaugh's experiments] used to perform these linguistic abilities was designed by natural selection for such tasks; rather, that was just a feature of Kanzi's brain, which could, under this extremely special environment [the research lab], learn to do those things" (pg. 583). Lloyd further alludes to themes common with the current "evo-devo" trend in ecology. Like pluripotent cells, cognitive brain tissue may have the theoretical capacity to develop to any level of ability; constrained only by the environment or rules surrounding it (Laundauer and Dumais, 1997, also speak of the constraints of rules on language development, that they appear to view as dangerously close to quashing the wide open semantic spaces of the mind). This evo-devo-esque spin on the development of language also may open the door a little wider for the idea that language has its roots in cognitive tasks like tool making or manual tasks like gesture (Lloyd, 2004).

The role of high dimensional models

High-dimensional memory models such as Hyperspace Analog to Language (HAL) and Latent Semantic Analysis (LSA) offer a neurally plausible architecture that can scale up to large computations as found in the brain (Landauer, Foltz, & Laham, 1998; Lund & Burgess, 1996). For example, semantic priming, which deals with the advantage a word has for retrieval if it is preceded by a related word (e.g., *cat* primes *dog*) may be largely due to how often words co-occur (Plaut, 1995); furthermore, semantic distances such as those measured by these models are very accurate indicators of retrieval time (Burgess, 1998; Lund & Burgess, 1996). It follows from this logic that global co-occurrence information better represents human learning and the semantic continuum than local co-occurrence or simple frequency measures. Indeed, others have argued that HAL is a very promising new alternative to traditional models of semantics (Henry & Lucas, 2008; Hutchison, 2003). As the HAL model introduces a certain flexibility to language analysis, it seems appropriate that the approach should be applied to an area where flexible techniques and innovative thinking are vital.

Goals of this study

This set of three experiments was aimed at comparing syntax and structure in the vocalizations of three very different species – a bird, a sea mammal, and a land mammal. The perspective used is a very global one; instead of examining specific conditional probabilities, the HAL model examines language from a contextual perspective, which has not been attempted before and which may be necessary to hundreds of constraints involved in any sort of higher order language (Landauer and Dumais, 1997). This perspective may be able to provide new insights because the species compared have very different communication systems on the level of individual vocalizations; however, a broader analysis may reveal contextual similarities in communication. It is my hypothesis that each of these species will show signs of structure in their communication systems, and, further, that these structures can be characterized by contextual co-occurrences.

METHODS

Systems for Animal Communication Research

The research discussed here involves three types of animals – an African gray parrot (*Psittacus Erithacus*), humpback whales (*Megaptera novaeangliae*), and white mice (*Mus musculus*).

Research conducted with Cosmo, the African gray parrot, was done with several goals: (a) to determine whether Cosmo learned individual words or entire phrases, (b) to discover if there were changes in Cosmo's speech patterns/behavior when her owner, Betty Jean, was not present, and (c) to find out if Cosmo used a global syntax in her language. The first and third investigations are intimately linked. If

Cosmo learned individual words one at a time, then she would have to put them together to form the phrases in her repertoire – some of which were four to five words long. This would mean that Cosmo has a very workable pattern of global co-occurrence in her speech. A simple phrase such as “Cosmo wanna talk,” could be permuted to “Cosmo wanna whistle,” “Betty Jean wanna talk,” “Cosmo wanna shower” and so forth. The Cosmo/Betty Jean and talk/whistle/shower sets are part of the global groups “names of people who live in the house” and “things Cosmo and Betty Jean do,” respectively. Conversely, if Cosmo learned her repertoire as phrases, her repertoire would be less flexible on the word level, although one might find global co-occurrence in phrases such as “where are you,” “I’m here,” “there you are,” and “come here” (contact calls). Lastly, a combination of the two might be possible, in which Cosmo used standard phrases and consistently altered only one word, for example, “that’s birdie,” “that’s squirrel,” and “that’s doggie”.

Many of the reasons for using marine mammals as a system to study animal communication and cognition have been detailed above. Bottlenose dolphins are naturally the most often used species for marine mammal research due to the relative ease of keeping them in captivity. Herman and colleagues, working with bottlenose dolphins, have examined the word order and syntactic abilities characteristic of simple human language, and have shown that dolphins understand that changes in these represent changes in meaning (Herman et al., 1984; Richards, Wolz, & Herman, 1984). The subjects in these studies were trained in either acoustic or gestural language, and showed comprehension of sentences with a variety of novel structural and syntactic features; these include word order changes, sentence reversals, and combinations of sentences (Herman, et al., 1984; Richards, et al., 1984). Field studies have shown vocal dialects in several species of large whales - sperm whales (*Physeter macrocephalus*), killer whales, and humpback whales in particular-- and longitudinal studies have further shown changes in these dialects over time and social groupings (Darling & Sousa-Lima, 2005; Deecke, Ford, & Spong, 2000; Eriksen, Miller, Tougaard, & Helweg, 2005; Rendell & Whitehead, 2003; Rendell & Whitehead, 2005). The research here seeks to add to the existing body of literature by integrating approaches that have been productive with human language investigations. Focusing on humpback whales takes advantage of the fact that vocalizations (songs) have already been shown to have a hierarchical nature (Payne & McVay, 1971), in addition to the potential for geographic dialects. Goals for this portion of the study include a comparison of song units (and their co-occurrences) across three geographical locations and a search for patterns that might indicate syntax or structure.

Lastly, the examination of ultra-sonic songs of male mice is an opportunity to take advantage of a relatively new direction of research. Only recently has it been found that male mice “sing” ultrasonic courtship songs (Holy & Guo, 2005). Additionally, these songs appear to change with genetically abnormal mice. Studies are already investigating the usefulness of these discoveries for behavioral phenotyping of mouse models (Scattoni, Crawley, & Ricceri, 2009). The mouse model used, *Fmr1* (The Dutch-Belgian Fragile X Consortium, 1994), is used as a model for Fragile X Syndrome. Because there are language deficits in Fragile X Syndrome, the language deficits in the mice are of extreme interest. For example, discovering an inability in the genetically altered mice to correctly produce calls may not indicate an intellectual deficit; however, discovering an inability to create phrases through the combination of lexical items might.

HAL Methodology

The Hyperspace Analog to Language (HAL) model is a high-dimensional model that provides a method for the contextual analysis of language (Burgess, 1998; Lund & Burgess, 1996). HAL uses word order in language to compute co-occurrence values between words in a particular body of text (a *corpus*). The input to the model is a series of segmented words.

Before discussing the co-occurrence methodology, it is important to consider the overall plausibility of the input for such a model. The HAL model works because it is provided with a segmented stream of words, much like what infants hear during language development. Previous experiments have demonstrated that infants heavily rely on statistical co-occurrence information at the phonetic level in learning word segmentation (Aslin, Saffran, & Newport, 1999; Estes, Evans, Alibali, & Saffran, 2007; Saffran, et al., 2008). Furthermore, it has been demonstrated that the segmentation information in the speech stream can be modeled; a simple recurrent network (SRN) can utilize this phonetic information to discover word boundaries (Cairns, Shillcock, Chater, & Levy, 1997; Christenson, Allen, & Seidenberg, 1998). Experiments comparing results from a SRN and HAL show that both models, when provided with the same input, produce virtually identical results (Burgess & Lund, 2000). Thus, it would appear vital that the input to HAL be in the form of segmented communication as well. The species discussed herein all have vocal repertoires in which semantic units are distinct from each other.

However, before being encoded by the HAL model, some of the vocalizations discussed here must be translated from acoustic data, segmented (in their electronic format), and, most importantly, classified. The most accurate method for doing this has been the topic of much research and debate (Clemins, Johnson, Leong, & Savage, 2005; Janik, 1999; Melendez, Jones, & Feng, 2006; Murray, Mercado, & Roitblat, 1998; Rickwood & Taylor, 2008; van der Schaar, Delory, Catala, & Andre, 2007), although the current favored techniques are segmentation by humans or by some variation on a self-learning neural network such as a Self Organizing Map (SOM).

In addition, none of the models currently in the literature are based on a global co-occurrence theory. HAL is a different kind of memory and language model, which, by using a global co-occurrence algorithm, is able to identify the similarities of a particular word's contextual uses across a large body of text (such as a language). For example, the words *cat* and *dog* often appear in the same sentence in human language (*I have a cat and a dog*). This is a local co-occurrence. However, *cat* and *dog* can also show a global co-occurrence pattern (*I have a cat that I'm in charge of feeding. She has a dog that she's in charge of feeding*). In global co-occurrence, *cat* and *dog* occur in the same context – in both sentences they are "the things that can be had and must be fed". This also makes them essentially (grammatically) substitutable. A traditional, local co-occurrence model would still identify *cat* and *dog* as being related , but would do so based only on the sentence *I have a cat and a dog.* In a more distinct example, the words *street* and *road* rarely occur in the same sentence, but are used in virtually the same contexts (*Make a left on that street. Make a left on that road*). The contextual similarity of the words *street* and *road* is reflective of their global co-occurrence, that would not be identified by a simple local co-occurrence procedure. While much valuable information can be obtained from both local co-occurrence models and conditional probabilities, they do not capture higher-order contextual relationships because they do not encode words in this broader, contextual, sense (Burgess, 1998; Lund & Burgess, 1996).

Global co-occurrence values in the HAL model are computed by use of a sliding window (typically ten words long for human language corpuses), that assigns a co-occurrence value to each pair of words in the window based on the number of intervening words. A matrix is created by encoding these values (see Figure 1a for an example matrix). Co-occurrences between a particular word and those that precede it are encoded in rows, while those that follow it are encoded in the columns of the matrix.

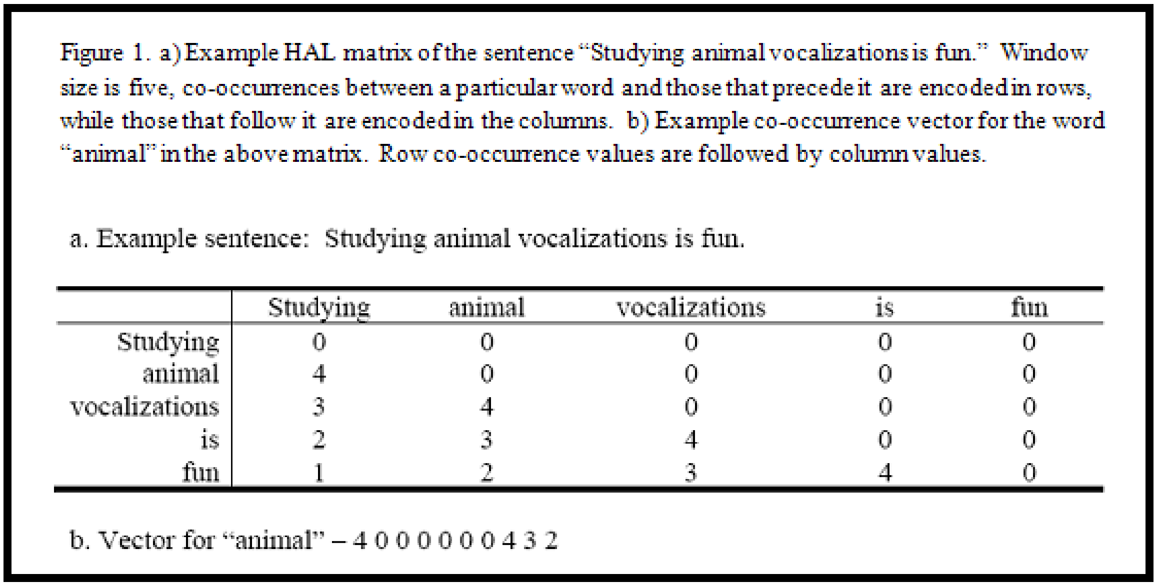


Figure 1. a) Example HAL matrix of the sentence "Studying animal vocalizations is fun." Window size is five, co-occurrences between a particular word and those that precede it are encoded in rows, while those that follow it are encoded in the columns. b) Example co-occurrence vector for the word "animal" in the above matrix. Row co-occurrence values are followed by column values.

a. Example sentence: Studying animal vocalizations is fun.

	Studying	animal	vocalizations	is	fun
Studying	0	0	0	0	0
animal	4	0	0	0	0
vocalizations	3	4	0	0	0
is	2	3	4	0	0
fun	1	2	3	4	0

b. Vector for "animal" – 4 0 0 0 0 0 0 4 3 2

By including co-occurrence values for words that occur both before and after a target word, the model provides a contextual perspective beyond conditional probabilities or measures of entropy that only encode co-occurrences in one direction. Once a matrix is formed, each word can be represented by a vector comprised of its row co-occurrence values and its column co-occurrence values (see Figure 1b). Theses vectors can be visualized and grouped by using either multi-dimensional scaling or hierarchical cluster analysis. The placement of words in these visualizations is a function of the similarity of their contextually driven vectors (see Figure 2), and words that are used in similar contexts will cluster in the visual output. A schematic of the entire process can be found in Figure 3.

Figure 2. Placement of words in a visualization of HAL vectors. From Lund and Burgess, 1996.

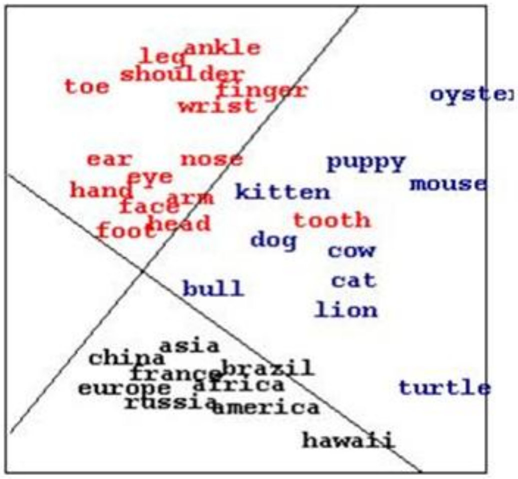
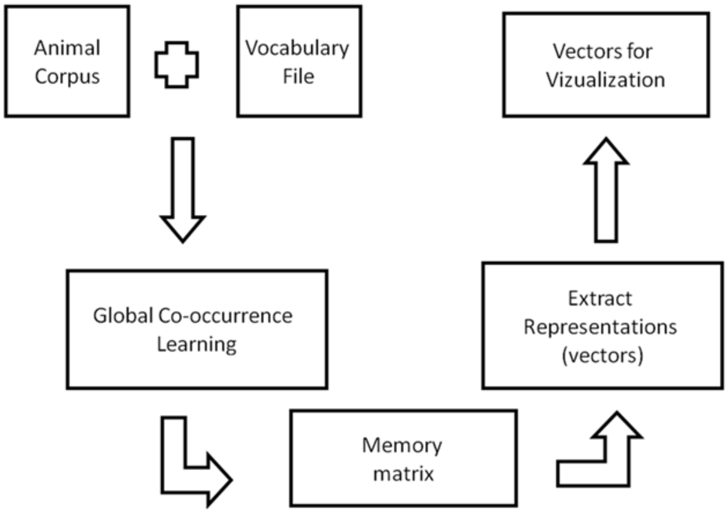


Figure 3. Flow chart of process to create a matrix and vectors



In the analyses presented here, Ward's (1963) method of hierarchical cluster analysis was deemed most useful in visualization of clusters. Ward's analysis is unique from other methods of cluster analysis in that the clusters it creates are based on attempts to minimize the error sum of squares between the two groups (Aldenderfer & Blashfield, 1984; Ward, 1963). This approach is particularly useful in visualization of a HAL analysis because the reduction to two dimensions naturally causes information loss, and, although the loss is much less than one might expect (Burgess, 1998; Lund & Burgess, 1996), Ward's method provides an ANOVA-like reliability for the clusters in high-dimensional space. One of the major disadvantages with using Ward's method is that it tends to give solutions with many small, distinct clusters (Aldenderfer & Blashfield, 1984). The analyses performed here were not troubled by this, which may provide additional support for the robustness of the data.

HAL parameters

When creating a HAL matrix and the resultant vectors, there are several options or parameters that can be set. The three options relevant to the experiments here are "window size," "cut," and "limit."

Window size controls the number of words[3] on either side of the target word that are used calculate the actual encoding of the word into the memory matrix . It is a measure of the length of the sliding window. The default window size (and size that has been found to be most appropriate for use with human language) is 10. Smaller corpuses and/or corpuses in which less sophisticated co-occurrence is expected warrant smaller window sizes (Burgess, 1998; Lund & Burgess, 1996).

The cut function removes all words in a corpus that occur with a frequency at or below a certain level (for example, a cut at 3 removes all words that occur only once, twice, or three times in the corpus). This allows for the removal of words for which there are not enough occurrences to create fully coherent representations. By varying where the cut is with the size of the corpus, it is possible to normalize the corpuses by forcing HAL to focus only on the, say, top 75% most frequent words, regardless if one corpus has 10,000 words and is cut at 30 and another has 1,000 words and is cut at 2 (these numbers are were chosen at random for the sake of the example and should not be construed as mathematically sound).

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[3] When working with human language, characters such as punctuation and numbers are included in the window as well; however, this is less of an issue with the animal corpuses

Limits serve to equalize frequency from the top down – in many corpuses (human or otherwise) a small set of words are a lot more frequent than others. The limit parameter tells HAL to “look” only at the first X number of instances of each word when calculating its co-occurrence, thereby controlling for a frequency effect (Burgess, 1998; Lund & Burgess, 1996).

Knowing when it’s “The” Answer

One of the most frustrating parts of the experiments described here is the lack of confirmation of results. Beyond playback studies, which are beyond the scope of this project, it is hard to know for certain if a conclusion is correct, almost correct, on the right track, or not even in the same ballpark. The decisions made throughout with regard to model parameters and corpus selections are based on extensive reading of the literature, discussions with individuals who work directly with animals and computational models, and an extensive process of testing of model parameters. The assumption was made that, like all systems, the communication systems of the species in question move toward stability and regularity; thus, the less entropic a solution was, the more plausible it might be as an actual solution. This assumption has been used in other information theory experiments (Ferrer i Cancho, Riordan, & Bollobas, 2005; Ferrer i Cancho & Sole, 2003; McCowan, Doyle, Jenkins, & Hanser, 2005; Suzuki, et al., 2006). However, it should also be noted that the present experiments were conducted with the full appreciation that important characteristics of the communication systems could easily be overlooked or even be completely imperceptible to humans.

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CHAPTER 2: COSMO

INTRODUCTION

Past research on the intelligence of psittacines has been limited almost entirely to that of Irene Pepperberg and her African gray parrot, Alex. Pepperberg's work has often been criticized for drawing conclusions based on only one subject. However, Lloyd (2004) makes an excellent point that if even one member of a species is capable of a particular task, it must be assumed that the species is capable of the said task (i.e. possesses the appropriate neural/physiological/cognitive structures), regardless if individual members have developed these capabilities into useful (or even demonstrable) skills. The type of study employed by Pepperberg is an experimental paradigm called a power study, in which a single subject is used to prove that something is possible in a particular species. A power study is specifically not for purposes of comparison of abilities, it merely determines the existence of said abilities. In addition, a negative result of a power study does not preclude the ability in other members of the species (and thus the theoretically ability in all members) (Triana & Pasnak, 1981). Say Triana and Pasnak,

> "A power study, because it depends on the behavior of one or a few individuals to provide evidence for the existence of a given conceptual ability, does not permit inter- or intraspecies comparisons. Yet, tabulating or statistically comparing the relative success and failures of multiindividual samples of animals would not identify the intellectual *capacity* of a species satisfactorily and, in fact, is often quite misleading. If one individual can consistently and reliably demonstrate a given level of concept attainment, the performance is proof that this level is within the capacity of the species. Many failures by other individuals cannot invalidate this conclusion; they may identify the typical *performance* of a species, but not the conceptual *ability* of the species" (1981, pp. 135-136)

Pepperberg trains her parrots using a model/rival method – two lab assistants model a training session – asking and answering questions and modeling both correct and incorrect responses and their outcomes (Todt, 1975). Subsequently, the model or rival changes positions with the parrot, allowing every participant to play every role (Pepperberg, 1999). This is an interesting parallel to how a parrot might learn speech in a home on a day to day basis; by observing conversations (and outcomes thereof) and, when vocabulary is sufficiently developed, actively participating in them. Pepperberg's experiments have shown that live tutors are necessary for learning referential English labels – parrots do not learn from videotapes, even when their attention is directed by human tutors and/or rewards are provided (Pepperberg, 1994; Pepperberg, Gardiner, & Luttrell, 1999; Pepperberg & McLaughlin, 1996).

After initially learning labels, Alex was taught the word "want" so that he might differentiate between naming and requesting. He easily generalized this to novel objects with no decrease in accuracy of the labels he had previously learned (Pepperberg, 1988). In fact, generalization of learned concepts has also been shown in blue-fronted parrots (*Amazona aestiva*), who demonstrated this ability in a task similar to one completed by cotton top tamarins (*Saguinus Oedipus*; de Mendonca-Furtado & Ottoni, 2008; Ghazanfar & Hauser, 1999). It has also been shown that parrots have a basic understanding of classes, and can understand when an object is a member of two different classes (i.e. "blue" and "round" as part of the classes "color" and "shape"). This particular type of learning is difficult for children, and young children often have much harder time learning the second label for an object than the first (Liittschwager & Markman, 1994). Parrots must be specifically taught to use color and label as a pair (Pepperberg & Wilcox, 2000), but are consequently able to answer questions directed at one of the two object classes (Pepperberg, 1983); Landauer and Dumais (1997) note that this difficulty with double labeling may be unique to humans – a result of overly specific constraints on language that in turn may cause children to make overly conservative assumptions about language and labeling.

There are other parallels to human language that can be found in Pepperberg's research. Alex has been recorded using spontaneous word play, including recombination of sounds and monologues (Pepperberg, Brese, & Harris, 1991); this spontaneous word play has been identified in human infants as key to private speech, one of two identified parts of monologue speech (Fusion, 1979). In human children, the meaning of words can be learned in two ways – fast mapping and full mapping. Fast mapping is the idea that children can learn the names of objects - and more importantly, understand that the names are used referentially for said objects – after just one exposure (Carey, 2001). In addition, this exposure to the object can be indirect – for example, an elimination task in which the child knows the names of all objects but one, and therefore can conclude that the novel name belongs to the novel object (Carey, 2001).

This indirect exposure is called emergent mapping (Wilkinson, Dube, & Mcilvane, 1998) and has also been formally identified in marine mammals and dogs (Herman, Richards, & Wolz, 1984; Kaminski, Call, & Fischer, 2004; Kastak & Schusterman, 2002; Schusterman & Krieger, 1984). Dogs have also been shown to learn object names by fast mapping at levels equivalent to three year old children (Kaminski et al., 2004). Schusterman and collegues (1984) were the first to use emergent mapping as a teaching process in non-human animals. After the initial learning of a small set of gestural signs, new "vocabulary" was introduced by pairing known gestures with novel ones. Teaching such as this requires a solid "match to sample" baseline (Wilkinson, et al., 1998). For an animal to identify a novel object by excluding other objects it must first be able to name the familiar objects (matching a known name to the sample object that is presented).

> "New object names were introduced by pairing the novel, and as yet unnamed object with an old, and already named, object. Under these conditions, both sea lions learned to associate or match the unfamiliar gesture with the unfamiliar object quite rapidly. Indeed, depending on the familiar-unfamiliar pairing, the match between a novel gesture and a novel object was frequently immediate as reflected by errorless performance." (Schusterman & Krieger, 1984, p. 13)

Pepperberg (1990) has identified a similar concept in parrots, dubbed referential mapping. Empirical data have also shown Alex understands that labels are built of individual units, which can be recombined to form novel, referential labels (Pepperberg, 2001, 2007). The idea of referential labeling has been demonstrated in other species of parrots as well; for example, it can be seen in the wild in speckled parrotlets (*Forpus conspicillatus*), a species that has referential calls for social companions or family members (Wanker, Sugama, & Prinage, 2005). This ability is closely linked with lexical substitution (Premack, 1976), which has been noted in marine mammals (Herman, et al., 1984; Schusterman & Krieger, 1986), nonhuman primates (Premack, 1976; Rumbaugh & Gill, 1977), and parrots (Pepperberg, 1990), and bears a striking resemblance to the substitutability of words in the HAL model. Further cognitive development leads to lexical creativity, or the combination of multiple words, each learned in independent contexts. When this is done intentionally and spontaneously in humans, it is called "segmentation" (Marler, 1970) or "combinatorial productivity" (Rexstad, et al., 1988).

There is also basic cognition research on psittacines and other birds. Several species of non-human animals – bonobos, chimpanzees, elephants, dolphins, orangutans, and possibly gorillas – have passed the "mirror self recognition" (MSR) test (Gallup, 1970; Inoue-Nakamura, 1997; McCowan & Reiss, 2001; Patterson & Cohn, 1994; Plotnik, de Waal, & Reiss, 2006; Povinelli, et al., 1997; Westergaard & Hyatt, 1994). As mentioned previously, MSR involves the understanding that a mirror reflection is specifically a reflection of the individual, and is thus used as an indicator of self-awareness (Gallup, 1970). These animals have all been observed engaging in self-directed behaviors when looking in a mirror. While parrots have not passed the MSR test, it has been shown that they can use a mirror to locate food that is hidden and cannot be found without the use (and understanding) of a mirror image (Pepperberg, 1995). Additionally, Stage 6 competence, or the ability to understand object permanence (Piaget, 1954), has been shown in psittacines and Eurasian jays (*Garrulus glandarius*) and, based on other studies, most likely exists in magpies (*Pica pica*) as well (Gomez, 2005; Pepperberg & Fink, 1990; Zucca, Milos, & Vallortigara, 2007). This ability is acquired by human infants between the ages of 18 and 24 months (Piaget, 1954).

Recent experiments have also investigated parrot's understanding of human concepts of music. When played music, one African grey was able to transpose notes accurately to an appropriate octave so that they could be sung back to the experimenter; the authors of the study hypothesize that this ability may be due to the variety of noises in a jungle setting and the demand for flexibility in order to be heard in different conditions (Bottoni, Masin, Lenti, Massa, & Massa, 2006; Bottoni, Massa, & Boero, 2003). These same experiments also showed that the parrot was able to insert musically appropriate sequences (i.e., ones in the right key) of its own into the song. In addition to singing, there have been experiments with dancing birds. Patel (2006) theorizes that, due to links between the auditory and motor systems, only animals whose brains are capable of complex vocal learning – such as humans and parrots – are able to learn beat synchronization. Later experimental research based on this hypothesis supports the idea – a sulphur-crested cockatoo (*Cacatua galerita eleanora*) was able to synchronize dancing movements to the beat of music, and was able to alter her beat with changes in the tempo of the song (Patel, Iverson, Bregman, Schultz, & Schultz, 2008). Studies such as these which reveal the abilities of parrots to understand and process music will be integral to studying language from a comparative and evolutionary perspective (Fitch, 2006).

Contact calls, used by birds in the wild to keep in touch with their mates (Cruickshank, Gautier, & Chappius, 1993), are reflected in domesticated parrots and their owners (Colbert-White, 2009). Interestingly, there is a degree of convergence between pairs with respect to contact calls, both before and after pairing. There is evidence that initial pairing is due to preliminary similarity in calls (Moravec, Striedter, & Burley, 2006) – a difficult parallel to make for pair bonds between domestic parrots and humans – however there is also evidence for a great deal of convergence of contact calls after pairing (Moravec et al., 2006; Scarl & Bradbury, 2009). In cases such as this an already designated pair of parrots – or, in the case of this study, a parrot and its owner – will develop a set of common calls that are used to locate each other when out of visual contact (Bergman & Reinisch, 2006). Additionally, there is evidence that pairs possess multiple, acoustically distinct calls (Cortopassi & Bradbury, 2006). As discussed in the results of this paper, the subjects of study do, in fact, possess a number of different contact calls, and they not only occur most often in situations of visual separation, but have high levels of global co-occurrence as well.

Several other species of non-human animals have displayed abilities that may be similar to those domesticated parrots display. For example, Kanzi, a juvenile bonobo, learned language spontaneously as a result of being in the room during his mother's training (Savage-Rumbaugh & Lewin, 1994), just as parrots likely learned much of their language by overhearing conversation (see above discussion of Pepperberg's model-rival method for teaching language). Studies on domestic dogs (*Canis familiaris*) may also prove to be applicable, as they are similar to parrots in that they are domesticated pets. There is evidence that domestic dogs not only match their owner's voice to face, but that they also develop a representation of the owner's face upon hearing his/her voice. In an experimental situation, dogs looked longer at photos of strangers shown to them after hearing their owner's voice than they did photos of the owner, suggesting they were expecting the photo to match the representation they had conjured after hearing the voice (Adachi, Kuwahata, & Fujita, 2007). In a study comparing the ability of wolves and dogs to read human cues to the location of hidden food, puppies raised by (domestic) mothers were more successful at reading cues than wolves raised by humans. The authors of the study speculate that this could be a result of genetic selection in domestic dogs for communication with humans (Hare, Brown, Williamson, & Tomasello, 2002). In addition, a subsequent study showed that dogs living in shelters (i.e. ones which were not pets) are able to understand a very basic pointing task, in which the experimenter held the point position, but not a task in which the experimenter retracted the point, a task that dogs living as pets are able to understand. However, it was subsequently shown that these shelter dogs were able to learn, with additional trials, the more complicated pointing task (Udell, Dorey, & Wynne, 2010). This again supports the hypothesis that interaction with humans may expose cognitive capacity that animals posses, but that they have had no use for in previous circumstances (Lloyd, 2004). It does not seem farfetched to hypothesize that similar skills have developed in parrots, which, like dogs, are domesticated animals which naturally live and feed in groups; and therefore naturally would need to both recognize and read the signals of others in their group.

The emergent perspective on language acquisition posits that language is learned not from an innate set of rules, but from the context and environment that surrounds us daily (Elman, 1991, 1995; O'Grady, 2008; Schoenemann, 1999). A parrot’s ability to learn language provides substantial support for this hypothesis; and if the parrot is in fact learning language (as opposed to mere imitation), then the most logical explanation is that it is doing so via an emergent process. It would be very hard to claim that we, as humans, share an innate grammatical, genetic, language mechanism with parrots. Emergent theory proposes that, instead, language is learned in relation (or by co-occurrence with) the environment; and a parrot’s exposure to language is fairly similar to that of a child’s. Parrot owners often narrate what they are doing for their birds, have short conversations with them, speak on the telephone in their presence, and even use “mother-ese” when addressing them (Kanzi the bonobo also appears to have learned to parse and comprehend human language in this indirect way (Lloyd, 2004)). Language is shaped by the environment, and, a la evolution, similar environments require similar adaptations.

One of the first goals of this study was to determine if a distinction could be made between Cosmo’s use of words and phrases; does Cosmo learn individual words that are substitutable within similar phrases (global co-occurrence), or does Cosmo learn static phrases that must learned for every situation she encounters? For example, has Cosmo learned to say “Cosmo wanna ________,” or must she learn “Cosmo wanna peanut,” “Cosmo wanna grape,” and “Cosmo wanna talk” each as a separate item? The global co-occurrence model being used, HAL, is specifically suited to this question; if the former hypothesis is true, HAL will create a high dimensional cluster of “things Cosmo wants,” such as peanut, grape, and talk. In addition, a secondary goal of this study was to examine if Cosmo uses words that are appropriate to the situation she is in, and to provide support for the conclusions of Colbert-White (2009), who found this to be the case.

METHODS

Subject

This study was based on the vocalizations of a 6 year old African gray parrot by the name of Cosmo. Cosmo is owned by Dr. Betty Jean Craige (henceforth BJ), Professor of Comparative Literature and Director of the Willson Center for Humanities and Arts at the University of Georgia (Craige, 2010). All data were collected between October 2007 and August 2008 in the home of BJ in Athens, Georgia. Data were collected in one hour sessions, and four sessions were combined to create a data set for a particular condition. Extra sessions were recorded so that anomalous sessions (for example, ones in which BJ received a phone call or left the room) could be discarded. For details on the specific equipment and logistics of data collection, see Colbert-White (2009). Transcription of the speech of Cosmo and BJ was conducted by Erin Colbert-White (ECW) of the University of Georgia. The author coded eight minutes of each condition (Alone, In, and Out) to check reliability, which was determined to be $\kappa = .65, .85$, and $.69$, respectively for each condition. As there is currently no standard for measuring inter-rater reliability in animal behavior (Kaufman & Rosenthal, 2009), human standards were used, and by human clinical standards, these indicate good to excellent agreement (Cicchetti & Sparrow, 1981). Data were then error-checked by ECW and files were created containing complete dialogue for each session, only Cosmo’s speech in each session, and only BJ’s speech in each session. Cosmo’s entire repertoire can be found in appendix A, and the frequency counts used in these experiments can be found in appendix D.

Conditions

There were three conditions examined. In, in which BJ was in the same room as Cosmo (and conversed freely and normally); Out (in which BJ was home, but in a different room than Cosmo, and again conversed freely and normally, albeit at a greater distance); and Alone (in which BJ was not at home and Cosmo was by herself, with the exception of two dogs). In the Out condition, BJ did not speak enough in order to build a HAL matrix. Therefore, analyses were done for the following corpuses –

In, both speakers
In, only Cosmo's speech
In, only BJ's speech
Out, both speakers
Out, only Cosmo's speech
Alone, only Cosmo's speech

Cosmo's vocalizations also included a significant number of sounds – bird calls, dog barks, telephone sounds, etc. As a result, corpuses were run with and without Cosmo's sounds (in order to determine if the event sounds were being used to convey meaning). "Phrase" and "word" corpuses were also run. This was an effort to determine whether Cosmo was learning speech as single words, or as phrases ("I love you" vs. "I," "love," and "you")

A variety of permutations of HAL settings were tested (for a discussion of reasons for trying a variety of HAL settings, see the general introduction to this paper). Based on these results, plus particular characteristics of each corpus (for example, length or frequency of individual items), the following parameters for each type of corpus were used –

phrases and sounds – cut 3, limit 10, window size 10
phrases and no sounds – cut 2, limit 10 window size 10
words and sounds – cut 10, limit 30, window size 10
words and no sounds – cut 5, limit 30, window size 10

For a discussion of the "cut," "limit," and "window size" parameters, refer to the general introduction to this paper. The limit parameters are higher on the "words" corpuses because they were significantly longer than the "phrases" corpuses. Window size 10 was chosen as a starting point for all corpuses specifically because it is the default HAL setting and has been shown to be appropriate for human language (Burgess, 1998; Lund & Burgess, 1996), and Cosmo's vocalizations are based on human speech.

Visualization

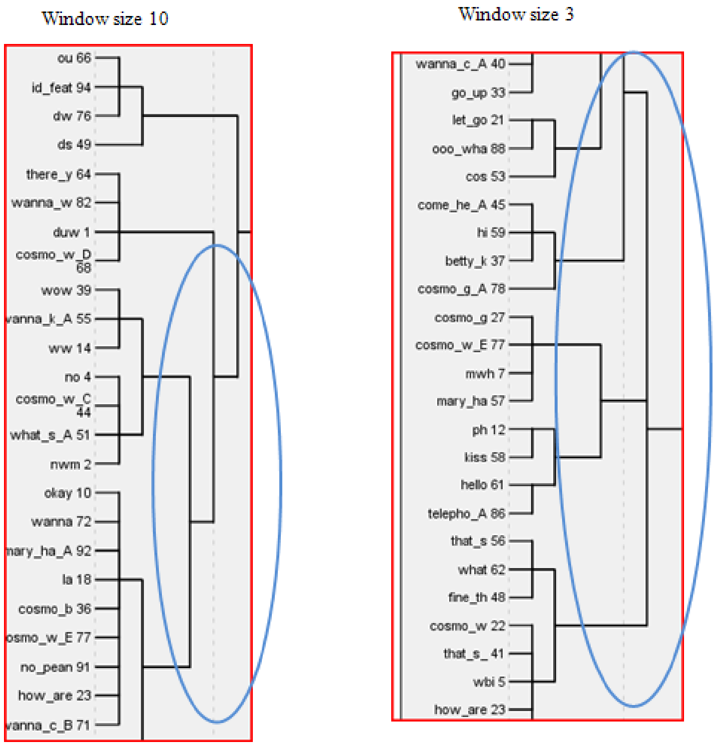
HAL output (vectors) were visualized using Ward's Cluster Analysis (Ward, 1963). Ward's analysis differs from other cluster analysis methods because it is based on joining clusters with the goal of minimizing information loss. This is done by minimizing the error sum of squares. This analysis was chosen because of its similarity to an ANOVA, in addition to the advantage that it provided very distinct clusters with clear cut off points.

Ward's clusters also provide definitive cluster patterns, so determination of where to divide clusters is generally not an issue (Aldenderfer & Blashfield, 1984). For better visualization, clusters were transposed from the cluster analysis dendrogram to an excel spreadsheet. By manipulating the spreadsheet, data could be examined with reference to condition and corpus parameters, and be examined for global and local co-occurrences, and novel grammatical structures and utterances.

Decisions to identify the final corpus

At this point in the analysis it became clear that sounds (notated in capital letters, such as the sound "BARK" as opposed to the word "bark") were an integral part of Cosmo's vocabulary. Sounds did not separate from words, instead they were incorporated into clusters according to subject; for example, phone sounds and phone words were clustered together. As a result, the decision was made to exclude the "no sounds" corpuses.

Figure 4. Comparison of window size 10 and 3 (respectively). Note that window size 10 has a much more "layered" appearance, making splitting the clusters a greater challenge and thus showing a weaker organization.



The Cluster Analyses obtained from this procedure at window size 10 were very tightly layered, which in turn resulted in less distinct clusters (see Figure 4). This seemed to indicate that if Cosmo were using global co-occurrence in her speech, the long distance dependencies between individual words were not as long as with humans. As this made sense, the data were run again, changing the window size parameter to 3. These data showed more independent clusters that were far simpler to distinguish from each other.

It also became clear at this time that the "only Betty Jean" and "both" conditions were less useful than expected. The vocabulary used by both Cosmo and BJ was exactly the same, and as the HAL analysis involves a calculation across all instances in which the word is used, it was not possible for HAL's encoding mechanism to distinguish Cosmo's utterances from BJ's in the "both" condition. The corpus resulting from the "only Betty Jean" condition, originally intended for comparison purposes, was determined to be both unrepresentative of BJ's normal speech (and thus of less use for a comparison), and too small for useful HAL analysis.

After these determinations, the final corpus parameters used for analysis (in both word and phrase form) were Cosmo only, with sounds, cut 3, limit 10, window 3.

Substitution corpus

Later in the experiment, a third type of corpus was developed, called the “substitution corpus.” In this corpus, all phrases that were variations on approximately the same sentiment were replaced by one, common, phrase. For example, “Cosmo’s a good bird,” “Cosmo’s a good, good bird,” and “Cosmo is a good bird” were all represented in the corpus as “Cosmo’s a good bird.” These corpuses were run on the parameters already established for the other corpuses.

RESULTS AND DISCUSSION

Corpus analyses

For the final HAL analysis, three forms of the corpus were used – words, phrases, and substitutions. For examples of cluster analysis results, see Figure 5.

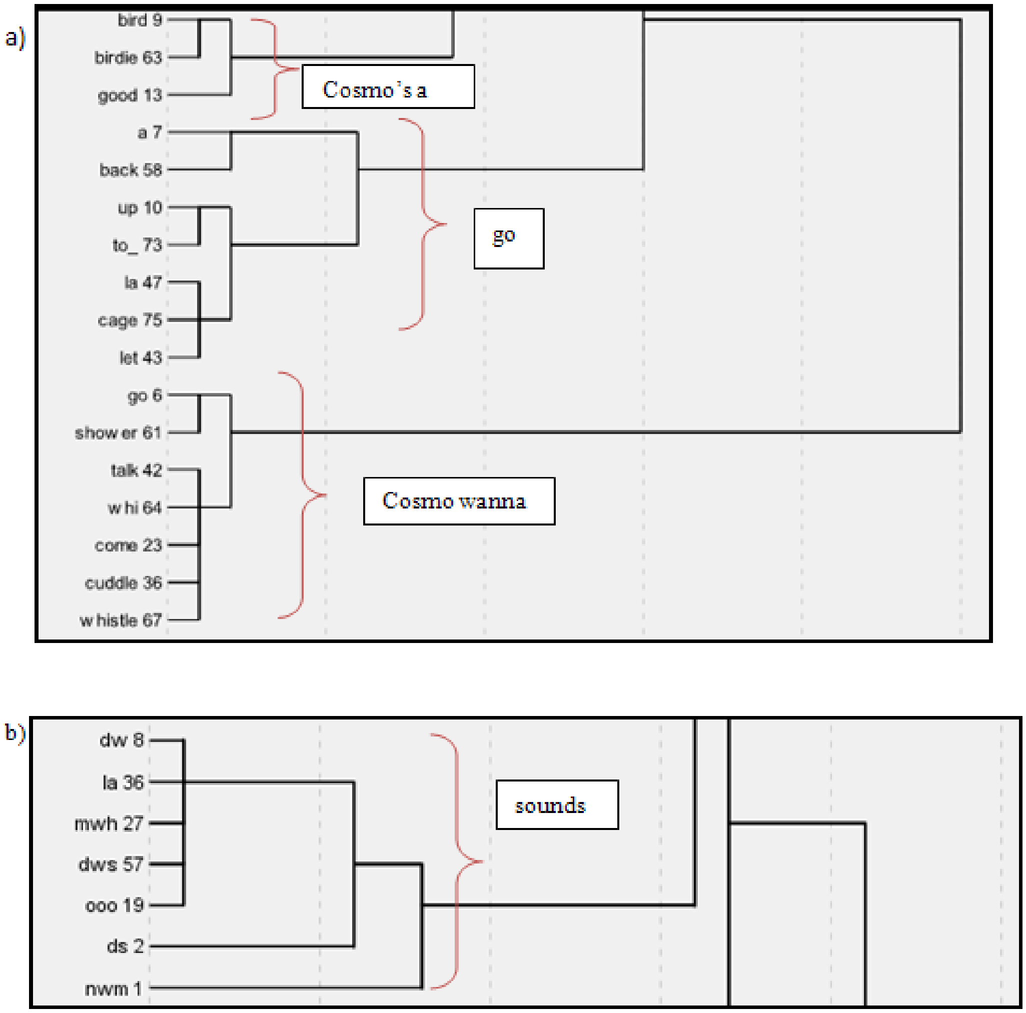
General trends

In general, as the input to HAL lengthened, i.e. moved from word to phrase, clusters became more general. When input was on the word level, HAL clusters showed specific use of global co-occurrence and within-sentence context. At a phrase level, clusters appeared to be “topical” – dealing with, for example, phone related contexts. At the substitution level, which essentially collapsed the members of each of these topical clusters into one representative phrase, there was much less organization to be seen.

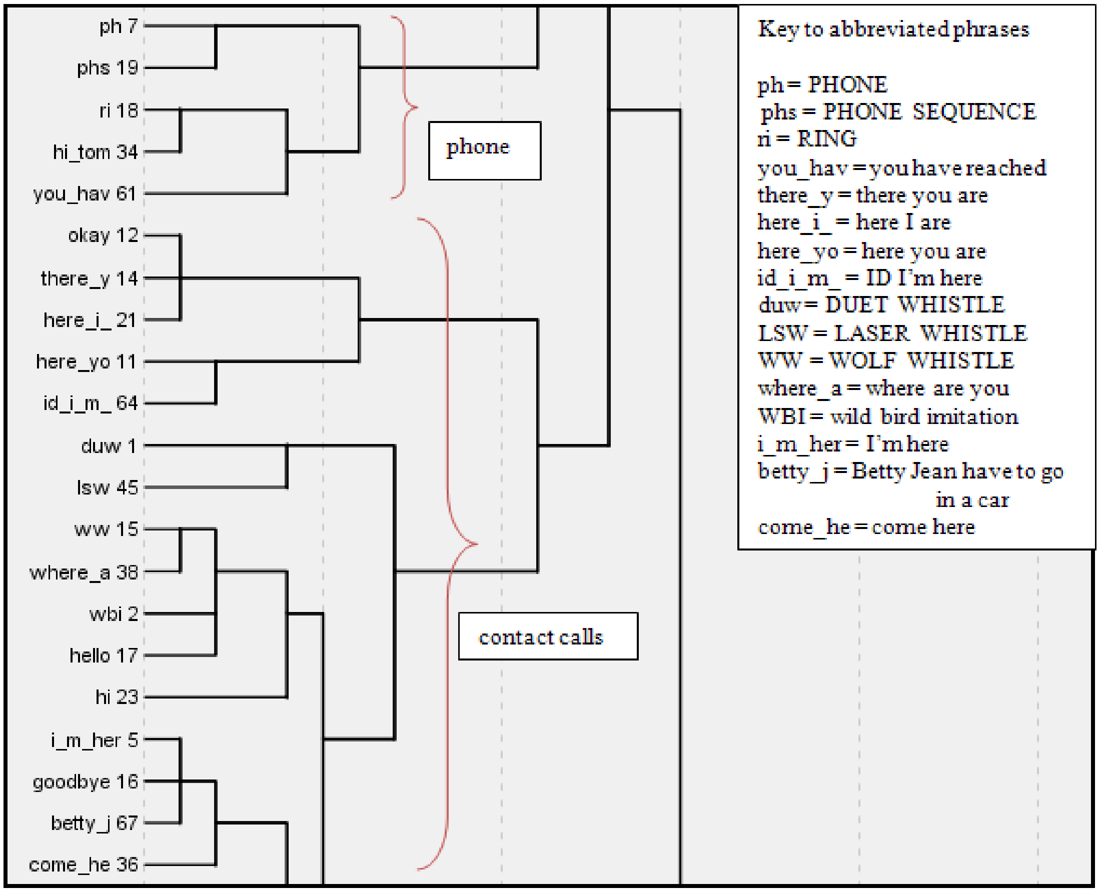
The Word Level Corpus

Sounds appear to play a very important role in Cosmo’s vocalizations in the Alone condition. Her vocalizations in this condition feature a large cluster composed entirely of sounds, indicating the sounds are integrated throughout her vocabulary when she is alone (bear in mind, items occurring in the same cluster share context, they do not necessarily occur in the same sentences or phrases). Potentially, this could be similar to bilingualism in humans; these are the sounds that come naturally to Cosmo, however they have less communicative value when BJ is present and are therefore given a much less prominent place in Cosmo’s speech when she is around. However, much like a human bilingual would take notes in his or her native language instead of the one being used in the immediate environment; Cosmo may revert to her favored vocalization style when she is not interacting with BJ.

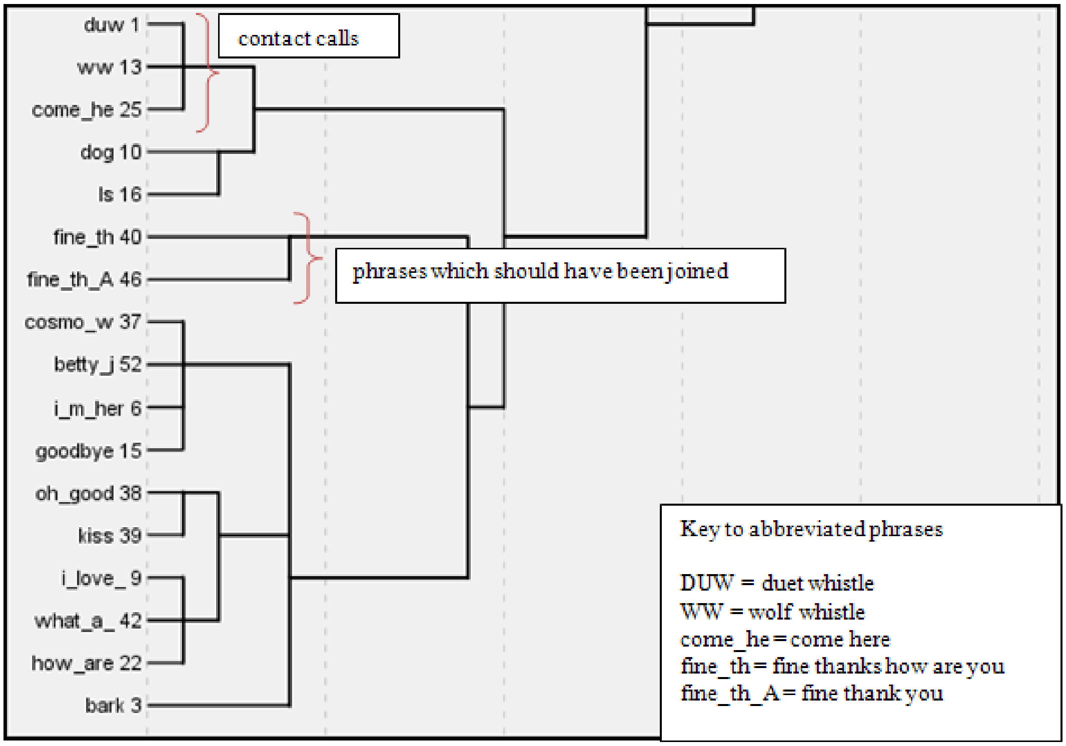
Figure 5. Sample clusters from a) Only Cosmo, In, words; b) Cosmo, Alone, words; c) Only Cosmo, Out, phrases; d) showing contextual co-occurrence within a cluster.



c)


ph 7
phs 19
ri 18
hi_tom 34
you_hav 61
okay 12
there_y 14
here_i_ 21
here_yo 11
id_i_m_ 64
duw 1
lsw 45
ww 15
where_a 38
wbi 2
hello 17
hi 23
i_m_her 5
goodbye 16
betty_j 67
come_he 36
phone
contact calls
Key to abbreviated phrases
ph = PHONE
phs = PHONE SEQUENCE
ri = RING
you_hav = you have reached
there_y = there you are
here_i_ = here I are
here_yo = here you are
id_i_m_ = ID I'm here
duw = DUET WHISTLE
LSW = LASER WHISTLE
WW = WOLF WHISTLE
where_a = where are you
WBI = wild bird imitation
i_m_her = I'm here
betty_j = Betty Jean have to go in a car
come_he = come here

d)


duw 1
ww 13
come_he 25
dog 10
ls 16
fine_th 40
fine_th_A 46
cosmo_w 37
betty_j 52
i_m_her 6
goodbye 15
oh_good 38
kiss 39
i_love_ 9
what_a_ 42
how_are 22
bark 3
contact calls
phrases which should have been joined
Key to abbreviated phrases
DUW = duet whistle
WW = wolf whistle
come_he = come here
fine_th = fine thanks how are you
fine_th_A = fine thank you

In all three conditions tested, global co-occurrence clusters reflecting different contextual usages of words were present. The most common of these clusters was of "things Cosmo wants." In the In condition, for example, this is represented by a cluster of the words "whi (presumably whistle), whistle, talk, come, cuddle, shower, go." All of these words are preceded by "wanna" in Cosmo's speech and are thus, in a very simplified sense, interchangeable over the category "things Cosmo wants." This is representative of a global co-occurrence pattern. There is also evidence of a "go" cluster in all three conditions.

The Phrase Level Corpus

Using Cosmo's speech in the HAL model in the form of phrases provided a new perspective. Cosmo has multiple spoken permutations of the same phrase, thus creating an abundance of synonyms, and, in turn a co-occurrence, due to the natural substitutability of synonyms. For example, just as "street" and "road" have the very similar meaning but would not be used in the same sentence, "we're gonna go for a walk" and "okay we're gonna go for a walk," or "DOG BARK SEQUENCE" and "DOG WHINE SEQUENCE" similarly seem to serve the same contextual purpose.

In the Alone Condition, Cosmo's speech was situationally appropriate. Of the 1185 phrases uttered by Cosmo in this condition (exclusive of phrases used 3 or fewer times), phrases from a "good Cosmo/bad Cosmo" class found elsewhere were completely lacking. Additionally, there were only two phrases from the "Cosmo wants" class, occurring a total of 16 times out of the 1185 total utterances. Lastly, vocalizations from the "contact calls" class were variations on "hello" and "goodbye"; they were not utterances such as "where are you" or duet whistles that request or elicit a response from BJ. All of these examples indicate an awareness that BJ is not present to respond to Cosmo's demands, reprimand or reinforce Cosmo, or to engage in conversation. Results from a previous study suggested the same situational awareness after comparing the In condition to a Company condition (in which BJ was in the room, but ignoring Cosmo and paying attention to another person in the room, a condition not analyzed in this study). In the Company condition, there was also a dramatic decrease in the amount of interactive language Cosmo used as compared to the In condition (Colbert-White, 2009).

The Out condition shows strong "contact call," "dog" and "phone" clusters. Contact calls are specific to BJ – they almost always elicit a response in which she whistles back to Cosmo or verbally identifies her location (I'm here) (Colbert-White, 2009). This may be Cosmo's attempts to contact her "flock," as duet calls such as these are known to be used for bonding in wild parrots (Cruickshank, et al., 1993). In addition Cosmo routinely interacts with the dogs, and therefore, dog contact calls such as barking (for lack of a better name for them), we can only suppose, are intended to attract the dog's attention. Three instances in this corpus provide examples of HAL identifying a situation unknown to the researcher and later confirmed by BJ. The first is the "wolf whistle," that consistently fell within the "contact call" cluster. It was confirmed with BJ, post hoc, that the wolf whistle is indeed used in a call and response manner by herself and Cosmo. Secondly was the presence of the strong "phone" cluster in the Out condition. While contact calls and calls to the dogs might serve to keep Cosmo in touch with others in the house, phone sounds did not seem to fit the pattern. However, upon further discussion with BJ, it appears that Cosmo will "make the phone ring" when BJ is out of the room (for example, when she gets in the shower or just as she leaves the house), as this causes BJ to come back into the room with Cosmo. Cosmo has been known to confess to the trick ("that's Cosmo"), showing a conscious awareness and intent to bring BJ into the room. Lastly, Cosmo's vocalizations showed she uses the phrase "hi Tom," although BJ knows no-one by the name of Tom. HAL analysis placed "hi Tom" within a contextual cluster that was easily recognizable to BJ as a very routine morning phone conversation that occurs with a person by the name of "Joan." The placement of the "hi Tom" vocalization within this cluster (and the absence of the name Joan), may indicate that "hi Tom" is a mispronunciation of "hi Joan."

The Substitutions corpus

Due to the abundance of variations on each phrase that occurs in the corpus, an additional corpus was run through HAL, in which all phrases that dealt with the same topic were grouped as the same. For example, the sounds PHONE RING and ANSWERING MACHINE, plus phrases such as "you have reached" were all re-named as "phone." This corpus showed much less organization than any of the others. It appears that the collapsing of similar phrases in the corpus created too much difference between individual units, thus disallowing substitutability or co-occurrence. There were two notable occurrences, however, that inform us that the integrity of the methodology was maintained (see Figure 5d). As the substitutions were done by hand, it was inevitable that some phrases were missed. The continued existence of these synonymous phrases was able to provide validation by their own continued clustering; for example, the phrases “fine thanks how are you” and “fine thank you.” In addition, groups of contact calls stayed together, for example DUET WHISTLE, WOLF WHISTE, and “come here.” Because these calls were semantically diverse, they were not combined in the substitutions; however, they remained in the same contextual cluster because the model was consistent methodologically.

Novelties

During the course of the analysis several novel structures and unique combinations of words were spotted. As HAL is not a model intended to find novelties in semantics, this section discusses findings that were noted during the course of working with the HAL results.

Unique constructions

Examination of Cosmo’s speech shows consistent use of constructions that must have been of Cosmo’s own invention. Very often, Cosmo will use “that’s wanna grape” instead of “wanna grape.” Because Cosmo is able to use “that’s” for identification purposes (“that’s bark,” “that’s squirrel”), this novel construction may come from a generalization of “that’s” to the “wanna grape” phrase; in a sense making “wanna grape” a noun. Cosmo also uses “here I are” as a contact call, again displaying a grammar of her own concoction; this is not a phrase BJ would have uttered. Cosmo also may have learned to use the word “don’t” on her own – she says “Cosmo don’t want to be a good bird,” a construction for which there does not seem to be an opportunity to learn by mimicry, given its lack of grammaticality and reflexive nature. She has also inserted the words “don’t” in other contexts, for example, the phrase “doggies don’t bark.”

These unique constructs provide further evidence for the hypothesis that global co-occurrence is present in Cosmo's speech patterns. The ability to parse words in and out of sentences correctly (or nearly so) shows an understanding that each word is an individual unit that has a specific meaning. More importantly, it shows an understanding that a single word can be appropriate in multiple sentences or contexts – a basic building block for semantic global co-occurrence. If it is the case, as the BJ claims, that Cosmo was not overtly taught the use of "don't" and that "don't" was not used in interaction with Cosmo, then it would appear that this word has been learnt by induction. Landauer and Dumais (1997) make a strong case for induction as the learning mechanism in early childhood vocabulary acquisition. They further argue that induction in this case can be embodied in a global co-occurrence model such has HAL (or in their case, LSA).

Humor

Although there is no way to specifically identify humor in Cosmo's vocalizations, she routinely makes utterances that sound in every way like humor. For example, Cosmo has learned the following phrases: "Cosmo has feathers," "Betty Jean has clothes," and "Mary has fur," (Mary is one of the dogs). "Playing" with these phrases has become a favorite "joke" of Cosmo's; she interchanges the direct objects (consistent with global co-occurrence as they are substitutable), and announces "Mary has feathers!" followed by "Noooooo! LAUGH, Mary has fur!" In addition, Cosmo will tease BJ in a variety of ways – the most interesting of which involves calling BJ over to her cage for a kiss and then ducking back into the cage (and out of range) at the last minute. Cosmo will do this multiple times and with appropriate pauses for BJ to resume her activities in between. The idea that Cosmo is using and understanding humor is especially intriguing in light of what it implies with regards to her cognitive abilities, and further investigating will be extremely interesting.

Word Meaning

The Cosmo corpus also provided several examples of Cosmo's ability to grasp word meaning. To begin, very existence of the clusters shows that meaning is clearly reflected in the statistical regularity of her speech. In addition, this clustering shows Cosmo's ability to use words referentially in a reliable fashion – all the words in, for example, the "phone cluster" are a reference to the same object. This is not unlike a child's learning to understand that there can be two labels for the same object. This is not an easy skill for children, and it would have been difficult for Cosmo to have learned that "bark" and "woof," for example, label the exact same thing (Liittschwager & Markman, 1994). However, the co-occurrence results provided by HAL do provide cautious support for this.

In addition, there is some evidence that Cosmo engages in a certain amount of word play; an advanced skill which requires understanding of word meaning and the relationship between words and their contexts (Pepperberg et al., 1991). For example, it is possible that Cosmo understands that "good" and "bad" have opposing meanings. BJ relates anecdotal evidence in which she says "Cosmo's a bad bird," and Cosmo responds "Cosmo wanna be a good bird." Cosmo's "phone jokes" are an even more complex example. BJ's answering machine has always said "you have reached (XXX) XXX-XXXX." When Cosmo began to imitate the machine, she first only imitated up to the area code (i.e. You have reached XXX). Later the vocalization changed and Cosmo began using the telephone number without the area code. She would say "You have reached XXX-XXXX." Subsequently, Cosmo continued with variations on the message that were both novel and appropriate in context and meaning. She began to say "You have reached bird," "You have reached Betty Jean," "You have reached Cosmo" and "You have reached me." The substituting of words with different specific meanings (bird, Betty Jean, Cosmo, me) but that all belong to the same grammatical class ("person" nouns), again shows the effect of global co-occurrence on Cosmo's vocalizations.

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CHAPTER 3: HUMPBACK WHALES

INTRODUCTION

Payne and McVay (1971) first demonstrated that the sounds made by humpback whales while "singing" were organized and sequential. After it was established that these patterns existed, characterization began. The first attempts to characterize song showed syllables that could be combined into motifs, motifs that could be combined into create phrases, and phrases that were joined into themes. Phrases and motifs were found to be extremely redundant, yielding a distinct hierarchical structure; for example, a particular phrase might be composed of one motif repeated three times, and three repeats of the phrase might be dubbed a theme (Winn & Winn, 1978). When these phrases and motifs were compared over the years, differences in the form of additions or subtractions of syllables or syllable types were noted. Small differences in song were also noted across locations; however, as the study site was small and therefore the absolute distance between locations was also small, no conclusions could be drawn (Winn & Winn, 1978). However, on a larger scale, very definitive geographic differences were later found between songs recorded in the North Atlantic, North Pacific, and South Pacific (Winn et al., 1981).

The general consensus was, and remains, that songs are used primarily for courtship purposes, as they are sung almost exclusively by males in breeding season. A recent study showed that 58% of male humpback whale singers were found associating with conspecifics, and singers were more likely both to join up with and stay longer with groups of whales containing mother-calf pairs and no other males (Smith, Goldizen, Dunlop, & Noad, 2008). However, other hypotheses do exist: (a) that the song is part of a search mechanism, possibly even long-range sonar (Frazer & Mercado, 2000); (b) that song plays a part in sexual selection, for example, the ability to sing a lengthy song without breathing could be a sign of greater fitness (Chu, 1988); (c) that song creates a social organizational structure, possibly even one that occurs cooperatively among males in mating season (Darling, Jones, & Nicklin, 2006); or (d) that song is indicative of a whale's position in a dominance hierarchy (Darling, 1983). See Parsons et al. (2008) for an excellent review of these and other hypotheses.

While humpbacks may be the most well-studied singers, there are other Mysticetes (baleen whales) - for example, bowhead whales (*Balaenoptera mysticetus*) and fin whales (*Balaenoptera physalus*) - that are suspected of singing for courtship purposes (Stafford, Moore, Laidre, & Heide-Jorgensen, 2008; Watkins, Tyack, & Moore, 1987).

Odontocetes (toothed whales) are also known to vocalize (although not in the form of song), and current data show more complex, socially dependent systems of vocalizations. However, Odontocetes tend to be much more social than Mysticetes, often traveling and/or hunting in groups and having a social order dictating movements within and between groups. For example, killer whales possess a set of vocalizations used by all members of the species, in addition to subsets that are specific to social or cultural groups (Eliades & Wang, 2008; Riesch, Ford, & Thomsen, 2006; Weiss, Symonds, Spong, & Ladich, 2007). The "cultural clan" hypothesis was first coined with reference to another species of toothed whale, the sperm whale, and details changes in vocalizations across social groups can be traced matrilineally (Rendell & Whitehead, 2001). And, of course, bottlenose dolphins – also toothed whales – are well known for their complex social systems and their signature whistles, suspected to be used for individual identification (Caldwell & Caldwell, 1965). Odontocetes tend to be more surface active than Mysticetes as well, making it feasible to conduct observational studies linking behavior to vocalization (Deecke, 2006; Frantzis & Alexiadou, 2008; Riesch et al., 2008). Baleen whales such as humpbacks tend to travel alone or in small groups, dive deep, stay underwater longer, and feed at deeper depths (Clapham, 2000); thus, data collection beyond the acoustics of song is nearly impossible. These factors may be the largest reasons why there is as yet no definitive answer on the purpose of humpback whale song.

One of the main focuses of the research presented here are the geographical differences in song. Differences in vocalizations have been identified across geographical or ecological areas in many species of marine mammals: Atlantic spotted dolphins (*Stenella frontalis*; Baron, Martinez, Garrison, & Keith, 2008), Atlantic bottlenose dolphins (Baron, et al., 2008), fin whales (*Balaenoptera physalus*; Delarue, Todd, Parijs, & Di Lorio, 2009), and blue whales (*Balaenoptera musculus*; Berchok, Bradley, & Gabrielson, 2006). Recently, vocal differences such as these were also found in a primate, the pygmy marmoset (*Callithrix pygmaea*; de la Torre & Snowden, 2009). If sufficient behavioral data cannot be obtained to aid in the understanding or purpose of song, it is hoped that differences in song over geographical area (or even across time) will help us to understand how song is transmitted between whales, if dialects exist, and, most importantly, what key aspects of the song are, based on what properties are evolutionarily conserved. Towards this end, there is some evidence for the conservation of adaptive vocalizations from songbirds; in a species of songbird, the black capped chickadee (*Poecile atricapillus*), successful memes (pieces of song) persist as traditions across the population. These successful memes appear to be carried by older, larger birds (hypothesized as a function of body condition, but potentially also a function of longevity, and, therefore, of an individual's experience). Other memes studied were unsuccessful and quickly went extinct. These memes tended to be confined to small geographic areas and used less frequently (Baker & Gammon, 2008). For this reason, variation over geographical distance may be a key component of cultural development of vocalization. The work here is with song recorded in three geographic locations that happen to be aligned. Support for geographical dialects might, for example, be evidenced by a song pattern in the middle geographic area (Puerto Rico), that is a combination of styles from the two other areas.

In addition to the basic rhythmic structure, early observers noted other properties of humpback whale song; for example, average sequence lengths of 4-10 units, and transitional phrases located between themes that included elements of both of the themes they served to separate (Payne & McVay, 1971). Recently, others have used ideas from mathematics, physics, and engineering to further these initial observations; for example, Suzuki et al. (2006) used an entropy analysis to conclude that the most probable average length of a sequence within a song is 6-8 units. In addition, a new variable was recently examined – the duration between the units. While the duration of the units themselves seems to be consistent, the time between units seems to be highly dependent on the units to follow and/or other units in the pattern. This is hypothesized to be one of the ways humpbacks may be able to recall and repeat such large portions of song (Handel, Todd, & Zoidis, 2009). This is not particularly surprising, given the human phenomenon of chunking, which allows us to remember large amounts of information by dividing and remembering it as manageable “chunks” of information; thus remembering multiple groups, rather than specific instances, of information (Miller, 1956). If this parallel were true, the whales could be remembering songs by learning groups or patterns of sequences or units, rather than individual units. This would make memorization and recall easier, in addition to extending the animal’s capacity for information storage.

METHODS

The corpus

The corpus used in this experiment stemmed from vocalization data obtained from the Macauley Library (Cornell Laboratory of Ornithology) and was classified by a Self Organizing Map (SOM; Kohonen, 1982). Original data were obtained via DVD data disks and included 325 distinct recordings made by 17 scientists. The recording dates ranged from 1964 to 2006 and included locations in both Atlantic and Pacific Oceans. Twelve songs from three locations were originally selected for analysis (three recordists, years ranging from 1970-1976), although only 11 songs were used in the final analysis (reasons for this are discussed below). The internal sequence order of each song was maintained (with some exceptions, discussed below).

The SOM

Prior to analysis, the elements of the humpback whale song were classified by a 25-unit SOM. The SOM used 53 acoustic features to create vector representations of each unit of vocalization, and then used a competitive learning algorithm to classify the vocalization into one of 25 distinct nodes or units of vocalization. All work concerning the translation of acoustic units to a written sequence, in addition to the creation of the SOM, was done by Sean Green; for more information on the procedure used to create the SOM, see Green, Mercado, Pack, & Herman, 2007. A 100 node SOM was also attempted; however it appeared that the extra nodes provided no additional information. Artificial neural networks, of which the SOM is an example, are gaining in popularity for the classification of animal vocalizations and have become fairly standard in the literature for a variety of species (Deecke, Ford, & Spong, 1999; Kirschel, et al., 2009; Mellinger, 2008; Placer, Slobodchikoff, Burns, Placer, & Middleton, 2006; Pond, Darre, Scheifele, & Browning, 2010; Rickwood & Taylor, 2008; Selin, Turunen, & Tanttu, 2006; van der Schaar, Delory, Catala, & Andre, 2007).

HAL parameters

As the corpus used in this study was large (a total of several thousand acoustic units), a default window size of 10 was deemed appropriate (Lund & Burgess, 1996). In this corpus, unit frequency ranged from as high as 500 to 600 occurrences of a particular unit to as few as 14 occurrences of a unit – although in most cases the minimum number of occurrences of any particular unit in a corpus was 150. In cases such as this, it is often beneficial to "limit" the matrix at the mean or median frequency. The limit acts as a quota; as HAL moves through the corpus calculating co-occurrence values, it disregards any occurrences of a particular unit after that unit's limit has been reached. The limit on all of the matrices used was 250[4], unless otherwise indicated.

Mixing the corpus

Because it was advantageous to limit the maximum unit occurrence in the HAL matrix at 250, it was necessary to "mix" the corpus to avoid problems with songs that contained particularly high numbers of any specific unit. For example, if the first song in the corpus contained 250 occurrences of a particular unit, HAL would reach the limit for that unit almost immediately, and, thus, would ignore any occurrences of that unit in any other song for the remainder of the corpus. In order to avoid this problem, and to balance the first and second halves of the songs, songs were "mixed" as follows (parts A and B designate the first and second halves of each song)

---

[4] This limit was chosen because prior experimentation indicated that the median of the unit frequencies was the most appropriate value to use when limiting a matrix.

Split 1
Song1, partA
Song2, partB
Song3, partA
Song4, partB
etc…

Split2
Song1, partB
Song2, partA
Song3, partB
Song4, partA
etc…

The two splits were then concatenated to create a final corpus to be used in the experimental procedure. A template was created and used each time a corpus needed to be mixed. Additionally, the splits created were used in the split-half reliability checks discussed later.

HAL analysis

The mixed corpus was subjected to HAL analysis as described previously. The result of this analysis was a 25-dimensional space containing 25 vector representations--one for each unit ("word"). Following the procedures discussed in the introduction, these vectors were visualized via Ward's Cluster Analysis and mapped onto the original corpus.

Confirmatory analyses and final corpus selection

When a HAL analysis is used with human language, there is no need for confirmatory analysis. Because we know the language, it makes sense to us that "cat" and "dog" should be more likely to co-occur (either globally or locally) than "cat" and "file." This luxury is not afforded when working with a corpus comprised of animal vocalizations, and, therefore, two separate techniques were used to validate the results.

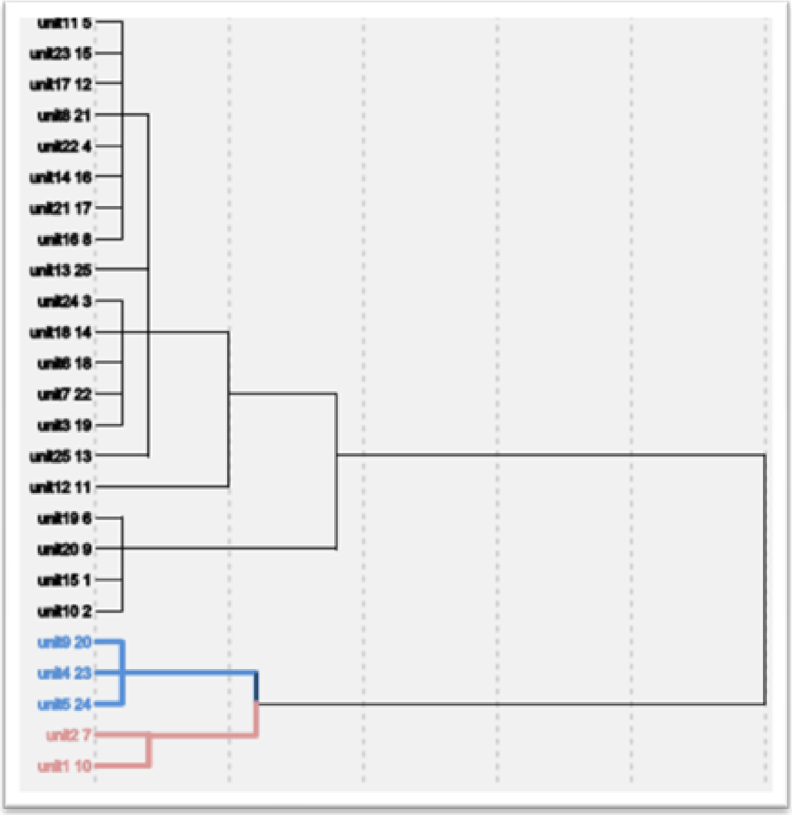
Song removal

Three new corpuses were created by removing songs. Song numbers 117762 and 128296, henceforth referred to as song62 and song96, were removed, as they appeared to be more irregular due to inordinately high proportions of a particular unit or group of units (92% of song62 was composed of four units, 45% of song96 was composed of one specific unit) (see discussion in Miksis-Olds, Buck, Noad, Cato, & Stokes, 2008). Song96 was also much shorter than any other song. These removals created the corpuses “without117762” (or wo62), “without128296” (or wo96), and “without117762and128296” (wo62and96), in addition to the “full” corpus. A comparison of all four corpuses was used as a test for robustness of the procedure, in addition to being used in the final corpus selection process detailed below.

Song62 and song96 were removed in the acoustic stage, prior to unit classification by the SOM. Because of this procedure, however, there was an inherent problem with comparing the four corpuses. When classification is done by different SOMs, the identification of each acoustic unit (i.e. the unit’s “name”) is different. For example, a particular acoustic unit could have been called unit1 by the full SOM, unit16 by the wo62 SOM, unit22 by the wo96 SOM, and unit25 by the wo62and96 SOM.

To solve this problem, color coding was used as a way of marking clusters when they were output from the clustering procedure using the corresponding HAL vectors. Each of the clusters created by the cluster analysis was assigned a color. For example, in Figure 6, a cluster analysis of the full corpus, the cluster containing unit4, unit5, and unit9 is assigned the blue color. Consequently, all of the units 4, 5, and 9 in the full corpus are colored blue. In addition, because the temporal order within the corpuses was maintained, the acoustic units were still ordered the same, regardless of what they were called. In this way it was possible to approximate equivalent clusters in the four corpuses by reading horizontally (i.e. examining acoustic sounds that occurred at the same place in the sequence) and labeling their respective, equivalent, clusters by color, despite the different unit names (see Figure 7). This procedure could be used for comparison across corpuses by individual song as well as along the complete corpus, and was used throughout the analyses in this dissertation.

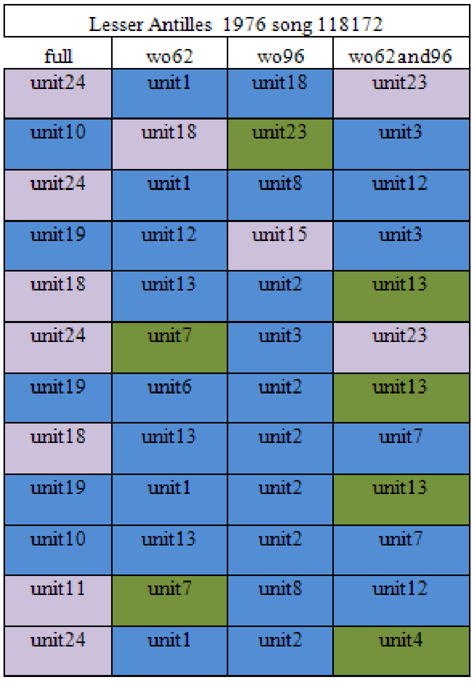
Figure 6. Wards cluster analysis of HAL vectors from the "full" corpus. Note how the Dark Blue and Pink clusters are color coded.



Split-half analysis

A split-half confirmation of the clusters produced by the HAL model was also performed. Each of the songs was split into an A section and a B section, and two "splits" were created from alternating A's and B's, as discussed before. However, the two splits were now treated as two separate corpuses, instead of being concatenated to one corpus. Because there is no accepted statistical method to compare categorical data, Cohen's kappa (1960) was used as an experimental approximation. Cohen's kappa is an inter-rater reliability statistic used to compare agreement between two raters who code behavioral observations. In this case, the two versions of cluster membership (the full and one of the split halves) were each considered to be a "rater" and the cluster membership for each unit was considered the rating for each particular behavior. As a result, the model was created such that two "raters" (the two versions of cluster membership) were being compared on 25 "instances of behavior" (the 25 units), for which they had assigned one of eight "types of behavior" (the clusters).

Figure 7. Mapping of the color coding scheme onto the corpus. In this example, the same song is color coded with clusters obtained from each of the 4 corpuses (i.e. the "full" corpus grouped unit10 and unit19, while the "wo62" corpus grouped unit1, unit6, unit12, and unit13). As the sequence is maintained in all cases, each cell in a particular row is the same acoustic unit, regardless of the unit label assigned by the SOM. HAL, grouping the units by global co-occurrence, should maintain the same order with regard to cluster membership, and this can be read across rows as matching color patterns. Note this is only a small portion of a song.



Lesser Antilles 1976 song 118172

full	wo62	wo96	wo62and96
unit24	unit1	unit18	unit23
unit10	unit18	unit23	unit3
unit24	unit1	unit8	unit12
unit19	unit12	unit15	unit3
unit18	unit13	unit2	unit13
unit24	unit7	unit3	unit23
unit19	unit6	unit2	unit13
unit18	unit13	unit2	unit7
unit19	unit1	unit2	unit13
unit10	unit13	unit2	unit7
unit11	unit7	unit8	unit12
unit24	unit1	unit2	unit4

Types of Analysis

Two types of analysis were done, one that examined the frequency of occurrence of units and classes, and one that examined the overall entropy of the songs. Frequency of occurrence of each class was examined as a measure of change in song composition and perhaps dialect, whereas entropy analysis was performed to establish that only a certain number of the sequences that were possible actually existed (that in turn establishes that they are not random), and then to identify and compare these sequences across songs. The algorhythm for entropy analysis was developed and executed by Aaron Seitz of the University of California, Riverside.

Frequency Analysis

Although it is unknown if frequency of occurrence of unit or class plays a role in humpback whale communication, there is some precedent for it being studied as a variable. Suzuki et al. (2006) used frequency of occurrence to estimate the true distribution of units in humpback song, thus generalizing over a particular area. In killer whales, frequencies of occurrence of whistles within the sequence and transition patterns between whistles in sequences are nonrandom (Riesch et al., 2008). Frequency also plays a large part in calculations of conditional probabilities in other studies of humpback whale song (Green et al., 2007).

Entropy Analysis

Working on the assumption that the greater the organization, the closer to the correct clustering, an analysis was performed on each of the songs individually, using the clusters produced by building a HAL matrix using the entire corpus. This was done initially to identify empirically if any of the songs were in fact anomalous (song62 and song96 were suspected to be and because of this were removed for a test of robustness; however they could not be removed entirely without an empirical justification).

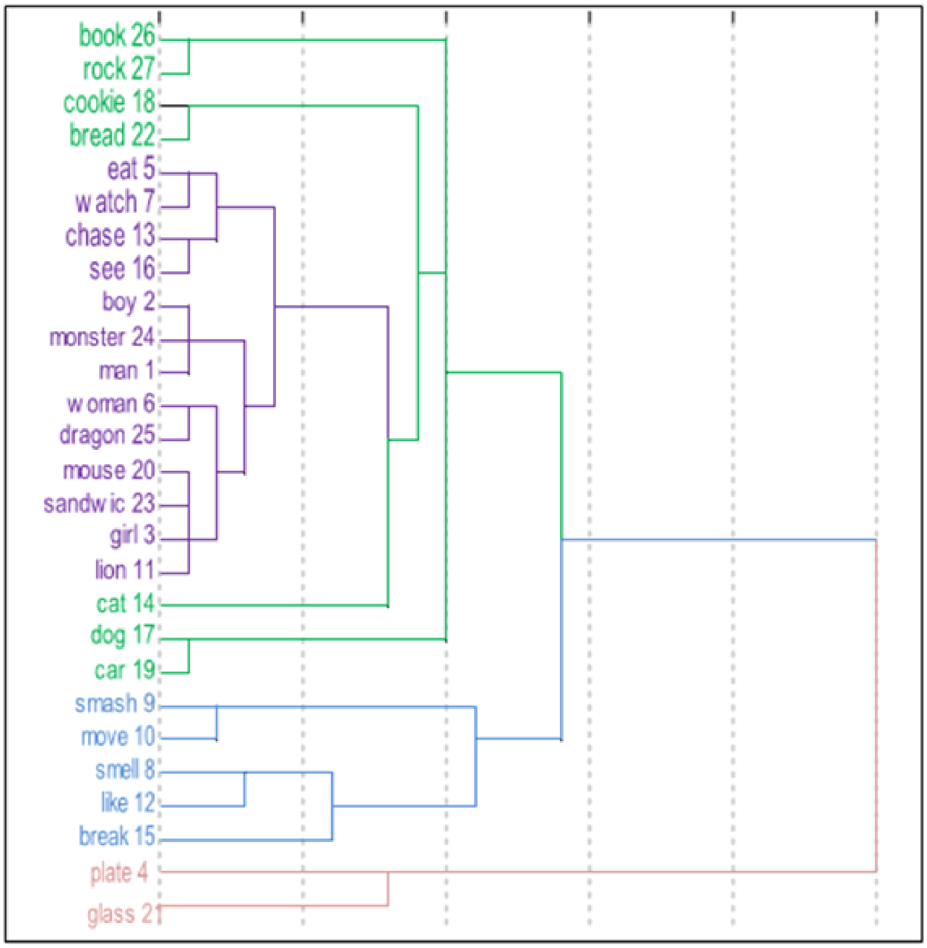
The analysis also provided a comparison of the sequence organization in the corpus to that of a random sequence. For example, when examining sequences that are four units in length in a completely random corpus, one would expect 256 (4*4*4*4) different sequences to occur, with the only constraint being the frequency of occurrence of each unit. A fewer number of distinct sequences would indicate a degree of organization. Entropy analysis provides that information, along with the actual identification of the sequences that are found.

Upon identifying the sequences that existed within each song (via the entropy analysis algorithm), further data analysis was based on sequences that occurred five or more times in a particular song (henceforth referred to as “the sequences found”).

The Elman Corpus

Because one of the goals of this study was finding semantic patterns within humpback whale song, it seemed relevant to perform a similar procedure on human language. The corpus chosen was one created by Elman (1990) when developing his Simple Recurrent Network (SRN). This corpus was chosen because it has been subject to HAL analysis previously and, despite a completely different learning mechanism (although both learn by encoding contexts), HAL yielded similar results to the SRN (Burgess & Lund, 2000). In addition, the corpus consists of approximately the same number of words (29) as there were units in the humpback whale song (25). The Elman Corpus underwent HAL analysis just as the humpback

Figure 8. Color coded cluster analysis of the "Elman corpus"



whale song was, although many of the elaborate confirmatory procedures did not have to be undertaken since the language and categories were known. HAL vectors were subjected to cluster analysis, and clusters were color coded and mapped on to the original corpus, just as had been done in the case of the whale song (see Figure 8).

RESULTS

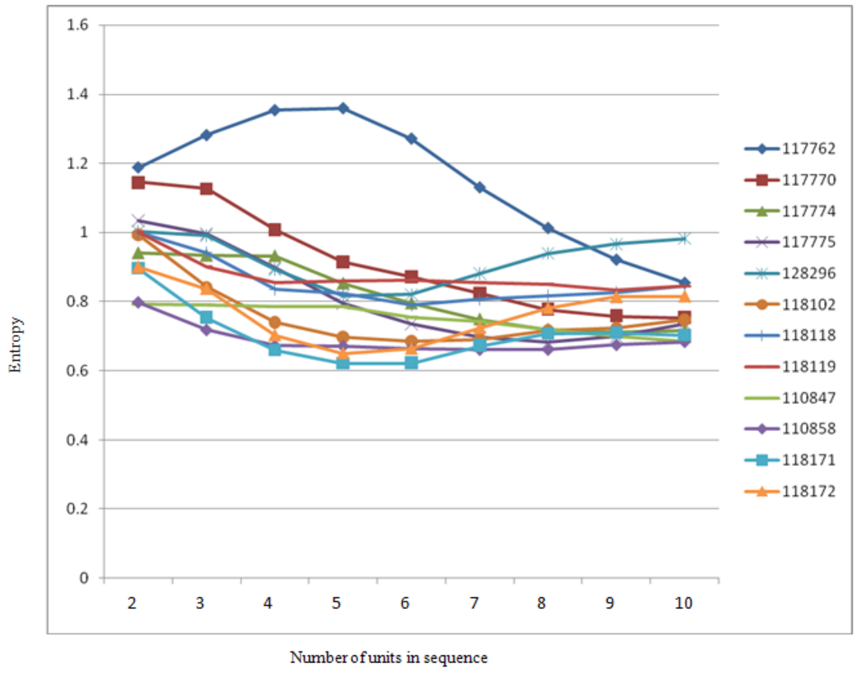
Perhaps most crucially, HAL was able to produce distinct cluster patterns from the SOM output, showing that the units, as classified by the SOM, do indeed have some form of organization. Because the HAL model uses an inductive learning mechanism, it is completely independent of human judgments or ratings; there is no outside influence on the model's learning process. Additionally, it is impossible to introduce regularity via the model itself, as the language input to the model essentially *creates* the model itself through the global co-occurrence learning algorithm. The fact that the HAL output *has organization at all*, means that there was organization (i.e., statistical regularities) in the input.

Final corpus selection

A comparison of all possible sequences of lengths two to ten, to the number of actual sequences of lengths two to ten, was used to measure entropy. Low entropy (high organization) songs were characterized by having a small percent of the possible sequences present. The possible sequences were calculated, for comparison purposes, by randomizing the sequence order, keeping frequency consistent (Seitz, personal communication, 2010). The entropy analysis was conducted on the entirety of each of the four corpuses (full, wo62, wo96, wo62and96), plus each individual song in each of the following conditions: full, wo62split, wo62lumped, wo96split, wo96lumped, wo62and96split, wo62and96lumped. Split and lumped versions referred to alternate readings of the Ward's Cluster Analysis, which does not always provide an exact solution.

Graphs of the entropies at each sequence length for songs in the full corpus condition were compared (see Figure 9). This comparison showed that song62 was anomalous, having a very different structure than any of the other songs, namely an entropy that increased with sequences of length three to

Figure 9. Graph of entropy values for sequences of lengths 2 to 8 for each of 12 humpback whale songs.



four and then decreased at lengths of six to seven. This is the only song whose entropy is not highest (most random) at sequences of two units. One would expect to see the highest entropy at the two unit sequence, as sequences of two units are very easy to "make," and therefore a higher proportion of the ones possible (represented by the random condition) would appear.

It was therefore determined that the wo62 corpus would be used for all further analysis. The split version of the corpus was used because it generally yielded lower entropies. The clustering pattern produced by this corpus yielded six Classes, which were regarded as grammatical and/or semantic classes and used to characterize patterns in the songs.

Confirmatory analysis

After the wo62 corpus was chosen, a split-half procedure using the "mixed" halves referred to above was completed in order to confirm reliability of the overall technique. Using Cohen's kappa (1960), each of the split halves was compared to the full corpus, and kappas of .4 and .5, respectively, were calculated. Comparison of the wo62 corpus to randomized versions of split1 and split2 yielded trivial kappa values of .01 and .1, respectively. This final comparison to a randomization of each of the splits was done because there is no precedent for the use of Cohen's kappa in a situation like this. In clinical psychology, kappas of magnitude .4 and .5 would indicate "moderate" agreement (Cicchetti & Sparrow, 1981).

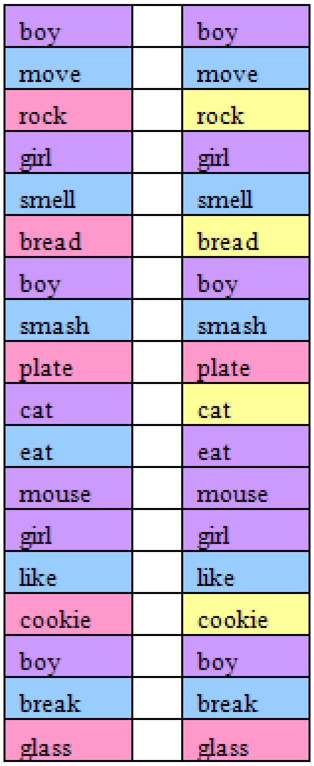
Are sequential patterns equal to grammatical patterns?

The human language system is composed of grammatical classes from which we are able to choose words to piece together sentences. For example, to create a basic sentence structured *subject + verb + direct object*, we are able to choose from a huge vocabulary of subjects, verbs, and direct objects; many of which are interchangeable. Consider, for example;

Boy sees dog
Boy sees cat
Boy sees mouse
Boy walks dog
Girl sees dog

And so forth. Imagine you did not know what a dog, cat, or a mouse was. Given one sentence from the above set, you would have very little information. Given the first three, you would have more. Dog, cat, and mouse are contextually similar in that they are all things a boy can see, in addition to belonging to the class that is direct objects. Given all five sentences, you could then surmise that the act of seeing is not exclusive to the male gender, as the girl can also see the dog (and, therefore, she can most likely see the cat and mouse as well). In addition, you would learn that not only can the boy see the dog, he can also walk it – and therefore most likely the girl can as well. These inferences are all made possible by contextual similarities within the sentence.

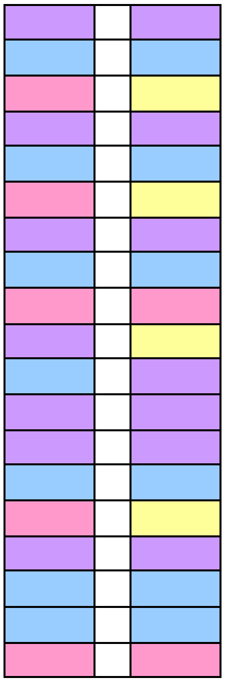
Figure 10. Elman corpus color coding.
A) The "correct" answers, manually coded,
and B) The clusters created by HAL.



A)		B)
boy		boy
move		move
rock		rock
girl		girl
smell		smell
bread		bread
boy		boy
smash		smash
plate		plate
cat		cat
eat		eat
mouse		mouse
girl		girl
like		like
cookie		cookie
boy		boy
break		break
glass		glass

To demonstrate the technique used in this study in a more familiar format, the Elman corpus discussed above was used. After classes were color coded and mapped onto the original corpus, it is possible to compare HAL's accuracy to the correct grammatical categories in human language – a luxury we do not have when dealing with animal vocalizations. HAL does fairly well; there is a noun cluster (purple) and a verb cluster (blue). HAL categorizes direct objects into two categories – pink and tan, with the pink cluster representing breakables (see Figure 10). The categorization is fairly comparable to the "correct" categorization of the three classes directly to the left (that, in and of itself, is not always exact – for example, the pattern is briefly interrupted at "cat eat mouse" because "mouse" has received the overall classification of noun, not direct object). However, what if we did not know the words? In Figure 11 the words are removed and we just see patterns of color. These color patterns represent the patterns of grammatical classes that occur in our language. There is similar patterning throughout the humpback whale corpus. Because these patterns are based on classes distinguished by the HAL model, they are not recognizable simply by examining the order of the units. Likewise, the colored patterns from the Elman corpus come from the grammatical classes (whether they were created by HAL or by the experimenter's hand), not from the words themselves. The existence of

Figure 11. Removal of words from figure 10 to show patterns of grammatical classes.



these patterns in humpback whale songs provides strong support for the hypothesis that the whales use global co-occurrence when creating their courtship songs.

Frequency Analysis

Initial analysis of the songs was accomplished by examining the frequency of occurrence of each of the classes. Because the number of songs available for comparison here is low, these results must be confirmed by additional analysis. In addition, the development of statistical techniques that could be used for a comparison across songs, despite the units being categorical data, is a necessity. Lastly, three classes – Class Green, Class Pink, and Class Yellow – consist of one unit, that makes generalization beyond mere presence or absence impossible to justify. However, there are some conclusions about class frequency that can be supported.

Turks and Caicos have the most distinctive repertoire. Class Orange is almost completely unique to this region, and Class Pink and Class Dark Purple never appear there at all.

The Lesser Antilles songs seem to differ with the year of recording (and are generally regarded as different groups throughout this experiment). This is particularly apparent in the use of specific units from Class Dark Blue; while the overall usage of Class Dark Blue remains roughly the same over time, in 1973 the Class Dark Blue units that are used are nearly all units 20 and 21 (unit20 = 10.0%, unit21 = 12.3%, unit1 = 0%, unit12 = 1.1%). However, in 1976, this is completely reversed, and the composition of Class Dark Blue is almost entirely units 1 and 12 (unit20 = 3.5%, unit21 = 1.5%; unit1 = 10.4%, unit12 = 11.1%). If general meaning conveyed by Class Dark Blue remains the same, then it is not unrealistic to surmise that the dialect changed over this period of time from one set of units to the other, in a way similar to the introduction of new words to the human language that may be similar to ones already established. This finding may be support for the inherent substitutability of units within a particular class.

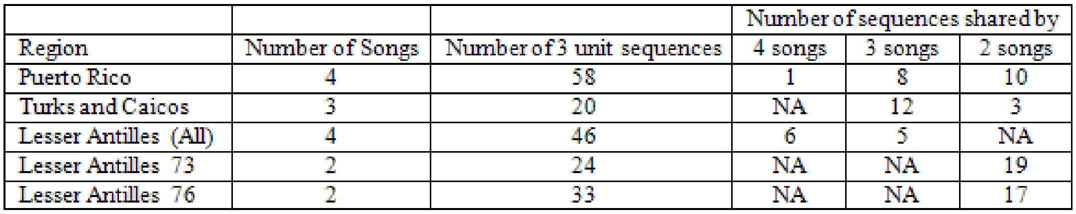
Lastly, the songs in Puerto Rico appear to be slightly more diverse than songs in other regions. In the other locations approximately 70 percent (TC = 72%, LA73 = 68%, LA76 = 70%) of all units can be accounted for by the two Classes that are also highest in frequency. However, in Puerto Rico, the top two frequency classes account for 61% of the units. This decrease in uniformity, although seemingly slight, will appear in other analyses as well.

Sequence Analysis

Some generalizations regarding the sequences can be made across all songs. It was very common for a song to consist of one or two "backbone" Classes, from which units occurred many times in a row (bearing in mind that although the units themselves might be different, the class is the same, so this backbone would not appear in a conditional probability analysis, where the units would simply appear as their identified selves). Within this backbone, single "drop in" units occurred at intervals that were too large and too variable for a sequential analysis to handle.

Differences in the composition of the backbone were evident, as were distinct patterns of classes within the songs. Songs had "roots," or sequences which appeared consistently. These roots were fairly consistent across all songs from a region, with the exception of songs from Puerto Rico. Using three unit

Figure 12. Number of three unit sequence "roots" similar across songs in a region.



			Number of sequences shared by		
Region	Number of Songs	Number of 3 unit sequences	4 songs	3 songs	2 songs
Puerto Rico	4	58	1	8	10
Turks and Caicos	3	20	NA	12	3
Lesser Antilles (All)	4	46	6	5	NA
Lesser Antilles 73	2	24	NA	NA	19
Lesser Antilles 76	2	33	NA	NA	17

"roots," (as there were consistently more of these than any other length), Figure 12 shows the proportion of similar roots across songs.

What follows is a review of some of the more significant sequences found. Their implications and relationships to each other and across songs and regions will be discussed in the following sections.

Puerto Rico

Songs from Puerto Rico were the least uniform of the geographical locations. Song96 was particularly anomalous, being composed primarily of long strings of Class Pink (P) interrupted by units from Class Light Purple (LP), and shorter strings of Class Light Purple interrupted by units from Class Pink. Most likely this song should have been removed from the analysis at an earlier point; however, it was not identified as anomalous by the entropy analysis, potentially because it was disproportionate in terms of the frequency of a single unit as opposed to an entire Class. Further discussion of songs from Puerto Rico will exclude this song. However, it is important to note that the dissimilarity within the region's songs is not entirely due to Song96.

There was no clear backbone in the songs from Puerto Rico – song70 had a backbone of units from Class Light Blue (LB), song75 had a backbone of units from Class Light Purple, and song74 had a backbone composed of units from each. Song70 and song74 were most alike, sharing the root sequences LB+DB+LP and DB+LP+LB (see Figure 13), in addition to having units from Class Dark Blue (DB) nearly always occur as single units (i.e. there were very few examples of more than one unit from Class Dark Blue in a row). Song75 contained units from Class Yellow (Y) in its patterns, and these patterns appeared to be more complex variants (e.g. additional repeats) on the patterns appearing in the other two songs. In addition, the backbone in song75 was much more difficult to distinguish.

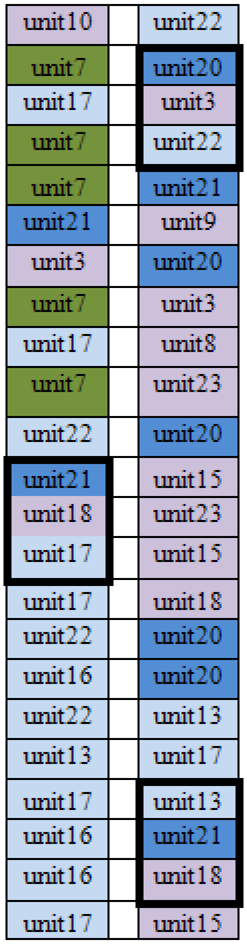


Figure 13. Sequences from song70 and song74 showing the LB+DB+LP and DB+LP+LB sequences.

unit10	unit22
unit7	unit20
unit17	unit3
unit7	unit22
unit7	unit21
unit21	unit9
unit3	unit20
unit7	unit3
unit17	unit8
unit7	unit23
unit22	unit20
unit21	unit15
unit18	unit23
unit17	unit15
unit17	unit18
unit22	unit20
unit16	unit20
unit22	unit13
unit13	unit17
unit17	unit13
unit16	unit21
unit16	unit18
unit17	unit15

Turks and Caicos

Songs recorded at Turks and Caicos were far more consistent than songs recorded in other locations. All three songs showed a backbone of Class Orange (O), a Class almost exclusive to this region, with drop-ins from Class Light Purple (although the backbone was more mixed between these Classes in song119). In all cases, any sequence of a length of more than three units (with the exception of one sequence in one song) was composed entirely of units from Class Orange and Class Light Purple. In addition, in sequences longer than three to four units, units from Class Light Purple were generally only found singly. Only in song119 were there a sufficient number of sequences with consecutive units from Class Light Purple to warrant mention.

Lesser Antilles

Songs recorded in the Lesser Antilles tended to share more characteristics when they were recorded in the same year; however, general trends across years were present as well. In 1973, the backbone of Lesser Antilles songs was from Class Light Purple; however, in 1976, the backbone was split between Class Light Purple and Class Light Blue. In 1973, the patterns for creating sequences were straightforward. The non-backbone classes (Dark Blue, Dark Purple (DP), and Yellow) never co-occurred in the moving window; they only occurred in sequences with units from Class Light Purple, where they either alternated (i.e. DB+LP+DB+LP), or occurred in doubles (LP+DP+DP+LP or DP+LP+LP+DP). When these patterns occurred in the songs from 1976, they were less organized – for example, instead of simply two units in the middle of a sequence such as DP+LP+LP+DP, the number present was much more variable. More elaborate sequences were seemed to be present, such as DB+LB+G+LB+LB or LP+G+LP+LB; however, they could not be claimed to be entirely consistent as units would occasionally switch places or repeats would be added.

Entropy Analysis

Examining the results of the analysis of entropy (as defined by the number of sequences of a particular length in a song divided by the number of sequences of the same length when the units in that song are randomized) provided data that parallels the sequence analyses.

The entropy at each sequence length in a particular song can be graphed (Figure 14). Looking at these figures, the similarities and differences identified by the sequence analysis are evident.

In Puerto Rico (Figure 14a), the two most similar songs, song70 and song74 have very similar patterns of change in entropy over time, while song75, the more complex of the songs, occupies a different trace; it finishes with a higher entropy (less organization) than the other two. This is indicative of larger, less organized sequences at longer lengths, and is congruent with the addition of units from Class Yellow (which appears in song75 but not song70 or song74).

In Turks and Caicos (Figure 14b), there is a similar pattern. Although the songs in this region are generally more ordered, song102 and song118 are quite similar and their entropy graphs are indicative of this. Song119, as mentioned above, differs from the other two in that the backbone is less obvious and it is the only song in which multiple units from Class Light Purple could be found consecutively. Song119 has higher entropy at longer length sequences.

Finally, the entropy graphs for the Lesser Antilles (Figure 14c) are particularly interesting because they reflect the uniformity found within the sequence patterns. All four songs have very similar patterns of entropy measurements, most likely owing to similar rules for sequence construction. Additionally, the two songs recorded in 1973 are represented by the two lowest traces and the two songs recorded in 1976 are the two highest traces. This parallels the conclusions drawn from the sequence data; the 1976 songs are less organized than the 1973 songs; they have variable numbers of repeated units, and thus higher entropy.

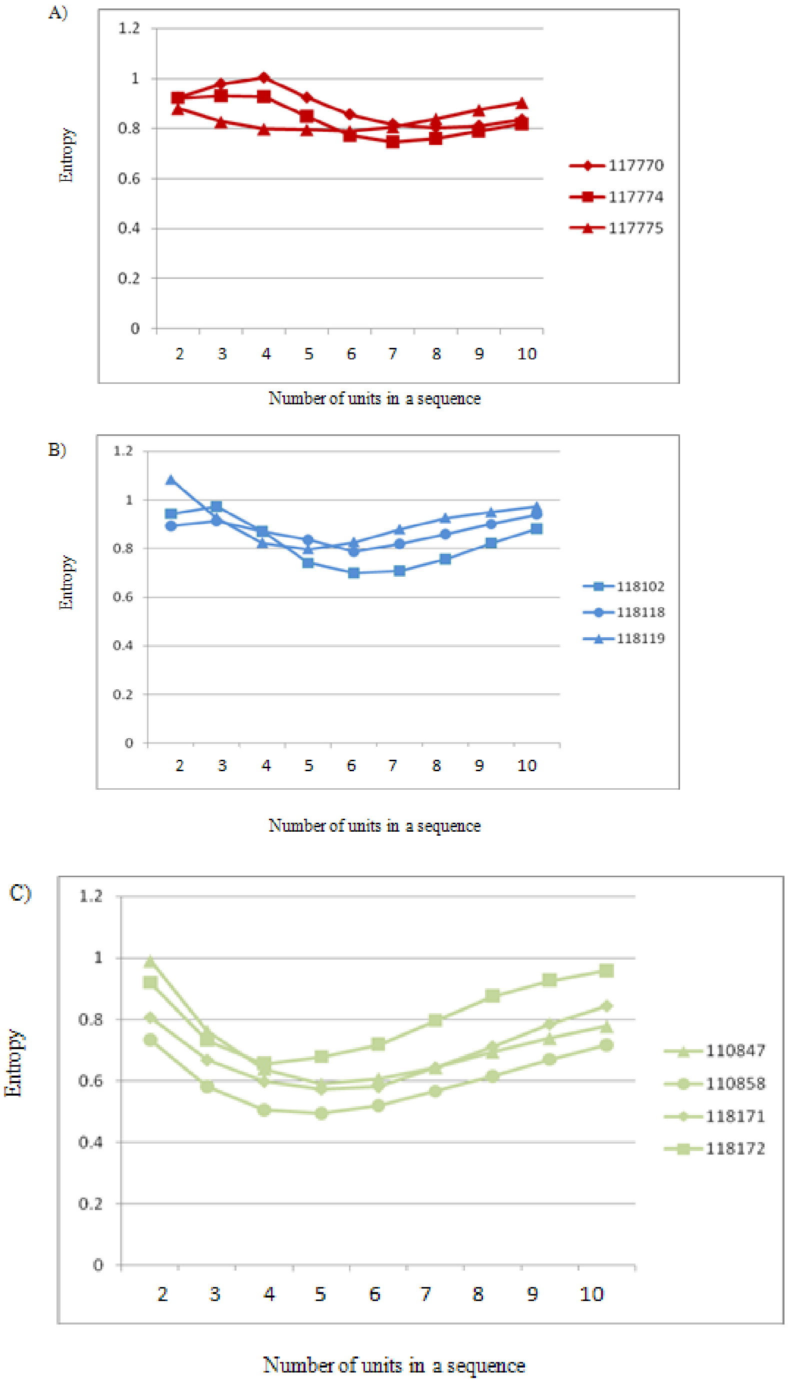
DISCUSSION

The HAL model is meant to measure global co-occurrence, the formation of cognitive representations by the use of context in language. The Classes identified by the analysis come directly from the whale song input. HAL requires no outside teacher and does not alter the input beyond summing and weighting co-occurrences, and adjusting for frequency of occurrence. The result is that there is no chance that the patterns found are artifacts of a computational process - the model is completely transparent. The Classes that were identified can be posited to be grammatical or semantic categories; if a pattern is found within a song that, for example, alternates between Class Yellow and Class Light Purple, it does not matter which units from within these Classes are used, as they all serve the same semantic or grammatical purpose. Just as English grammatical rules dictate the three classes “noun, verb, and direct object” to be ordered as such in a sentence, patterns found in humpback whale song may be obeying similar rules.

Frequency Analysis

Analysis of the frequency of occurrence of units in each cluster provides a basic description of songs in the three geographic areas.

Figure 14. Entropy graphs for sequences of length 2 to 8 units, by song and region. A) Puerto Rico, B) Turks and Caicos, and C) Lesser Antilles.



Some Classes are almost entirely unique to a particular region, such as Class Orange is to Turks and Caicos. Monitoring the usage of Class Orange would be an excellent way to empirically test the transition of vocalizations between geographic areas, as its progress could be tracked into nearby geographical locations.

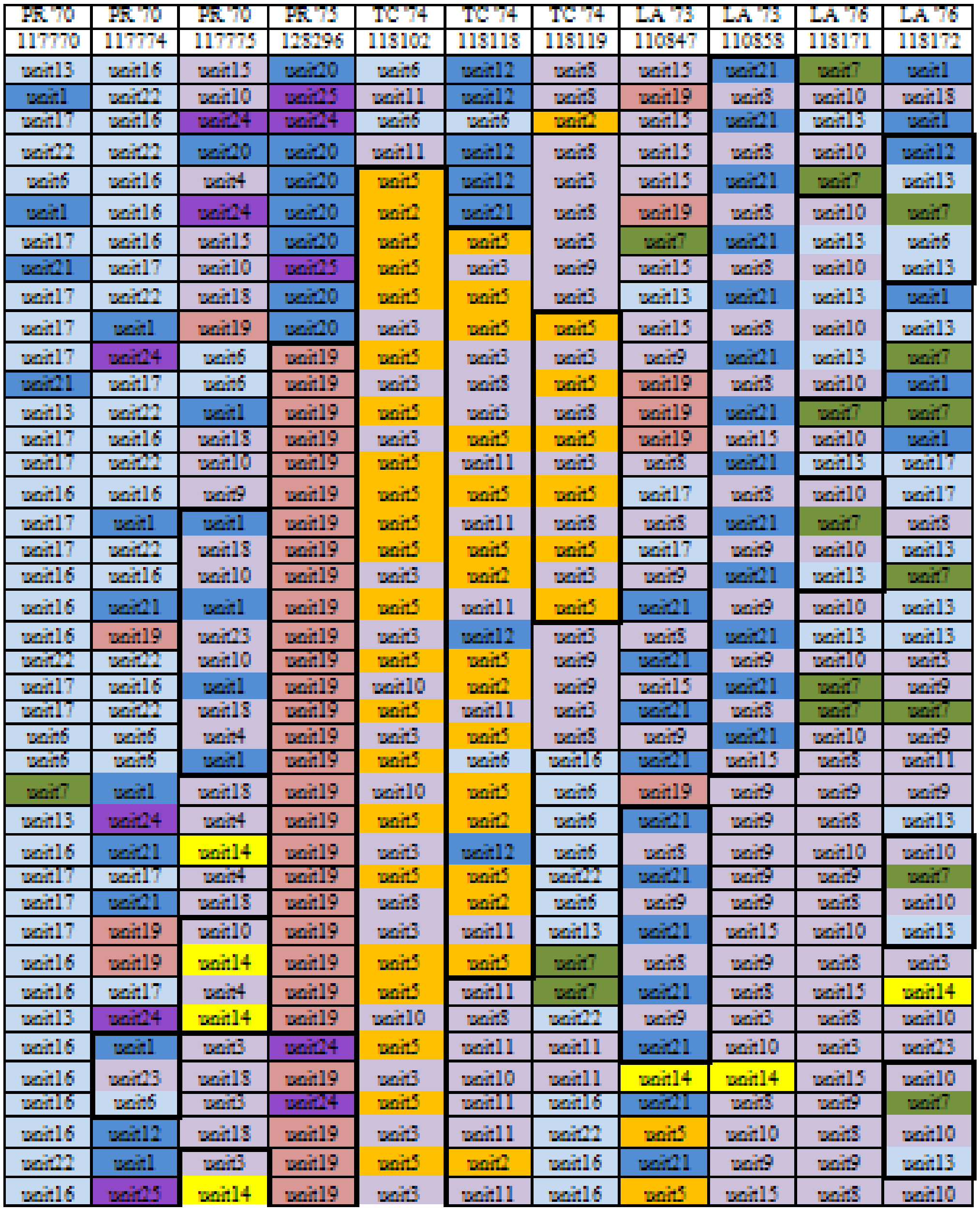
On the other hand, the Class usage in Puerto Rico appears to be more diverse, supporting the idea that the Puerto Rican songs are at least in part the product of convergence of the songs from neighboring areas.

Frequency also is a key factor in substitutability. If the Classes shown by the HAL model are the result of lexical co-occurrence, then the units in a particular Class should have some degree of basic substitutability. For example, just as different regions of the United States use the words "soda" and "pop" to refer to the same type of beverage, it is possible that in the Lesser Antilles in 1973 unit20 and unit21, the more frequent units in Class Dark Blue, were used to convey the meaning of that Class, while in 1976, unit1 and unit12 – which became most the frequent units in these years - were used to convey the same meaning.

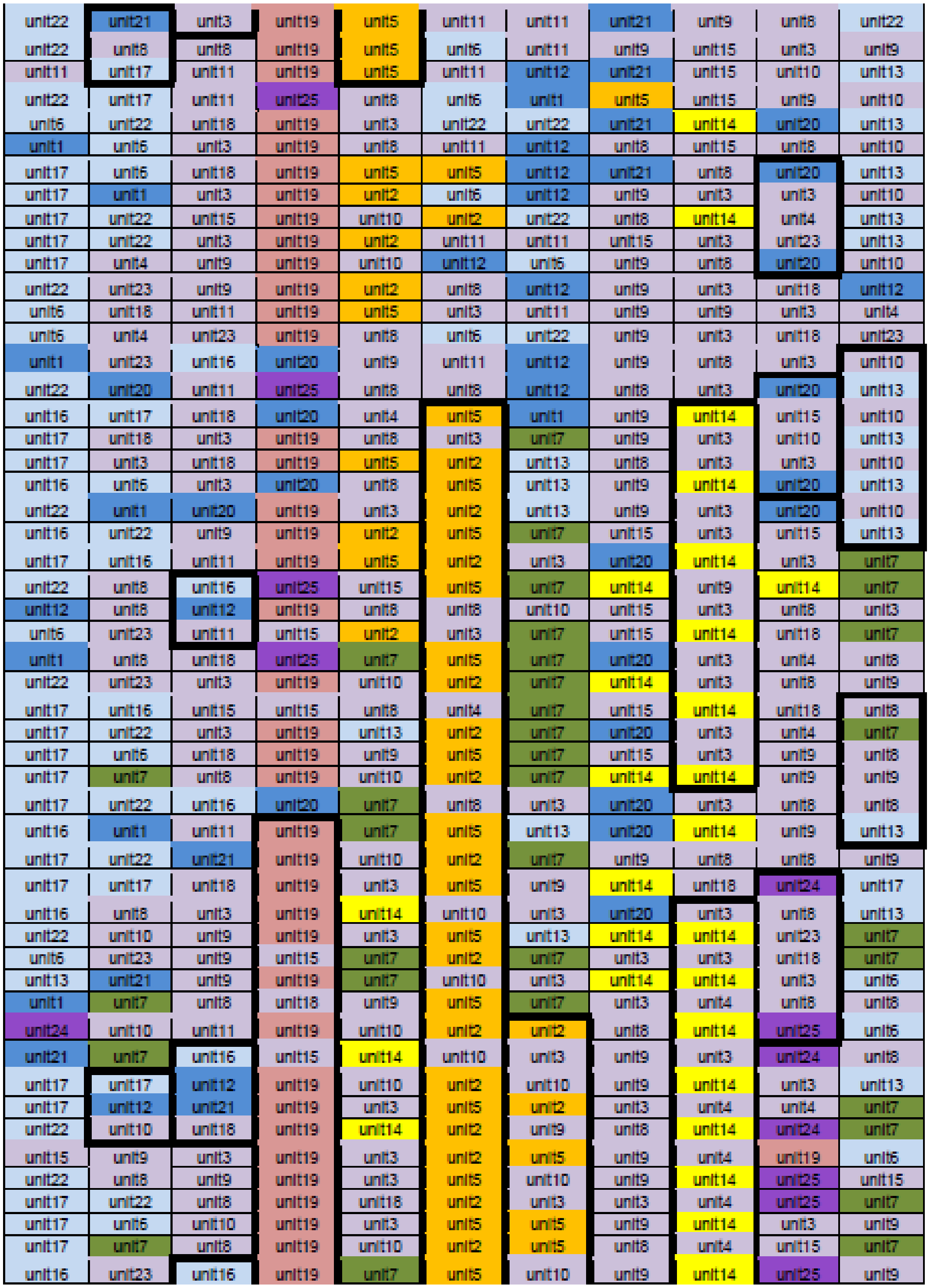
Sequence Analysis

One of the more important theoretical insights from HAL analysis has to do with the role of sequence. When unit identity is analyzed, for example in a conditional probability, the analysis, naturally, focuses on the unit. In human language, this is the equivalent of only being able to recognize "Boy sees cat" as a grammatical pattern if it is repeated over and over without variation. "Boy sees dog" or "Girl sees cat" would not be recognized as a correct grammatical pattern. The sequence analysis presented here was able to identify sequences at the Class level that were unique to both geographical regions (or, in the case of the Lesser Antilles, time), and to individual song. The specifics of the most consistent of these patterns have been discussed previously and are highlighted in Figure 15 (full corpuses can be found in Appendix B, while frequency counts can be found in appendix D).

Figure 15. Examples of sequences found. Note that sequences are made from Classes, and units within a Class may vary.



PR '70	PR '70	PR '70	PR '73	TC '74	TC '74	TC '74	LA '73	LA '73	LA '76	LA '76
117770	117774	117775	128296	118102	118118	118119	110847	110858	118171	118172
unit13	unit16	unit15	unit20	unit6	unit12	unit8	unit15	unit21	unit7	unit1
unit1	unit22	unit10	unit25	unit11	unit12	unit8	unit19	unit8	unit10	unit18
unit17	unit16	unit24	unit24	unit6	unit6	unit2	unit15	unit21	unit13	unit1
unit22	unit22	unit20	unit20	unit11	unit12	unit8	unit15	unit8	unit10	unit12
unit6	unit16	unit4	unit20	unit5	unit12	unit3	unit15	unit21	unit7	unit13
unit1	unit16	unit24	unit20	unit2	unit21	unit8	unit19	unit8	unit10	unit7
unit17	unit16	unit15	unit20	unit5	unit5	unit3	unit7	unit21	unit13	unit6
unit21	unit17	unit10	unit25	unit5	unit3	unit9	unit15	unit8	unit10	unit13
unit17	unit22	unit18	unit20	unit5	unit5	unit3	unit13	unit21	unit13	unit1
unit17	unit1	unit19	unit20	unit3	unit5	unit5	unit15	unit8	unit10	unit13
unit17	unit24	unit6	unit19	unit5	unit3	unit3	unit9	unit21	unit13	unit7
unit21	unit17	unit6	unit19	unit3	unit8	unit5	unit19	unit8	unit10	unit1
unit13	unit22	unit1	unit19	unit5	unit3	unit8	unit19	unit21	unit7	unit7
unit17	unit16	unit18	unit19	unit3	unit5	unit5	unit19	unit15	unit10	unit1
unit17	unit22	unit10	unit19	unit5	unit11	unit3	unit8	unit21	unit13	unit17
unit16	unit16	unit9	unit19	unit5	unit5	unit5	unit17	unit8	unit10	unit17
unit17	unit1	unit1	unit19	unit5	unit11	unit8	unit8	unit21	unit7	unit8
unit17	unit22	unit18	unit19	unit5	unit5	unit5	unit17	unit9	unit10	unit13
unit16	unit16	unit10	unit19	unit3	unit2	unit3	unit9	unit21	unit13	unit7
unit16	unit21	unit1	unit19	unit5	unit11	unit5	unit21	unit9	unit10	unit13
unit16	unit19	unit23	unit19	unit3	unit12	unit3	unit8	unit21	unit13	unit13
unit22	unit22	unit10	unit19	unit5	unit5	unit9	unit21	unit9	unit10	unit3
unit17	unit16	unit1	unit19	unit10	unit2	unit9	unit15	unit21	unit7	unit9
unit17	unit22	unit18	unit19	unit5	unit11	unit3	unit21	unit8	unit7	unit7
unit6	unit6	unit4	unit19	unit3	unit5	unit8	unit9	unit21	unit10	unit9
unit6	unit6	unit1	unit19	unit5	unit6	unit16	unit21	unit15	unit8	unit11
unit7	unit1	unit18	unit19	unit10	unit5	unit6	unit19	unit9	unit9	unit9
unit13	unit24	unit4	unit19	unit5	unit2	unit6	unit21	unit9	unit8	unit13
unit16	unit21	unit14	unit19	unit3	unit12	unit6	unit8	unit9	unit10	unit10
unit17	unit17	unit4	unit19	unit5	unit5	unit22	unit21	unit9	unit9	unit7
unit17	unit21	unit18	unit19	unit8	unit2	unit6	unit9	unit9	unit8	unit10
unit17	unit19	unit10	unit19	unit3	unit11	unit13	unit21	unit15	unit10	unit13
unit16	unit19	unit14	unit19	unit5	unit5	unit7	unit8	unit9	unit8	unit3
unit16	unit17	unit4	unit19	unit5	unit11	unit7	unit21	unit8	unit15	unit14
unit13	unit24	unit14	unit19	unit10	unit8	unit22	unit9	unit3	unit8	unit10
unit16	unit1	unit3	unit24	unit5	unit11	unit11	unit21	unit10	unit3	unit23
unit16	unit23	unit18	unit19	unit3	unit10	unit11	unit14	unit14	unit15	unit10
unit16	unit6	unit3	unit24	unit5	unit11	unit16	unit21	unit8	unit9	unit7
unit16	unit12	unit18	unit19	unit3	unit11	unit22	unit5	unit10	unit8	unit10
unit22	unit1	unit3	unit19	unit5	unit2	unit16	unit21	unit9	unit9	unit13
unit16	unit25	unit14	unit19	unit3	unit11	unit16	unit5	unit15	unit8	unit10



unit22	unit21	unit3	unit19	unit5	unit11	unit11	unit21	unit9	unit8	unit22
unit22	unit8	unit8	unit19	unit5	unit6	unit11	unit9	unit15	unit3	unit9
unit11	unit17	unit11	unit19	unit5	unit11	unit12	unit21	unit15	unit10	unit13
unit22	unit17	unit11	unit25	unit8	unit6	unit1	unit5	unit15	unit9	unit10
unit6	unit22	unit18	unit19	unit3	unit22	unit22	unit21	unit14	unit20	unit13
unit1	unit6	unit3	unit19	unit8	unit11	unit12	unit8	unit15	unit8	unit10
unit17	unit6	unit18	unit19	unit5	unit5	unit12	unit21	unit8	unit20	unit13
unit17	unit1	unit3	unit19	unit2	unit6	unit12	unit9	unit3	unit3	unit10
unit17	unit22	unit15	unit19	unit10	unit2	unit22	unit8	unit14	unit4	unit13
unit17	unit22	unit3	unit19	unit2	unit11	unit11	unit15	unit3	unit23	unit13
unit17	unit4	unit9	unit19	unit10	unit12	unit6	unit9	unit8	unit20	unit10
unit22	unit23	unit9	unit19	unit2	unit8	unit12	unit9	unit3	unit18	unit12
unit6	unit18	unit11	unit19	unit5	unit3	unit11	unit9	unit9	unit3	unit4
unit6	unit4	unit23	unit19	unit8	unit6	unit22	unit9	unit3	unit18	unit23
unit1	unit23	unit16	unit20	unit9	unit11	unit12	unit9	unit8	unit3	unit10
unit22	unit20	unit11	unit25	unit8	unit8	unit12	unit8	unit3	unit20	unit13
unit16	unit17	unit18	unit20	unit4	unit5	unit1	unit9	unit14	unit15	unit10
unit17	unit18	unit3	unit19	unit8	unit3	unit7	unit9	unit3	unit10	unit13
unit17	unit3	unit18	unit19	unit5	unit2	unit13	unit8	unit3	unit3	unit10
unit16	unit6	unit3	unit20	unit8	unit5	unit13	unit9	unit14	unit20	unit13
unit22	unit1	unit20	unit19	unit3	unit2	unit13	unit9	unit3	unit20	unit10
unit16	unit22	unit9	unit19	unit2	unit5	unit7	unit15	unit3	unit15	unit13
unit17	unit16	unit11	unit19	unit5	unit2	unit3	unit20	unit14	unit3	unit7
unit22	unit8	unit16	unit25	unit15	unit5	unit7	unit14	unit9	unit14	unit7
unit12	unit8	unit12	unit19	unit8	unit8	unit10	unit15	unit3	unit8	unit3
unit6	unit23	unit11	unit15	unit2	unit3	unit7	unit15	unit14	unit18	unit7
unit1	unit8	unit18	unit25	unit7	unit5	unit7	unit20	unit3	unit4	unit8
unit22	unit23	unit3	unit19	unit10	unit2	unit7	unit14	unit3	unit8	unit9
unit17	unit16	unit15	unit15	unit8	unit4	unit7	unit15	unit14	unit18	unit8
unit17	unit22	unit3	unit19	unit13	unit2	unit7	unit20	unit3	unit4	unit7
unit17	unit6	unit18	unit19	unit9	unit5	unit7	unit15	unit3	unit9	unit8
unit17	unit7	unit8	unit19	unit10	unit2	unit7	unit14	unit14	unit9	unit9
unit17	unit22	unit16	unit20	unit7	unit8	unit3	unit20	unit3	unit8	unit8
unit16	unit1	unit11	unit19	unit7	unit5	unit13	unit20	unit14	unit9	unit13
unit17	unit22	unit21	unit19	unit10	unit2	unit7	unit9	unit8	unit8	unit9
unit17	unit17	unit18	unit19	unit3	unit5	unit9	unit14	unit18	unit24	unit17
unit16	unit8	unit3	unit19	unit14	unit10	unit3	unit20	unit3	unit8	unit13
unit22	unit10	unit9	unit19	unit3	unit5	unit13	unit14	unit14	unit23	unit7
unit6	unit23	unit9	unit15	unit7	unit2	unit7	unit3	unit3	unit18	unit7
unit13	unit21	unit9	unit19	unit7	unit10	unit3	unit14	unit14	unit3	unit6
unit1	unit7	unit8	unit18	unit9	unit5	unit7	unit3	unit4	unit8	unit8
unit24	unit10	unit11	unit19	unit10	unit2	unit2	unit8	unit14	unit25	unit6
unit21	unit7	unit16	unit15	unit14	unit10	unit3	unit9	unit3	unit24	unit8
unit17	unit17	unit12	unit19	unit10	unit2	unit10	unit9	unit14	unit3	unit13
unit17	unit12	unit21	unit19	unit3	unit5	unit2	unit3	unit4	unit4	unit7
unit22	unit10	unit18	unit19	unit14	unit2	unit9	unit8	unit14	unit24	unit7
unit15	unit9	unit3	unit19	unit3	unit2	unit5	unit9	unit4	unit19	unit6
unit22	unit8	unit9	unit19	unit3	unit5	unit10	unit9	unit14	unit25	unit15
unit17	unit22	unit8	unit19	unit18	unit2	unit3	unit3	unit4	unit25	unit7
unit17	unit6	unit10	unit19	unit3	unit5	unit5	unit9	unit14	unit3	unit9
unit17	unit7	unit8	unit19	unit10	unit2	unit5	unit8	unit4	unit15	unit7
unit16	unit23	unit16	unit19	unit7	unit5	unit10	unit9	unit14	unit25	unit9

unit17	unit3	unit12	unit15	unit7	unit10	unit3	unit3	unit3	unit19	unit9
unit17	unit10	unit12	unit19	unit7	unit5	unit9	unit3	unit14	unit24	unit8
unit17	unit13	unit11	unit19	unit7	unit5	unit5	unit2	unit4	unit4	unit23
unit17	unit4	unit18	unit15	unit9	unit2	unit8	unit19	unit14	unit15	unit4
unit3	unit23	unit3	unit19	unit2	unit3	unit2	unit3	unit4	unit4	unit23
unit8	unit4	unit9	unit15	unit5	unit3	unit5	unit3	unit14	unit25	unit6
unit1	unit23	unit3	unit19	unit2	unit8	unit6	unit9	unit4	unit19	unit8
unit22	unit4	unit9	unit19	unit5	unit4	unit8	unit8	unit14	unit19	unit7
unit16	unit22	unit9	unit20	unit5	unit2	unit6	unit3	unit4	unit23	unit8
unit17	unit23	unit16	unit15	unit3	unit5	unit5	unit14	unit14	unit4	unit9
unit13	unit4	unit12	unit19	unit5	unit10	unit6	unit4	unit4	unit9	unit8
unit17	unit3	unit12	unit19	unit6	unit2	unit2	unit14	unit14	unit9	unit20
unit17	unit23	unit21	unit15	unit5	unit5	unit11	unit3	unit4	unit25	unit3
unit7	unit4	unit18	unit19	unit6	unit2	unit7	unit14	unit14	unit24	unit15
unit17	unit21	unit3	unit15	unit6	unit10	unit11	unit3	unit4	unit3	unit3
unit16	unit4	unit15	unit19	unit6	unit8	unit7	unit14	unit14	unit9	unit20
unit17	unit22	unit2	unit15	unit6	unit10	unit12	unit3	unit4	unit4	unit8
unit13	unit23	unit15	unit19	unit6	unit2	unit9	unit9	unit14	unit25	unit8
unit7	unit4	unit9	unit9	unit6	unit5	unit12	unit9	unit3	unit25	unit10
unit22	unit14	unit11	unit15	unit6	unit2	unit9	unit8	unit3	unit24	unit8
unit21	unit3	unit16	unit19	unit6	unit5	unit11	unit3	unit14	unit3	unit15

Using the color coding technique developed here, the sentences “Boy sees cat,” “Boy sees dog,” and “Girl sees cat” would all be identified as grammatically and semantically similar; “boy” and “girl,” being nouns, would belong to one Class and would be identified with the same color; “sees”, a verb, would be a different color; and “cat” and “dog,” both direct objects in this case, would be a third color – creating an identifiable pattern. That said, there are still variations in contextual usage and it is speculated that meaning differences would still be important within Classes.

It is important to note, when reviewing Figure 15, that some of the assertions in the results section may appear to be untrue. For example, it is discussed that no more than three or four units from Class Light Purple ever appeared consecutively in song102 or song118. Yet there is clearly a sequence of six units from Class Light Purple in song118. This contradiction is due to the fact that only sequences that occurred more than five times within a song were considered in the analysis. Therefore, although it may seem that the general rules for sequences identified via the entropy analysis are violated in the example provided, it is important to remember that the exceptions in this example are unique or rare occurrences.

Puerto Rico

Songs recorded in Puerto Rico were the least uniform of the three regions. Song96 was particularly anomalous – it was notably shorter and contained long repetitions of Class Pink, a class consisting of one unit and found infrequently in other songs. As a result, it was generally excluded from the analysis, although it should be noted that the variation within the Puerto Rican songs was not entirely due to song96.

Song "backbones" in Puerto Rico were either composed of units from Class Light Blue, Class Light Purple, or both. However, in all cases it is important to note the diversity of units here – because these backbones are composed of different units from the same Class, they could only be distinguished by an analysis of global co-occurrence. Geographically, Puerto Rico is located between Turks and Caicos (to the north) and the Lesser Antilles (to the south). As a result, if song elements were passed between whales (and populations) over geographic regions, it is plausible that songs recorded in a central area would be a mixture. For example, song70 and song74 both display elements common to song171 (recorded in the Lesser Antilles) - a backbone of units from Class Light Blue and Class Light Purple; "drop in" units from Class Light Blue, Class Light Purple, and Class Dark Blue; and root patterns composed of units from these Classes.

Turks and Caicos

Songs from Turks and Caicos were categorized by both their consistency and the presence of Class Orange, which was almost exclusively unique to this region (the highest occurrence in any other song was 1.6%, and in any other song it appeared in its frequency was less than 1%). For all intents and purposes, any sequence of more than three to four units in the Turks and Caicos was composed solely of units from Class Orange and Class Purple. In addition, longer sequences saw units from Class Purple only in single occurrences. Units from other Classes were recorded in Turks and Caicos, but only in shorter sequences. This lack of diversity may be evidence of a smaller "vocabulary" in the Turks and Caicos region; Class Orange is composed of only two units, and although all of the units from Class Purple appear at some time in the region, there was a distinct bias towards unit3, unit8, unit9, unit10, and unit11. Out of the nine units in Class Light Purple, these five accounted for 95.4% of the occurrences of the Class in the Turks and Caicos. This effectively created a vocabulary of seven units with which to build sequences of song at length greater than three to four units in this geographic region. For purposes of comparison, the song with the next smallest vocabulary was song74, which had 16 units and the only potential bias being towards unit16 and unit22 (Class Light Blue) - two units representing 75% of the occurrences of their five unit Class. A smaller vocabulary creates less lexical and/or semantic flexibility and thus less diverse songs. With this knowledge, one might hypothesize that this population of whales is relatively new and/or fairly isolated, which would consequently slow the process of change in song. Thinking back to the diversity of songs in Puerto Rico, a scenario such as a new or isolated population in the Turks and Caicos might explain why there appears to be very little similarity between the songs from these two regions, relative to the similarity between the songs of Puerto Rico and the Lesser Antilles.

Lesser Antilles

Songs in the Lesser Antilles appeared to get more complex over time. Over the course of the three years between sets of recordings, the backbone of the songs changed from exclusively Class Light Purple to a combination of Class Light Blue and Class Light Purple. In addition, the root patterns became more complex and sometimes even unpredictable. It is possible that there is a pattern of divergence here. The songs recorded in 1973 show similarity in pattern, containing root patterns that alternate Classes in a x+y+x+y or x+y+y+x pattern. In 1976 the songs change more. As previously mentioned, song171 is similar to some of the songs recorded in Puerto Rico, as if the whale(s) singing this song influenced or was influenced by singers in this region. Song172 becomes much more diverse and much less predictable; almost as if a new song or variation thereof were in the process of being created.

Entropy Analysis

The proposed ideas from the sequence data are supported in the overall entropy analysis. The variation in the Puerto Rican songs is evident; they show no agreement on the sequence length at which organization is the highest (song70 – eight units, song74 – seven units, song75 – six units). In the entropy graphs of the Lesser Antilles, one would expect that if singers in the Lesser Antilles are branching out over time, the songs recorded in 1976 would have more entropy than those recorded in 1973 (which is true). In Turks and Caicos, one needs to bear in mind that the strong decrease in the number of Classes used to create sequences occurred at sequences longer than three to four units. At five units, the decrease in the number of units causes increased predictability (decreased entropy). However, entropy increases from this point on. Just as prediction is a moot point when a series is random, so is it when a series is too repetitive; and even more so when the series is repetitive with one insertion at random intervals, as becomes the case in longer sequences in the Turks and Caicos due to the backbone and drop-in units.

It is vital that, while considering the ideas in this discussion, that one keep in mind the small sample size involved in this analysis. Although the actual songs contained large numbers of units, the number of Classes is relatively small, and several Classes only contain one unit. In addition, although the region comparison provides intriguing avenues to investigate, a sample size of two to four songs per region and/or year is far too small to draw firm conclusions. However, the results and ideas presented here are intriguing and should serve as a foundation for continued discussion and experimentation.

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CHAPTER 4: MICE

INTRODUCTION

When Holy and Guo first published on the courtship vocalizations of male mice, they thought they were unique in deeming these ultrasonic vocalizations "songs" and identifying structural and temporal regularities (Holy & Guo, 2005).   As they soon became aware, studies from as early as 1857 existed detailing audible courtship songs from mice (Guo & Holy, 2007); however, in combination with recent advances in genetic modeling of language disorders, this information was now a powerful new research technique.

Calls in several of strains of mice have been linked to specific behaviors, many of which facilitate the sequence of actions involved in courtship (Bartholemy, Gourbal, Gabrion, & Petit, 2004; White, Prasad, Barfield, & Nyby, 1998). For example, after pairing, the male mouse begins vocalizing with great intensity; continuing to do so throughout the series of sexual behaviors, and only ceasing (or severely decreasing his rate of) singing when engaged in tasks other than sniffing or mounting the female (Nyby, 1983). The feeling is mutual - playback experiments show that the ultrasonic songs produced by these males are excellent at attracting the attention of female mice – even as compared to artificial songs or the cries of pups. Furthermore, although desensitization is more rapid than might be expected, and the female's interest is independent of her reproductive state (Hammerschmidt, Radyushkin, Ehrenreich, & Fischer, 2009). Curiously, although female mice may be interested in the songs of males regardless of their own reproductive state, male mice are more selective - they produce songs only in response to urine scent from reproductive female mice, as opposed to other males or from sexually immature females (Pomerantz, Nunez, & Bean, 1983). They also respond at higher rates to the scents of novel females (as do females respond at a higher rate to the songs of novel males) (Musolf, Hoffmann, & Penn, 2010). Taken together, this appears to be strong evidence that songs are not only a key part in mating, but in sexual selection as well (Holy & Guo, 2005; Musolf et al., 2010; Pomerantz et al., 1983). The idea of a direct relationship to of mouse song to sexual selection is in turn compatible with the idea of analogous evolution of the use of ultrasonic songs for courtship in a variety of species. This is indeed the case for bats (e.g. Bohn, Schmidt-French, Ma, & Pollak, 2008), cetaceans (Lammers, Au, & Herzing, 2003; Madsen & Wahlberg, 2007), several species of rodent (Kapusta & Sales, 2009; Toro & Trobalon, 2005; Wohr & Schwarting, 2007), at least one species of amphibian - the concave-eared torrent frog (*Amolops tormotus*; Feng et al., 2006), and at least nine different species of moths (Nakano et al., 2009). It is hypothesized that this type of communication has evolved at least in part as a result of noisy environments (Feng et al., 2006; Tyack, 2008) and that it is advantageous because it can be heard by the intended recipient, who would be located nearby, and not by those who it is not intended for, such as predators or rivals (Nakano et al., 2009). As the previous species list is extremely diverse, it can only be proposed that ultrasonic courtship songs such as these evolved analogously, and therefore the evolutionary pressures that are (were) conducive to this would be useful to study.

It has been suggested that vocalizations (and their unique variants) can be used for behavioral analysis, such as identifying the phenotype of a genetic condition (Scattoni, Crawley, & Ricceri, 2009). In fact, mouse models exist for several disorders involving communication, including Down Syndrome, Rett Syndrome, and social aspects of schizophrenia (Holtzman et al., 1996; Picker, Yang, Ricceri, & Berger-Sweeney, 2006; Scearce-Levie et al., 2007). This experiment focuses on another mouse model, the *Fmr1* knockout mouse (henceforth, KO mice), that is used as a model for fragile X syndrome (The Dutch-Belgian Fragile X Consortium, 1994). People with fragile X syndrome experience a range of symptoms dealing with cognitive and social impairment; included in this spectrum are linguistic deficiencies, however, the exact nature of their cause remains under debate (Abbeduto & Hagerman, 1997; Roberts, Price, et al., 2007). Sudhalter and colleagues tested males with linguistic deficits due to fragile X syndrome with two hypotheses in mind; that the deficit was due to deficiencies in syntactic abilities, that in turn caused characteristic repetitious speech, and/or that linguistic problems were due to difficulties with what they called “expressive semantic competence,” which they defined as “the ability to choose the correct word from one's mental lexicon so as to produce a meaningful and well-formed thought” (1992, p. 66). They found the latter to be the case – showing more semantic errors in fragile X children than normal four year old children, in addition to more semantic errors in sentences without contextual constraint than in those with. They further attributed the redundant speech of fragile X children not to syntax, but to the use of "placeholders" while attempting to recall the correct words, and believe the linguistic deficit in fragile X children is not one of word identification, but rather word expression (Sudhalter et al., 1992). However, many have questioned some of the methodologies of this study, and more recent studies have supported an approach that identifies syntactic abilities as the main root of language deficiency in fragile X syndrome (Price et al., 2008; Roberts, Hennon et al., 2007).

Similarities in both pitch and pattern have been found between the unusual cries of autistic infants and autistic model mice pups, that support the use and generalizability of mice as a model system for autism related disorders such as fragile X in humans. Even more specific to the construct of communication, there is strong evidence that the ultrasonic vocalizations of mice may be an appropriate parallel system to study vocal impairments in humans. Mice contain an analog to the human FOXP2 gene, often called the "language gene" (Lai, Fisher, Hurst, Vargha-Khadem, & Monaco, 2001), that, when tampered with, causes deficits in vocalization. Using recombinant technology, researchers have been able to re-create a human mutation in the mouse gene and then "knock-in" the gene, thus developing a mouse model of the human mutation. In a heterozygous mouse (one with only one copy of the knock-in gene), impairments were less severe than in a homozygous mouse (one with two copies of the gene), showing a direct correspondence between the gene and the impairment (Fujita et al., 2008). In addition, there is also an analog of FOXP2 in songbirds. Male zebra finches have two types of singing behavior linked to the FOXP2 gene – one in which song is directed toward females and one in which it is not (Jarvis, Scharff, Grossman, Ramos, & Nottebohm, 1998; Zann, 1996). Curiously, male mice with the vocalization difficulties inherent in the *Fmr1* model also display these patterns; their song appears much more scattered – sometimes directed at females and sometimes directed elsewhere (Rotschafer, personal communication). It is not unimaginable to hypothesize a sort of three way interaction between the communication and behavioral deficits evident in the fragile X model mice and mutations in both *Fmr1* and FOXP2; indeed, Holy and Guo (2005), in the paper originally characterizing ultrasonic songs in mice, speculate just this.

It has already been observed that KO mice vocalize differently than their “normal” or wild type (WT) conspecifics (Rotschafer, in preparation), and the main goal of this experiment was to establish whether the difference in communication is semantic (in which case the HAL model would show contextual differences in the usage of individual sounds by the two strains), or syntactic (in which case either the differences in vocalizations would stem more from the sequential acoustic make up of the sounds or there would be no common syntax at all; both cases in which the HAL clusters would not reflect any pattern of co-occurrence). Because recent research shows that, in terms of the expression of language deficits, fragile X syndrome and autism are comparable (Kover & Abbeduto, 2010), and because of the high degree of comorbidity between fragile X and Autism Spectrum Disorders (Abbeduto, Brady, & Kover, 2007), this information has potential to provide important insight into the types of communication deficits present in several severe disorders.

The study presented here examines two components of communication – syntax, or sentence structure (represented here as patterning), and semantics, or word meaning (represented here as global co-occurrence). To enable this to happen, two different perspectives were taken for comparison of the corpuses. In order to compare the syntax of the WT and KO corpuses, it was necessary to assume that the Classes identified in the HAL analysis of the WT corpus were “correct,” and could therefore be mapped on to the calls produced by the KO mice. This would essentially result in a simulation of what the KO corpuses would look like if these mice understood the meaning of the calls they used (and therefore used them in the correct contextual relationships). With this assumption (done with the understanding that it is, to some degree, a leap of faith), it is possible to examine how the KO mice put together patterns – i.e., construct syntax. For example, this would be similar to a case in which despite understanding the words boy, ball, girl, tossed, threw, football; sentences such as “The football threw the boy” and “The ball tossed the girl” would be constructed. In this example, ball and football, and boy and girl, share global co-occurrences, however, the nouns and direct objects in the sentences – i.e. the syntax – are incorrect. Second, the Classes created by the KO corpus itself were examined as if they were unique to the KO corpus. This comparison essentially checks semantics; as the patterns (or syntax) are held constant and the

Classes (meaning or semantics) used to create the patterns are evaluated. For example, this would be similar to comparing two romance languages – the general sentence structure remains the same while the meaning changes between the two languages.

METHODS

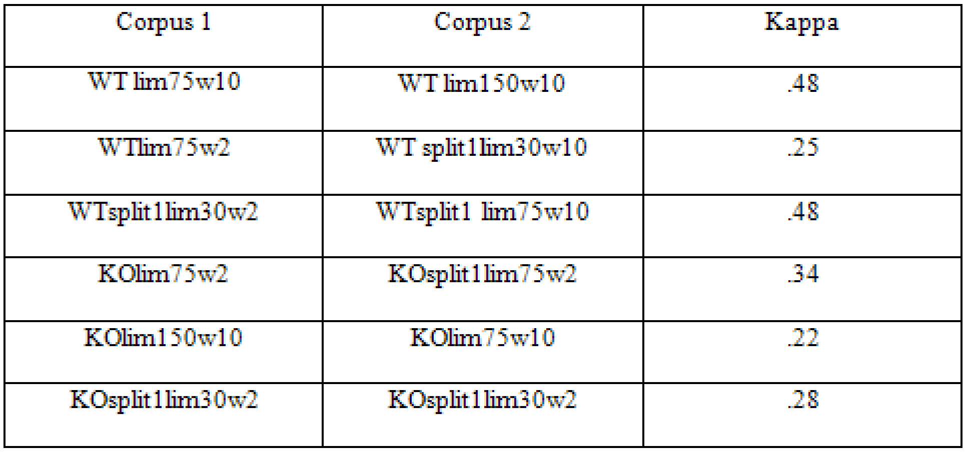
Mouse songs were recorded between April 25, 2008 and June 5, 2009 in the lab of Khaleel Razak at the University of California, Riverside. Male mice were placed in a container accompanied by a female mouse and recordings were made of ultrasonic vocalizations until either a) the female allowed the male to mount, or b) the female was inattentive to the male for periods long enough to be deemed unreceptive by the experimenter. Songs were recorded with a Petersson D 1000X Ultrasonic Detector. For more information on the recording process, see Rotschafer (in preparation).

Two strains of mouse were used in this experiment. A control, or wild type (WT) mouse, and a genetically altered mouse, the *Fmr1* knockout (KO). The *Fmr1* knockout mouse is a model for Fragile X syndrome in humans (The Dutch-Belgian Fragile X Consortium, 1994), a disorder consisting of autism like social impairment and mental disability due to insufficient or complete lack of production of the FMR protein (Sutcliffe et al., 1992).

After collection, vocalizations were digitized and classified by hand according to visual inspection of their spectrograms; a classification method that, though time consuming and labor intensive, has been shown to be quite robust (Deecke & Janik, 2006; Janik, 1999). The classification was actually conducted as a part of an experimental procedure, however the goal of the classification in both experiments was identical (Trujillo, in preparation). A total of 23 call types were classified, although one type was a "noise" category (ambient sounds such as doors opening and footsteps), and one occurred so infrequently that it did not appear in the analysis. In total, calls from 13 WT mice and 30 KO mice were recorded (although later in the analysis, when the songs of individual mice were being compared, several mice with extremely short songs (less than 20 calls) were dropped, effectively making this number 12 and 24, respectively, during that portion of the analysis). Songs sung by WT mice were significantly longer than those sung by KO mice, so the difference in quantity of songs was balanced by the length of songs in the two overall corpuses. Full corpuses can be found in Appendix C and frequencies can be found in Appendix D.

As discussed in the general methods, mouse songs were concatenated according to condition (WT or KO) and matrices were built using the HAL model. A variety of model parameters were used, including an unlimited matrix (almost no clustering), limits of 150 and 75, and window sizes of 10, 5, and 2. Using the split half comparison described in the humpback whale methodology, a limit of 150 and a window size of 2 were found to be the most robust when comparisons were made between whole and split corpuses (WT$\kappa_{split1, split2}$ = .71, .94; KO$\kappa_{split1, split2}$ = .85, .89). Additional kappas between outcomes of different parameter settings were calculated and can be found in Figure 16. These ranged from fair to moderate agreement, and while the agreement here may be less than that of the final corpus and its split halves, it is still substantially higher than a randomization such as that found in the humpback whale experiment, in which kappas were equal to .1 and .01. Frequencies of calls occurrence in the corpuses was positively correlated at r = .853 ($p \leq .01$), so frequency did not play a part in experimental outcomes.

Figure 16. Calculated kappas for comparison between models with different parameter settings.

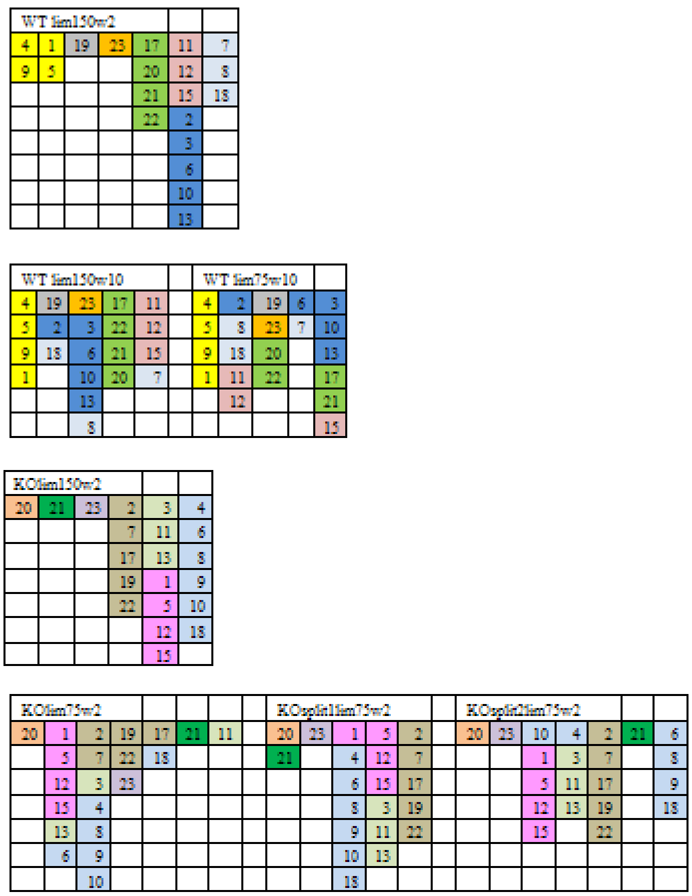


Corpus 1	Corpus 2	Kappa
WT lim75w10	WT lim150w10	.48
WTlim75w2	WT split1lim30w10	.25
WTsplit1lim30w2	WTsplit1 lim75w10	.48
KOlim75w2	KOsplit1lim75w2	.34
KOlim150w10	KOlim75w10	.22
KOsplit1lim30w2	KOsplit1lim30w2	.28

RESULTS

The final clustering (Class) patterns for the WT and KO mice can be found in Figure 17. In these diagrams vertical rows represent clusters output by the Ward's cluster analysis, while colors represent final mouse call Classes. In the case of each of the KO and WT condition, the top diagrams represent the final corpus parameters used in the experimental manipulations. However, as previously mentioned, multiple sets of parameters were tested, and several are also exemplified in the figure, below their respective final corpuses. In some cases, these tests had bearing on the final classification. For example, although the final corpus parameters chosen (limit 150 and window size 2) were deemed to be most appropriate overall, it was also the case with these parameters that Class Yellow (calls 1, 4, 5, and 9) in the WT corpus was divided into two output clusters in the Wards Analysis (hence two vertical rows in the diagram). Therefore, experience with testing at other parameters, in which these four calls nearly always occurred together, justified their grouping into one Class. Calls clustered

Figure 17. WT and KO mouse clusters. Clusters are read vertically. Numbers are Call numbers.



WT lim150w2						
4	1	19	23	17	11	7
9	5			20	12	8
				21	15	18
				22	2	
					3	
					6	
					10	
					13	

WT lim150w10						WT lim75w10				
4	19	23	17	11		4	2	19	6	3
5	2	3	22	12		5	8	23	7	10
9	18	6	21	15		9	18	20		13
1		10	20	7		1	11	22		17
		13					12			21
		8								15

KOlim150w2					
20	21	23	2	3	4
			7	11	6
			17	13	8
			19	1	9
			22	5	10
				12	18
				15	

KOlim75w2								KOsplit1lim75w2						KOsplit2lim75w2						
20	1	2	19	17	21	11		20	23	1	5	2		20	23	10	4	2	21	6
	5	7	22	18				21		4	12	7				1	3	7		8
	12	3	23							6	15	17				5	11	17		9
	15	4								8	3	19				12	13	19		18
	13	8								9	11	22				15		22		
	6	9								10	13									
		10								18										

differently for WT and KO mice. Cluster membership was almost completely altered between the two strains of mouse.

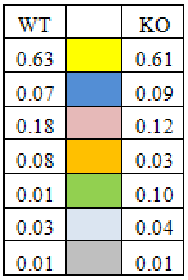
Manipulation 1: Checking syntax

WT Classes, if considered to be valid and reliably mapped onto the KO corpus, were completely distributed among the KO clusters. However, frequency of occurrence of each Class remained nearly the same between the two strains of mice (see Figure 18), with the only exceptions being Class Orange and Class Green.

Patterns also remained approximately the same, as judged by the length of uninterrupted stretches of the Class Yellow "backbone." The mean number of sequential calls from Class Yellow (i.e. number of calls in a row from Class Yellow before a call from another Class was "dropped in") in the WT corpus was 4.46 (SD = 4.2) and in the KO corpus was 4.81 (SD = 3.69). While the standard deviations on these averages may be very large, the two distributions overlap considerably, (t(1172) = 1.96, n.s. p is greater than .05). For samples of the corpuses, both mapped with the Classes as established via the WT clusters, see Figure 19.

Class Orange (in WT mice) and Class Green (in KO mice) were anomalous in that they each appeared to be found almost entirely in their respective strains of mouse. Possible reasons for this will be explored later.

Figure 18. Proportion of usage of each of the WT Classes, out of 100.



WT		KO
0.63	🟨	0.61
0.07	🟦	0.09
0.18	🟥	0.12
0.08	🟧	0.03
0.01	🟩	0.10
0.03	⬜	0.04
0.01	⬛	0.01

Manipulation 2: Checking semantics

As can be seen in Figure 17, when calculated independently in their separate corpuses, the resulting Classes in WT and KO strains of mice appear to be quite different. However, when the KO Classes were mapped back on to the KO corpus, it is initially evident that – as would be expected after the result of Manipulation 1 – patterns (or syntax) do exist. Once again, using the WT Classes as a standard for comparison purposes, the patterns can be assessed.

The Class Yellow backbone evident in the WT corpus is replaced by two classes – Class Light Blue and Class Pink. Specifically, where Class Yellow comprises from 47-89% of calls in each of the 12 songs in the WT corpus (beyond one exception, at 36%), the combination of Class Light Blue and Class Pink accounts for a slightly higher percentage of the KO corpus - 63-100% of calls in each of 23 songs (with 3 exceptions, two at 42%, and one at 47%). Mean length of uninterrupted sequences of Class Light Blue and Class Pink were 3.18 (SD = 1.64), and 3.70 (SD = 2.32) , respectively. Again, while the standard deviations here are extremely high, the populations are shown to overlap significantly (t(974) = n.s., p is greater than .05).

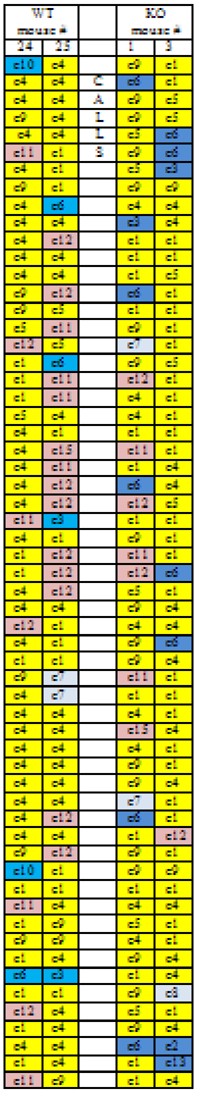
With respect to the specific order of Classes, it appeared as though the KO Classes were "trying" to maintain the patterned syntax established by the WT Classes. The pattern seemed similar; however the Classes that made up the patterns were not; meaning call order was similar, however, Classes were not. There was no one to one correspondence. For example, Figure 20ashows a comparison of two segments of KO mouse song coded twice - once with the KO Classes and once with the WT Classes. The WT Classes again show the Class Yellow backbone and drop ins, and there are some similarities in the patterns created by the KO Classes. However, the KO patterns are not a complete match for the correct WT patterns, as the individual units in semantic classes do not match. As shown in Figure 20b, for example, the calls in WT Class Dark Blue fall into a variety of Classes in the KO corpus; although they seem to do so in pairs, almost as if the KO mice were "trying" to keep the calls grouped together.

DISCUSSION

Manipulation 1

The WT and KO corpuses appeared similar when they were both mapped with the Classes from the WT corpus. This may be primarily due to the frequency of the four calls that composed the Class Yellow backbone, which was disproportionately high in both corpuses. The HAL model was run with a limit that controlled for this high frequency when creating the Classes; however, the effect is circular. Because there are such a high number of calls 1, 4, 5, and 9, there is a high probability that any one of these calls will be followed by another in the group. When strings of just these four calls become longer than a plausible window size (i.e. longer than one would expect from a mouse, even considering a global contextual scheme), co-occurrence vectors for each of the calls will, very often, consist solely of the other three calls. As HAL creates representations (whose relationships can then be visualized as clusters) strictly from these co-occurrence vectors, these calls are, in turn, are grouped in the same cluster.

Figure 19. Sample of songs with Classes created by WT corpus coded on to both.



WT mouse #			KO mouse #	
24	25		1	3
c10	c4		c9	c1
c4	c4	C	c6	c1
c4	c4	A	c9	c5
c9	c4	L	c9	c5
c4	c4	L	c5	c6
c11	c1	S	c9	c6
c4	c1		c5	c3
c9	c1		c9	c9
c4	c6		c4	c4
c4	c4		c3	c4
c4	c12		c1	c1
c4	c4		c1	c1
c4	c4		c1	c5
c9	c12		c6	c1
c9	c5		c1	c1
c5	c11		c9	c1
c12	c5		c7	c1
c1	c6		c9	c5
c1	c11		c12	c1
c1	c11		c4	c1
c5	c4		c4	c1
c4	c1		c1	c1
c4	c15		c11	c1
c4	c11		c1	c4
c4	c12		c6	c4
c4	c12		c12	c5
c11	c3		c1	c1
c4	c1		c9	c1
c1	c12		c11	c1
c1	c12		c12	c6
c4	c12		c5	c1
c4	c4		c9	c4
c12	c1		c4	c4
c4	c1		c9	c6
c1	c1		c9	c4
c9	c7		c11	c1
c4	c7		c1	c1
c4	c4		c4	c1
c4	c4		c15	c4
c4	c4		c4	c1
c4	c4		c9	c1
c4	c4		c9	c4
c4	c4		c7	c1
c4	c12		c6	c1
c4	c4		c1	c12
c9	c12		c9	c1
c10	c1		c9	c9
c1	c1		c1	c1
c11	c4		c4	c4
c1	c9		c5	c1
c9	c9		c4	c1
c1	c4		c9	c4
c6	c3		c1	c4
c1	c1		c9	c8
c12	c4		c5	c1
c1	c4		c9	c4
c4	c4		c6	c2
c1	c4		c1	c13
c11	c9		c1	c4

This means that despite the fact that the KO corpus does not identify the same patterns of co-occurrence as the WT corpus – remember that calls 1, 4, 5 and 9 are NOT in the same cluster in the KO cluster analysis – the KO mice still manage to create some of the same syntactic structure using individual units (recall Figure 19). To put it another way, while the WT mice may be building the "backbone" of their songs with any one of the four calls in Class Yellow, the KO mice may be building the backbone of their songs by putting together combinations of call1, call4, call5, and call9. It is the difference between a "choose one of" type instruction and an "or… or… or" type of instruction. In essence, the KO mice can create the correct syntax; however they are not doing so by using any sort of global semantic system.

Lastly, this particular mapping shows large amounts of Class Orange in particular songs – those sung by WT mice 26, 27, 35, and 36, and those sung by KO mice 31, 32, and 33 – and nearly none in other songs. Further investigation into the cause of this anomaly is warranted; if these recordings and/or classifications were carried out by a specific person whose technique may have been different, identifying this will be vital for future work. If this is not the case, other avenues by which vocalizations may be transmitted must be investigated. Ideas for exploration include housing conducive to Class Orange spreading in a population, rather like the cultural dialects that have

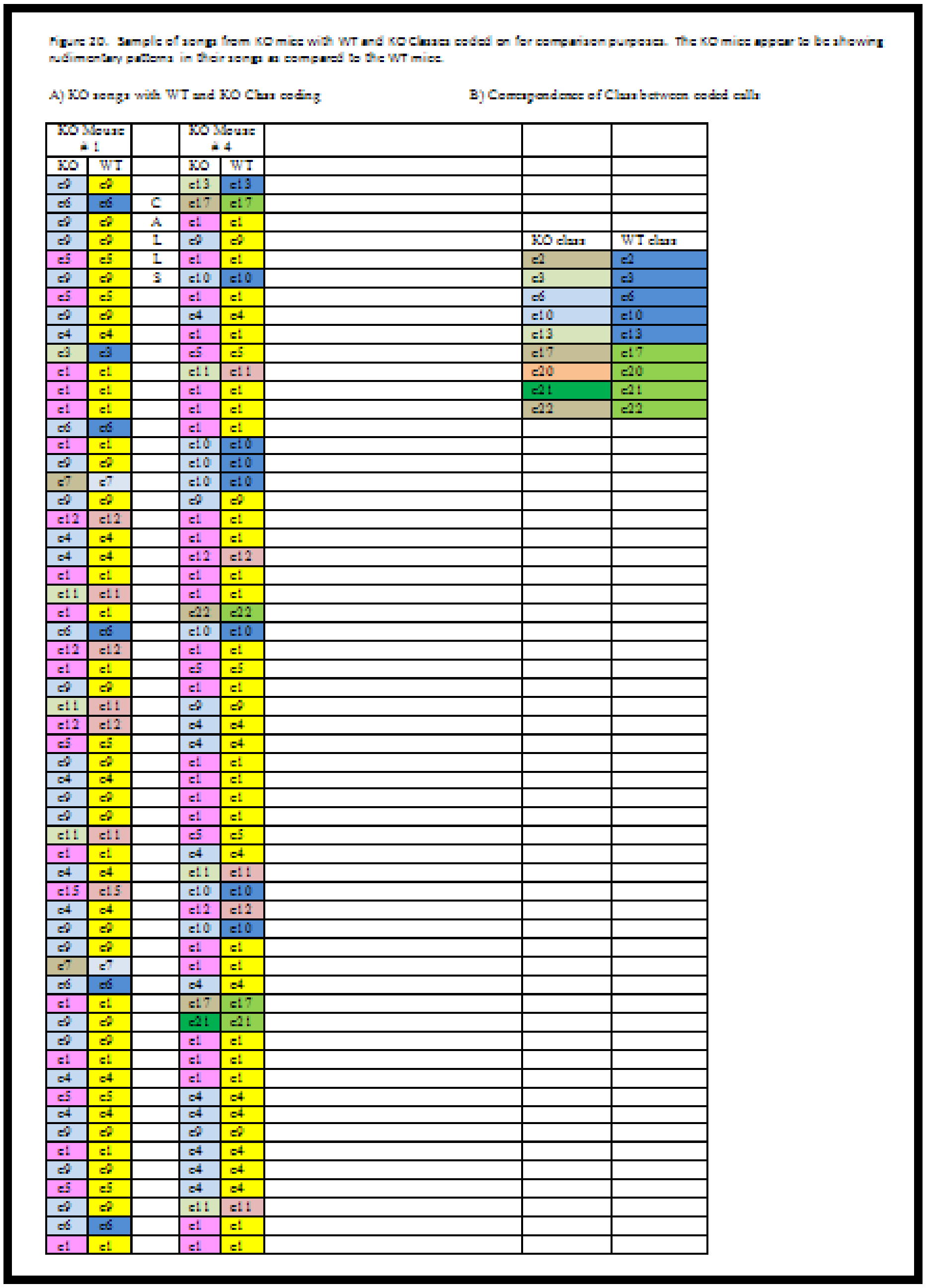


Figure 20. Sample of songs from KO mice with WT and KO Classes coded on for comparison purposes. The KO mice appear to be showing rudimentary patterns in their songs as compared to the WT mice.

A) KO songs with WT and KO Class coding

B) Correspondence of Class between coded calls

KO Mouse # 1			KO Mouse # 4				
KO	WT		KO	WT			
c9	c9		c13	c13			
c6	c6	C	c17	c17			
c9	c9	A	c1	c1			
c9	c9	L	c9	c9		KO class	WT class
c5	c5	L	c1	c1		c2	c2
c9	c9	S	c10	c10		c3	c3
c5	c5		c1	c1		c6	c6
c9	c9		c4	c4		c10	c10
c4	c4		c1	c1		c13	c13
c3	c3		c5	c5		c17	c17
c1	c1		c11	c11		c20	c20
c1	c1		c1	c1		c21	c21
c1	c1		c1	c1		c22	c22
c6	c6		c1	c1			
c1	c1		c10	c10			
c9	c9		c10	c10			
c7	c7		c10	c10			
c9	c9		c9	c9			
c12	c12		c1	c1			
c4	c4		c1	c1			
c4	c4		c12	c12			
c1	c1		c1	c1			
c11	c11		c1	c1			
c1	c1		c22	c22			
c6	c6		c10	c10			
c12	c12		c1	c1			
c1	c1		c5	c5			
c9	c9		c1	c1			
c11	c11		c9	c9			
c12	c12		c4	c4			
c5	c5		c4	c4			
c9	c9		c1	c1			
c4	c4		c1	c1			
c9	c9		c1	c1			
c9	c9		c1	c1			
c11	c11		c5	c5			
c1	c1		c4	c4			
c4	c4		c11	c11			
c15	c15		c10	c10			
c4	c4		c12	c12			
c9	c9		c10	c10			
c9	c9		c1	c1			
c7	c7		c1	c1			
c6	c6		c4	c4			
c1	c1		c17	c17			
c9	c9		c21	c21			
c9	c9		c1	c1			
c1	c1		c1	c1			
c4	c4		c1	c1			
c5	c5		c4	c4			
c4	c4		c4	c4			
c9	c9		c9	c9			
c1	c1		c4	c4			
c9	c9		c4	c4			
c5	c5		c4	c4			
c9	c9		c11	c11			
c6	c6		c1	c1			
c1	c1		c1	c1			

been evidenced in a variety of other species (Baker & Gammon, 2008; de la Torre & Snowden, 2009; Deecke, Ford, & Spong, 2000; Fehér, Wang, Saar, Mitra, & Tchernichovski, 2009; Putland, Nicholls, Noad, & Goldizen, 2006; Rendell & Whitehead, 2001; Wright, Dahlin, & Salinas-Melgoza, 2008), or transmission of vocalizations via learning or tutoring as has been shown in birds and is speculated upon by Holy and Guo (2005) (Beecher, Burt, O'Loghlen, Templeton, & Campbell, 2007; Belzner, Voigt, Catchpole, & Leitner, 2009; Nelson & Poesel, 2009; Pepperberg, 1994; Wheelwright et al., 2008).

Manipulation 2

Manipulation two was intended to check for semantics while maintaining a constant syntax between the corpuses. As previously noted, the Classes created by co-occurrence of calls in the KO corpus are quite different than the Classes that exist in the WT corpus. However, referring to Figure 20, rudimentary patterns of syntax are in evidence. Instead of one backbone Class, the KO mice appear to be using both Class Light Blue and Class Pink to comprise the backbone of their songs. In 14 out of 23 of these cases, the proportion of calls from Class Light Blue and Class Pink is approximately equal; the number of calls from each of the Classes was within ± 10 percent of the midpoint of their sum (for example, in KO Mouse #1, 90% of a song's units came from Class Light Blue and Class Pink (midpoint = 45%); of this, 55% were from Class Light Blue and 35% were from Class Light Pink). In these 14 cases, the ratio of the two backbone Classes would be closer to equal than not, as if the KO mouse were attempting to balance the semantic groupings. Of the remaining, less equalized mice, all save one mouse had a majority of their backbone vocalizations from Class Light Pink, almost as if these mice had determined that the backbone should be made out of one correct class as opposed to the other.

The KO mice in this manipulation showed the beginning of banding patterns similar to the syntax in the WT mice [describe on figure). However, the Classes are not consistent. If the KO mice had mastered the semantics involved in global contextual usage of Classes, one would expect equivalent clustering – in other words, all the calls in Class Green in the WT corpus would be in the same Class in the KO corpus (regardless of what it was called), not in three different "Classes. The KO mice have enough of a grasp on the song to use syntax to some extent, but do not have enough of a grasp of semantics to use more complex patterns of global co-occurrence.

From the perspective of high-dimensional modeling, it is interesting to think of this differentiation between syntax and semantics in a way similar to the high dimensional vectors built in Latent Semantic Analysis (LSA; Landauer & Dumais, 1997). The computational vectors in LSA are built from semantic word representations, which are abstract and gleaned over multiple experiences, and episodic contextual representations (Landauer & Dumais, 1997). Another perspective on these results might be that the KO mice are lacking in the abstract semantic portions (or equivalents thereof) to their call vectors, thus leaving them quite literally in the middle of a contextual representation – that of song in the context of courtship – but not the correct abstract knowledge to put together a meaningful sequence of vocalizations.

The ideas explored in the results of both of these manipulations are an important parallel to a classic symptom of fragile X in humans. Clinical signs of fragile X include problems with rate or speed of speech, including stuttering or repetition (Abbeduto & Hagerman, 1998). This may be represented in the case of the KO mice as problematic syntax. Furthermore, it is important to note that the syntax deficiency is specifically due to repetitions, which, in terms of the KO mice – very plausibly might be expressed as repetitions of individual calls (as opposed to members of a Class). In addition, with humans, there are impairments to lexical development in fragile X syndrome, which may be manifested in an ability to master a vocabulary (calls), but not a semantic grammar (Classes) (Abbeduto & Hagerman, 1998).

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CHAPTER 5: CONCLUSION

Cosmo

This study, despite the limitation of being conducted on a single subject, provides considerable insight into the cognitive abilities of an African Gray Parrot. A power study such as this provides information on the capabilities of a species by measuring the abilities of one individual. If an individual in a species is able to demonstrate a particular cognitive capacity with reliability, it can be assumed that the entire species possesses the mechanical *capabilities* for such cognition, regardless of the extent to which these abilities are displayed (Lloyd, 2004; Triana & Pasnak, 1981).

It appears that Cosmo can exploit the patterns of statistical regularity in language, and, in particular, global co-occurrence, in her language learning. The HAL model, which detects these language patterns, was able to identify meaningful clusters within Cosmo's speech. When Cosmo's speech was input into the model as individual words, the co-occurrence clusters that appeared were similar to those found in humans (albeit less definitive); words that Cosmo used in similar contexts were grouped together. This pattern also held at a phrase level; when Cosmo's utterances were entered into the HAL model in phrase form, the clusters which resulted had contextual themes – for example, contact calls or vocalizations dealing with the telephone. These phrases show the same global co-occurrence patterns within conversations (or their equivalent) as words do within sentences.

In addition, coincident with working with the HAL model, several other insights into Cosmo's language abilities became apparent. Cosmo has several distinct areas in which she shows an ability to create novelties in language, namely unique phrase constructions, humor, and the generalization and transfer of word meaning. Cosmo consistently uses phrases that are agrammatical in human language; however they cluster normally within their intended contextual groups as one would expect with a model like HAL. These are phrases Cosmo has created. BJ would not use grammar this awkward, and thus Cosmo could not have copied the phrases (as such) from her. Yet, Cosmo still uses them in the correct context; she is not randomly playing with or re-arranging words. The HAL model, when analyzing typed human language, will group “the” and the typo “teh”, because they occur in the same context (Burgess, 1998; Burgess & Lund, 2000; Lund & Burgess, 1996). This type of grouping is a nearly identical circumstance to Cosmo’s agrammatical usage, the only difference is that Cosmo has “created” the “typo” (and consistently uses it).

Cosmo also demonstrates humor of her own creation. After learning that birds have feathers, dogs have fur, and people wear clothes, she mixes and matches with “jokes” such as “Mary (the dog) has feathers!” and then loudly scolds herself “Nooooo! Mary has fur!” In addition to the humor in these phrases, they are also uniquely Cosmo’s creation.

Lastly, Cosmo provides evidence of the ability to generalize meaning. She uses words referentially and has multiple labels for one object. She is also able to substitute words in context, having learned “you have reached … [phone number]” as an answering machine message, and subsequently creating her own phrases by plausibly substituting a variety of words (for example, “Betty Jean”) for the phone number.

Because this study used *N* = 1, it is an understatement to say that more research is necessary before any definitive generalizations with regards to anything beyond the basic capability can be drawn. However, the language abilities demonstrated here by an African gray parrot support the idea that the species may indeed possess the substrate necessary for many higher cognitive functions (Kako, 1999).

Humpback Whales

One of the initial goals of this research was to provide support for the existence of cultural clans in humpback whales by showing dialects that were unique to regions, but seemed to share traits with nearby regions or across periods of time. There is some evidence for this in the case of songs recorded in Puerto Rico, which is located geographically between the Lesser Antilles and Turks and Caicos (the other two locations in which data were recorded). The songs in Puerto Rico were much more diverse than the songs recorded in the other locations. It was also harder, in this region, to identify a uniform, overall, region-specific pattern in the songs. However, the songs did share some characteristics of the songs recorded in the other two areas; most notably, there was a similarity between song70 and song74 (Puerto Rican songs), and song171 (recorded in the Lesser Antilles).

Songs recorded in both the Lesser Antilles and in Turks and Caicos show signs of change by forms of dispersion, or spreading, of song patterns (or lack thereof). The Turks and Caicos songs are uniform and conform to a fairly strict set of rules. In addition, the vocabulary (both number of unit types and number of Class types) used by whales in this area is limited. This small vocabulary may be indicative of a population that is isolated by geography to some extent, and that, as a result, is not exposed to songs from other populations; these factors might also result in additional, region specific novelties. Thus, this limited vocabulary could be indicative of a newly developing population that is just establishing a distinct dialect and, therefore, would show a specific necessity to maintain a clear, easy-to-sing dialect with few elements in order to promote retention. In the Lesser Antilles, there is possible evidence of the divergence of songs over time, as in 1973 the songs measured are far more similar to each other than those measured in 1976. This is roughly the same pattern that would be expected in the future for the songs from the Turks and Caicos (Putland, Nicholls, Noad, & Goldizen, 2006; Rendell & Whitehead, 2005; Weilgart & Whitehead, 1997).

Additionally, the results provide support for global co-occurrence in humpback whale song, as many of these patterns (plus the song backbones) would not have been identifiable without initially identifying the Class that is encoded in the statistical regularities of the song sequences. Classes, whether they are semantic or grammatical or represent a combination of the two language components, do appear to be involved in the creation of humpback whale song. These patterns, which may be similar to patterns in human language, could be identified in all of the songs. For example, one could compare the English grammar pattern noun + verb + direct object to a pattern in the humpback song such as Class Light Blue + Class Dark Blue + Class Light Purple. In both cases, the categories (be they human grammar or whale Class) consist of a variety of individual elements, and any of these elements would serve the proper contextual purpose in the pattern or sentence.

Mice

The goal of the manipulations presented here was a comparison of male courtship songs from a group of *Fmr1* knockout mice – which are used as a model for fragile X syndrome – to normal, or "wild type" mice.

HAL analysis reveals that the KO mice appear to have limited use of syntax, but that their syntactic patterns are formed at the local co-occurrence level only. For example, the songs of WT mice are characterized by a backbone made from one particular Class. HAL analysis shows the calls in this Class to be contextually similar, and tokens in the backbone can come from any of the four calls in the Class. The same four calls appear with very high frequency in the songs of the KO mice, and if they are coded with the Classes established by the WT mice, it is apparent that they could form a backbone. However, the matrix built from the KO corpus shows that these mice do not use the same global co-occurrence clusters as the WT mice (which, for purposes of this experiment, were assumed to be an appropriate baseline). HAL does not identify the four calls that create the backbone in the WT corpus as a Class in the KO corpus. Therefore, the KO mice are only able to create songs with the correct syntax because they are putting together the backbone of the song at a local level. To phrase it differently, KO mice create the background of their songs by creating sequences of call1, call4, call5, and call9, while WT mice build their songs by creating sequences of calls from Class Yellow (the class which contains these calls).

When examining the Classes created from global co-occurrence directly in the KO corpus, the ways in which the KO mice are creating their songs and the "mistakes" they are making (in comparison to the WT mice) become more apparent. Using the KO corpus and mapping on the "correct" Classes obtained in the WT analysis, a rough comparison can be made between the co-occurrence structure in the KO mice and what it might have been had they been using the typical contextual relationships (relative to what they are using in reality). KO mice divide the four calls in the backbone (Class Yellow) into two Classes in their own dialect (for lack of a better word). However, there appears to be a tendency toward a higher frequency of one Class over the other, creating the possibility that the KO mice have some sense of what "should be" happening. In addition, the KO mice show patterns of drop-in calls that are very similar to those of the WT mice; however, these patterns exist because of call identification – not Class. For example, if we coded a drop in of call17 using the “correct” Classes, it would appear as a Class Green token in a Class Yellow backbone. However, using KO Classes, it appears as a Class Beige token in a Class Pink backbone. This would be appropriate, if the other members of WT Class Green were *also* members of KO Class Beige – but they are not. Again, the WT mice are using a system in which they can pick any call from a particular Class, whereas the KO mice are confined to building syntactic patterns with specific call type.

Currently, conclusions from the literature dealing with the language impairments in fragile X syndrome in humans lack consistency. There is evidence that links the language deficit to problems with expressive semantics, or difficulty retrieving the word desired from already learned vocabulary to complete the expression of a thought (Sudhalter, Maranion, & Brooks, 1992). The results here support this mechanism for language difficulties. Other studies, however, have shown that there is a delay in the learning of syntax in people with fragile X syndrome (Roberts, Hennon, Price, Dear, Anderson, & Vandergrift, 2007; Price, Roberts, Hennon, Berni, Anderson, & Sideris, 2008). The study here provides evidences contrary to this, as the KO mice showed signs of being able to appropriately use syntax, at least on a local level.

High dimensional modeling of language acquisition in humans and animals

High dimensional modeling in linguistics has never erred on the side of traditionalism. Starting in the 1990’s, high dimensional models such as the SRN, HAL, and LSA challenged the traditional notions of innate natural language and began to replace traditional theories of language acquisition (“Induction explained?”, 1997). The expansion of this success into the arena of animal communication is unsurprising proof of their universal applicability. In fact, a recent paper has even used emergent models to account for aspects of the more traditional language acquisition models they themselves replaced. Mayor and Plunkett (2010) recently assembled a computational model based on self organizing maps that accounts for, among other things, fast mapping as a method of language acquisition and the rapidity with which language is learned in early childhood – both ideas (or part of ideas, as is the case of rapid language learning in the minimalist program) which likely should - and will - be replaced with emergent language theories.

High dimensional models such as HAL and LSA have introduced a new perspective on language acquisition in humans, that language is an emergent property that can be learned via a simple inductive mechanism despite a seemingly “impoverished stimulus.” The evidence of global co-occurrence patterns in animal vocalization presented here further supports this idea as it adds to a general convergence of evidence. This is particularly true because of the novelty of the situation – animal vocalizations – the continued robustness of the high dimensional approach in such a situation extends the universality of the models application.

Limitations of these studies

As mentioned in earlier chapters, much of the work presented here is novel. Because higher cognitive issues in non-human species are addressed, these results will naturally – and rightfully – be regarded with skepticism. However, this is only the second time that a concept such as contextual co-occurrence has been applied to animal vocalizations of any sort (McCowan, Doyle, Kaufman, Hanser & Burgess, 2008), and the results have been sufficiently encouraging to warrant further exploration.

The humpback whale and mouse studies are also limited by the fact that there is no way to understand the meanings of the classes that cluster as a result of the statistical regularities in the input stream. In the Cosmo study, it is easy to discern the success or failure of an analysis, because the results “make sense” in that one can understand them by human experience. The only recourse available in the other studies is playback, which is logistically complicated and technologically sophisticated. In light of this limitation, every effort has been made to make appropriate choices regarding model parameters. For example, efforts were made to gather opinions from those who work with the study specimens and to apply what is known from communication systems, such as the idea that the most stable structure is the preferred one.

Lastly, statistical techniques for the confirmation of many the patterns identified in this study have not been worked out. The color coding technique was developed specifically for these experiments as a method of visualizing patterns of Classes, as opposed to individual units. Techniques such as the entropy analysis help identify common patterns in the data; however, due to their categorical nature, there is little beyond qualitative description that can be used to describe the patterns once they have been found.

Future studies

Before anything can be definitively stated about the use of global co-occurrence in animal communication, other successful studies must be conducted and the parameters used in models need to be successfully standardized. In addition, a universal technique for examining data such as these must be adopted – be it the color-coded analysis developed and presented here, or some other technique.

One important way to validate the idea that global co-occurrence is a relevant construct in animal communication systems is by subjecting vocalization streams such as the ones tested here to other models - similar to the HAL model - which operate by very different mechanisms, yet produce similar results. Two models that are closely related to HAL are Latent Semantic Analysis (LSA; Landauer, Foltz, & Laham, 1998) and the Simple Recurrent Network (SRN; Elman, 1990). Both models - like HAL - learn from context and without outside training, and both models have shown similar results with similar data sets (Burgess & Lund, 2000; Yan, Li, & Song, 2004). These models would be the most appropriate starting point for a comparative model of these types of models but also the theory they test..

It may also be worthwhile to examine new corpuses for analysis. Two traits, absent in these three experiments, would be particularly appealing: a smaller-sized and/or more discernable vocabulary, and the availability of behavioral data. The former, as a problem, is strikingly evident in the lack of progress that has been made on dolphin vocalizations; this species is by far the most well studied of all the marine mammals, the most accessible (in both captivity and in the wild), and the species for which behavioral data are easiest to obtain. However, because the dolphin whistle stream is extraordinarily hard to segment and classify into individual tokens, very little progress has been made beyond the issues under debate, and into concepts such as syntax and structure (Buck & Tyack, 1993; Deecke, 2006; Deecke & Janik, 2006; Janik, 1999; McCowan & Reiss, 1997, 2001; Sayigh, Esch, Wells, & Janik, 2007). With the exception of the large literature on signature whistles, which are theorized to be “names” (Caldwell & Caldwell, 1965), there is only a single study that has examined meaning in dolphin whistles (McCowan, Doyle, Kaufman, Hanser, & Burgess, 2008). A communication repertoire in which individual elements are much more readily defined – for example, the time dependant codas of sperm whales or a particularly well categorized species of bird’s song-- would be particularly desirable for the type of analyses discussed here. In addition, while a small corpus limits generalizability and precision, corpuses with as many synonyms or as large of a vocabulary as the corpus used for the Cosmo experiments can also be unwieldy.

In the absence of “word” meaning knowledge, behavioral data would be a major asset. The ability to understand the words spoken by a parrot is an undeniable bonus to the amount and nature of conclusions that can be drawn. The availability of behavioral data that is paired with the communication stream would provide some context in which to place the communication and offer the possibility of making inferences about the meaning of the classes of information.

The advantage of being able to understand the Cosmo corpus (or that of any other language-speaking parrot) also enables the use of additional linguistic models. Programs such as Linguistic Inquiry and Word Count (LIWC; Pennebaker, Francis, & Booth, 2001) are particularly aimed at analyzing usage of concepts such as emotion words, positive and negative connotations, first and third person references, and other details of language that we might describe as “human like.” A comparison of these concepts could prove insightful into the cognition of the species being studied.

Figure 21. Re-coding of the Elman corpus to create a "backbone" Class

The introduction of the "backbone structure" found in both the humpback whale and mouse corpuses, is an important finding in this research. Initially, this backbone and the proposed "drop in" units may appear counter-intuitive to the patterning that was discussed as evidence of global co-occurrence. However, this is not the case. Returning to the example of the Elman corpus in Figure 10, we can also create Figure 21 by broadening the noun class to include direct objects. Upon doing this, a purple backbone becomes evident. Further studies on the parameters that create the backbone class could be theoretically important from a syntactic perspective.

Lastly, the use of less traditional measures such encephalization quotient or innovative ability may prove fruitful in providing direction for the selection of promising species for study. Many of the communication systems of species that are "traditionally" thought of as intelligent are already being studied; these include species such as great apes, marine mammals, monkeys, parrots, corvids, elephants, and carnivores such as pinnipeds and, more recently, dogs. However, other markers for intelligence might open up other promising species as subjects for investigation; marmots and foxes for their relatively higher EQ's, Australian bowerbirds for their innovative abilities, pigs for their rapid learning, octopuses for their problem solving abilities, otters for their elaborate play, and several species of birds for their tool use and innovative techniques for prey capture (Broom, Sena, & Moynihan, 2009; Finn, Tregenza, & Norman, 2009; Keagy, Savard, & Borgia, 2009; Lefebvre, 1995; Lefebvre, Nicolakakis, & Boire, 2002; Ralls & Siniff, 1990; Roth, 2003; Werdenich & Huber, 2006).

Benefits of this research

The benefits of the research presented here encompass both theoretical and practical arenas. From a theoretical perspective, the idea of the evolution of language is a hotly debated topic in recent academic literature (Hauser, Chomsky, & Fitch, 2002). The comparative perspective taken here is a vital one; it is only from a truly cross-species, comparative, perspective that we can really hope to understand the selective pressures that have shaped the evolution of language. By finding common (or lack of common) threads in communication capabilities among species, we can trace what environmental conditions may have been conducive for the analogous development of such abilities in species as diverse as birds and land and sea mammals.

The most important, general theoretical result from this research has been the discovery that some animals have statistical regularities in their communication that carry sophisticated information reflective of a range of categorical knowledge. Simple regularities, such as conditional probabilities, have been identified by others; however, these results represent a much higher-order level of knowledge.

From a practical perspective, any insight into the evolution of language will bring us one step closer to understanding the variety of language deficits and deficiencies that plague so many people. The *Fmr1* knockout mice discussed here provide a perfect example of this insight; while symptoms of fragile X syndrome can be created in mice for the purposes of experimental treatment and pharmacology, the root cause of the symptoms (such as deficits in linguistic abilities) can only be understood by identifying them specifically and comparing them to “normal” models. This comparison and the resulting information will be vital to treatment.

Understanding the complexities of communication and category learning in animals and what the categories might represent will be a key step in the future development of animal communication. In both the effort to understand the evolution of our own communicative abilities, and in the challenges faced in overcoming language impairments, the thoughts of the Chinese General Sun Tzu are particularly appropriate: “Know your enemy and know yourself and you can fight a hundred battles without disaster.”

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APPENDIX A

Complete repertoire for Cosmo, plus abbreviations of sounds. An “s” on the end of a sound denotes a sequence.

Legend of sound abbreviations	
AM	answering machine toot
CR	crow caw
DB (DS)	dog bark, gruff, or howl
DO	door opening creak
DUW	duet whistle/solicitation
DW	dog whine/whimper (can sound like a whistle)
FR	frog sound
HA	hawk sound
ID	indistinguishable (either too soft to hear, an indistinguishable fragment of a word, or a distinct word that is not recognized)
KS	kiss sound
LA	laugh
LS	laser sound
LSW	laser sound ID whistle combo
MWH	misc whistle
NWM	miscellaneous non-whistle
OOO	woo/ooh
OU	oww as in pain
OW	owl hoot. Long and drawn out flute sounding
PH	phone dialing beep sound
PHS	more than 5 beeps in a row. Usually 7 or 10 for a phone number)
RI	phone ring
SR	Squirrel chuck
WBI	wild bird imitation
WF	woo woo woo or "woo" (Betty Jean saying "woof")
WW	wolf whistle

Alone	**In**	**Out**
WBI	wanna come here	hello
MWH	wanna come here	WBI
NWM	cosmo be a good bird	NWM
WBI	cosmo go up here	NWM
NWM	wanna be a good bird	WBI
CR	cosmo don't bite okay	NWM
CR	cosmo wanna go up here	LS
CR	OOO	OOO
CR	WBI	cosmo wanna go for a walk
CR	NWM	no
CR	want peanut	DUW
CR	wanna come here	DUW
CR	cosmo don't be	DW
CR	wanna go up here	DWS
CR	okay	DW
CR	cos don't bite okay	DS
CR	wanna go up here	DW
CR	no	DW
CR	ID be a good bird	NWM
CR	don't bite okay	NWM
CR	cosmo wanna go up	DUW
CR	ID be a good bird	DUW
CR	cosmo don't bite okay	come here
CR	no	i'm here
DS	wanna be a good bird	DUW
DS	ID	DUW
DS	cosmo wanna go up	DUW
DS	cosmo don't bite okay	DUW
DS	wanna be a good bird	come here

DS	cosmo wanna go for a walk	there you are
DW	ID ID	DUW
WBI	betty jean wanna kiss	DUW
NWM	KS KS KS	DUW
NWM	come here please	DUWS
NWM	KS	i'm here
LS	wanna come here	there you are
OOO	cosmo be a good okay	DO
NWM	no	DUW
NWM	wanna be a good bird	WW
NWM	okay cos	i'm here
NWM	no	DUW
NWM	kiss	WW
DS	KS KS	DUW
DS	look	DUW
NWM	cosmo wanna talk	DUW
OOO	betty jean wanna whistle DUW	DUW
NWM	DUW	DUW
what's that	DUW	i'm here
that's cosmo's a birdie	cosmo wanna whistle DUW	there you are
betty jean want a kiss	cosmo and betty jean wanna whistle	hi
KS	DUW	DO
NWM	DUW	DUW
DS	i love you	WBI
DS	cosmo's a good good good bird	WBI
NWM	betty jean wanna kiss	hi
NWM	KS	hello
NWM	come here please	RI
cosmo step up please step up	no	DUW i'm here
cosmo please	wanna talk	there you are
NWM	we're gonna have company	DS
KS	that's cosmo we're gonna	DS

	have	
DUW	tele for bird	DW
WBI	you have reached	DUW i'm here
WBI	tele for betty jean	DUW
NWM	goodbye	DUW
wanna please step up kay don't bite	NWM	DUW
DS	telephone for bird	DUW i'm here
WBIS	ID ID ID ID	there you are
WBI	wanna come here	there you
what's that	ID no	i'm here
DW	betty jean wanna kiss	there you are
WBI	hi cosmo we're gonna have	DUW
what's that	look	DUW
that's paper	betty jean wanna kiss KS	DUW
okay cosmo we're gonna go for a walk	KS	DUW
doggies wanna go for walk	that's cuddle	hi
doggies wanna go for a walk	look	hello
cosmo stay home	no	DUW
okay step up	betty kiss okay	DUW
step up here	KS	DUW
where are you	kiss	DUW
here you are	that's cosmo's a birdie	cosmo we're gonna go for a walk
cosmo back in cage	wanna talk	no
doggies wanna go for a walk	wanna whistle	cosmo stay here
mary come on	DUW	NWM
DUW	no	WF
come mary	cosmo ID bird	DS
DUW	i love you	DS
come on	KS	WBI
wanna go for a walk	we're gonna have company	DUW

doggies wanna go for a walk	no	NWM
no	betty jean has to go in a car	LSW
okay goodbye	wanna come here	LS
we'll be back soon be back	no	hello how are you
DS	betty kiss KS	fine thank you
OOO	ID	goodbye
WBI	what a good	thank you
WBI	MWH	AM
WBI	DUW	WBI
WBI	look come here	PHS
WBI	KS	that's birdie OOO
WBI	betty jean want	oh goodbye
WBI	KS KS KS KS KS KS	NWM
WBI	hi	WW
WBI	wanna come here	WWS
WBI	betty jean wanna kiss KS	WWS
WBI	kiss okay	wow LA
WBI	KS KS	LA
WBI	go up	no
WBI	that's televi	i love you
WBI	OOO	WBI
PH	what	WBI
RI	that's televi	LS
hello	what	telephone for bird
hi	that's televi	hehehe
how are you	OOO	DS
ID	what	DS
doggies wanna go for a walk	that's tele	DS
no	OOO	DUW
HA	betty jean wanna kiss feathers	that's bark
HA	come here please	WF
HA	look	NWM
DW	where cosmo	wan go to bed
DS	NWM	DS

RI	LS	DW
RI	OOO	DS
you have reached five five four three ID	fine thank you	DW
AM	how are	DWS
DW	KS	DS
DWS	kiss okay	DWS
DSS	KS KS	DS
DWS	come here please	DW
DW	look cosmo we're gonna ID go to work	DS
HA	okay	mary
HA	cosmo wanna go for a walk	mary
that's televi	no	DUW
televi	i love you	DUW mary come
that's cosmo step up please	what a good bird	mary
RIS	look kiss KS	DUW
RI	cosmo wanna kiss KS KS	DW
hello	come here please	DW
hi tom how are you	KS	NWM
okay thanks ID bye	that's televi	DW
PH	OOO	NWM
DW	that's kiss	NWM
NWM	cosmo wanna talk	NWM
NWM	DUW	NWM
NWM	DUW	NWM
NWM	betty jean wanna kiss KS	NWM
NWM	WF	what's bye
okay wanna go for walk	i love you	DUW
DW	OOO	NWM
mary come on	peanut	hello
come mary	want be a good bird	hel
DUW	cos	WBI
we're gonna go for a walk	cosmo back cage don't bite	WBI

	okay	
DW	no	WBI
DW	cosmo go up	WBI
DW	okay go up	hello
DS	step up	WBI
DW	step up please	WBI
DW	please	WBI
DW	WF	WBI
we're gonna go for a walk	look cosmo we're gonna kiss	WBI
okay we're gonna go for a walk	that's kiss	NWM
come on	KS KS	WBI
come on	i love you	WBI
come on mary	cosmo's a birdie	NWM
DUW	wanna talk	what's that
mary	cosmo's a good good good good girl	that's bark
we're gonna go for a walk	betty jean wanna	WF
DW	WW	NWM
okay we're gonna go for a walk	KS	kiss
come on	KS	KS
okay we're gonna go for a walk	that's televi	DUW
come on	OOO	DUW
DUW	that's tele	DUW
DW	that's tele	DUW
we're gon go for a walk	OOO	NWM
kerri come come on	that's televi	KS
DUW	OOO	NWM
HA	cosmo wanna kiss KS	NWM
MWH	i love you	DS
we'll be back soon be back	birdie	DS
goodbye cosmo i love you	cosmo wanna whi DUW	DS
okay ID we're gonna go for a walk	DUW	DS

okay dogs we're gonna go for a walk	NWM	NWM
come on	DUW	DW
DUW	cosmo what's that	that's bark WF
DS	wanna come here no	WF
DW	betty kiss	WBI
DS	KS	WBI
DW	that's televi	WBI
NWM	OOO	WBI
DW	that's televi	PH
DS	OOO	PHS
DW	that's televi	hi tom
okay we're gonna go for a walk	cosmo wanna talk	hi tom how are you
DW	telephone for bird	okay bye
DW	no	PH
okay we're gonna go for a walk	you have reached	PHS
DWS	five four nine	RI
okay cosmo we're gonna go to car	you five four nine	DS
PH	tele for betty jean	OOO
PH	hello	PH
WBI	okay goodbye NWM	PHS
WBI	you have reached	hi tom
wanna	okay goodbye NWM	okay ID ID LA
DW	that's tele for bird	NWM
DS	betty jean wanna kiss the feathers	PH
NWM	cosmo is a birdie	PHS
NWM	cosmo wanna talk	RI
wanna go for a walk	wanna whi DUW	what's that
doggies wanna go for a walk	DUW	hi
doggies wanna	LS	how are

go for a walk		you
DW	OOO	cosmo wanna talk
DS	NWM	okay goodbye
DW	ID cos step up please	PH
RI	KS	PH
hi tom	want kiss	PH
ID wanna walk	WW	RI
okay bye	NWM	what's that cosmo
PH	NWM	telephone for bird
PH	that's WF	DS
RI	time for shower and peanut for cosmo	DS
hello	we're gonna have company	cosmo wanna go to work
hi tom	no	no time go to bed
oh thank you bye	yes cosmo's a girl	cos wanna go to bed
PH	you have reached	no
PH	telephone for bird	DW
PH	ID	MWH
RI	cosmo	WBI
PH	cosmo wanna talk	WBI
PH	KS	WBI
PH	ID	DW
RI	that's bark	WBI
PH	okay step up please	DWS
RI	that's paper	DS
hello	LS	WBI
hi	OOO	WBI
how are thank how are you	wanna peanut	WBI
okay goodbye	DUW	MWH
NWM	KS KS	MWH
PH	okay step up here cos	WBI
PHS	be a good bird okay go up	MWH
WBI	ID be a good	MWH

	bird	
WBI	go up	what's bye
WBI	wanna be a bird	DUW
WBI	okay go up	DUW
that's rain	cosmo don't bite okay	DUW
i love you	no	WBI
we're gonna go for a walk	what's that	that's ID
no betty jean go in a car	ID	betty jean have go
okay	that's WF	we're gonna go in a car
we'll be back soon	WF	cosmo's gonna go for a walk
PH	what's cosmo	that's
PHS	that's ID ID up here	NWM
WBI	NWM	MWH
DW	you have reached	here step up
hi	telephone for bird	let's go to betty jean room
hello	ID wanna peanut	come up KS
how are you	DUW	PH
DOS	DUW	RI
we're gonna go for walk	okay	telephone
OOO	time for shower and peanut	oh goodbye
DW	no cosmo's ID	NWM
NWM	wanna kiss	DS
DW	KS KS KS KS	DS
okay we're gonna go for a walk	NWM	DS
doggies go for walk	that's bark	DWS
PH	WF	WBI
DOS	cosmo's a girl	MWH
hello cosmo	LS	WW
we'll be back stay here be back	OOO	MWH
RI	fine thank you	thank you

DS	how are you	MWH
DOS	what a good bird	MWH
DSS	we're gonna have comp	WBI
WBI	no we're gonna stay home	DW
that's wanna grape	okay	MWH
peanut's in cage	betty kiss KS KS KS	DW
peanut's in cage	NWM	mary
HA	OOO	WBI
HA	hello mary	DS
WBI	WBI	DS
RI	KS	WW
what's bye	kerri	DS
i love you	NWM	DS
that's squirrel	DUW	WBI
goodbye	wanna kiss	NWM
be back	KS	WBI
PHS	KS KS	WBI
hi tom	wanna kiss	WBI
hi ID	no we're gonna here	DW
NWM	we're gonna cosmo and betty wanna talk	WBI
DOS	wanna kiss	WBI
DO	come here	DW
hello	no	DS
look we're gonna go up	wanna be a	DS
i'll be back be back go for a walk	ID ID ID	DS
no we're gonna go for a walk	OOO ID doggies	DW
DWS	MWH	DS
NWM	WW	DW
DW	NWM	DS
DS	okay	DS
DW	what's betty jean ID ID	DW
DS	want kiss	DS
DW	KS KS KS KS	DS
DOS	WBI	DW
hi	DUW	DS
hello	what a good	DS

	bird	
that's squirrel	DUW	DSS
we're gonna go for a walk	DUW	DS
doggies wanna go for a walk	DUW	DS
NWM	i love you	DW
DW	ID ID ID	DWS
RI	ID up here	DS
hello	DUW	DS
hi	yes	DS
how are thank you	DW	DS
PH	DS	DS
PH	DW	DSS
NWM	DS	DS
we're gonna go for walk	DW	that's doggie bark
doggies wanna go	ID wanna kiss	mary
NWM	KS KS	mary
WBI	you have reached betty jean	mary
WBI	hi	DUW
WBI	how are you	DW
WBI	NWM	DS
we're gonna go for a walk	LS	DS
we're gonna go for a walk	OOO	DW
NWM	wanna peanut okay	DW
NWM	be a good bird okay go up	DW
okay wanna go for a walk	wanna be a good bird	DS
DWS	wanna peanut okay	DWS
MWH	ID we're gonna have	DS
cosmo poop	look cosmo wanna peanut	DS
hi	no	DUW
we're gonna go for a walk	you have reached cosmo	DUW
NWM	you have reached	DUW
doggies time for	five four nine six two four	DUW

	three telephone	
DS	wanna be a good bird	DUW
DS	okay cosmo wanna go up there	DUW
DW	cosmo wanna poop	DW
hello cosmo	LA	DS
squirrel	hello kerri	DS
we're gonna go for a walk	mary has doggie has	DS
doggies ID go for a walk	ID ID ID KS	DS
okay ID cos be back soon	NWM	DS
we'll be back	DO	DS
we'll be back	DUW	DW
AM	DUW	DWS
HA	NWM	WBIS
HA	LS	MWH
HA	OOO	i'm here
DW	fine thank you	DUW
hello	how are you	WW
that's squirrel	you	hi
we'll be back ID we're gonna go for a walk	five four nine six two four three LA	MWH
we're gonna go for a walk	cosmo	let's go to betty jean have to go work
dogs go for go for walk	you wanna whistle	cosmo's a bird LA
NWM	DUW	you have reached betty jean
hello cosmo	DUW	NWM
we'll be back soon be back	DUW	WW
PH	ID ID WF	ID
PHS	WF	NWM
hi tom	WF	DO
hi tom	WF	AM
ID walk	WF	PHS
NWM	WF	doggies wanna go for a walk
DWS	NWM	no please stay here
hi	look	AM

hello	NWM	PH
how are you	NWM	DUW
time for ID shower	that's WF	DUW
time for betty jean	NWM	how are you
time	that's WF	fine thanks how are you
WBI	WBI	WBI
WBI	ID	DW
WBI	cosmo wanna talk	NWM
DUW	DUW	what's that
WBI	DUW	that's ID bark
we're gonna go for a walk	DUW	WF
we're gonna have company	NWM	WF
PHS	wanna come here	PHS
hi tom	no	WBI
ID ID ID ID ID	we're gonna stay home	that's we're gonna go in a car
OOO	we're ID here	telephone for bird
ID ID bye	DS	you have reached betty jean
RI	LS	hi
hello	OOO	WBI
RI	fine thank you	that cosmo wanna go to work
telephone	KS	no
okay	MWH	MWH
we're gonna ID	wanna come here	NWM
DS	DUW	NWM
NWM	KS KS	MWH
hello	OOO	WBI
WBI	NWM	hi
peanut's in cage	NWM	hidey ho
DS	what's that	DS
DUW	that's televi	DS
DUW	ID	DW
hello	mary has feathers	MWH

DS	MWH	NWM
DS	ID	WBI
WBI	mary has feathers	DUW
WBI	MWH	PH
WBI	hey mary	cosmo wanna go to bed
where wanna go	mary	i love you
we'll be back soon be back	cosmo is a birdie has feathers	DS
i love you	MWH	DS
goodbye	mary feathers	DS
let go	MWH	DS
DS	hello kaylee	WBI
DS	KS doggie has feathers	AM
DS	MWH	DS
DS	no	DS
DW	cosmo's a doggie	DS
DW	ID	DS
MWH	mary has feathers	DS
DUW	MWH	DS
DUW	ID for cosmo	DW
NWM	ID cosmo's a bird and has feathers	AM
that's rain	MWH	NWM
we'll be back soon	mary has feathers	cosmo wanna go up here
okay doggies go for walk	MWH	DUW i'm here
no	no	WBI
that's rain	wanna come here	DUW
fine	wanna come here	DUW
hello	KS	DUW
how are you	wanna come here	five four nine six two four three
PH	we're gonna go to kiss	telephone for bird
PH	KS	PH
PH	mary's a dog	WBI

PH	hello kerri	WBI
we're gonna go	mary's a doggie has	that
WBI	ID	WBI
OOO	WBI	DUW
wanna be a good	NWM	WBI
we're gonna go for a walk	wanna here	MWH
doggies wanna go for a walk	wanna be a good bird	MWH
no	okay go up	WW
that's rain	please KS	i love you
i'll be back soon	wanna be a bird	i love you KS
WBI	cosmo go up	telephone for
RI	be a go up	you have reached bet
DS	wanna be a	hello
DW	cosmo don't bite	hi
what's baylog	cosmo	WBI
DS	wanna go up	DUW
DO	wanna be a good bird	DUW
hello	okay go up	i love you
that's squirrel	wanna be a good bird	NWM
we're gonna go	okay	NWM
betty jean have to leave	cosmo go up	NWM
be back soon be back	cosmo wanna go up	NWM
AM	NWM	you have reached five four nine six two four three
PH	NWM	AM
PH	wanna be a good	LS
PH	want peanut	OOO
PH	ID ID cosmo go up	i love you
PH	cosmo wanna go back cage	WBI
WBI	NWM	NWM
hi	cosmo be	wanna up

		here
hello	wanna go up	DUW
how are you	wanna be a bird	DUW
DUW	ID cosmo	DUW
DUW	cosmo be a bird	we're gonna have company
oh hello	go up	hi tom thanks ID bye
hello cosmo	ID be good bird	PH
wanna go up	cosmo wanna go up	PH
NWM	cosmo be a good bird	PH
DS	go up	PH
RI	NWM	PH
DOS	ID that's WF	WBI
we're gonna go for a walk	NWM	DW
doggies wanna go for a walk	wanna peanut	you have reached
NWM	DUW	telephone for bird
NWM	cosmo be a good bird	KS
okay dogs we're gonna go for a walk	cosmo wanna go up	NWM
come mary	you have reached	DO
come on	LA	DO
DUW	OOO	LS
mary	wanna be a good bird	OOO
we're gonna go for a walk	ID	bye
WBI	wanna be a bird	hi tom
WBI	ID	ID ID ID to walk
DUW	cosmo go up	bye ID
we're gonna go for a walk	cosmo be a good bird	PH
hi	okay go up	MWH
hello	here step up	MWH
how are you	hi	MWH
KS KS KS	wanna be a	MWH

we'll be back soon	cosmo wanna come here	MWH
DW	okay cosmo wanna go up	WBI
DS	cos don't bite	WBI
MWH	no	WBI
hello	please	we're gonna go ID
PH	KS	DW
PH	what's that	DO
NWM	mary has	NWM
DOS	wanna whistle	NWM
we'll be back soon	DUW	NWM
we're gonna go for a walk	DUW	DW
okay	DUW	PH
be back soon be back	DUW	DO
be back soon i love you	wanna whistle	NWM
KS	DUW	wanna come here
DW	DUW	i love you
NWM	DUW	NWM
hello cosmo	DUW	NWM
squirrel	cosmo and betty jean wanna whistle	WBI
let's go back cosmo be back okay back	wanna peanut	WBI
okay back cosmo	be good bird	WBI
PH	no more peanut	that's birdie
PHS	cosmo wanna ID okay	that hurt
WBI	wanna be a good bird	come here
WBI	cosmo wanna go up	i love you
MWH	don't bite	HA
that's televi	wanna cuddle	HA
wanna go to work	come here	WBI
OOO	wanna kiss	DW
televi	betty jean wanna kiss	DS
televi	come here	DS

	please	
OOO	come here please	DS
WBI	KS	DW
WBI	kiss okay	NWM
DUW	NWM	WBI
DUW	step up cosmo wanna cuddle	wanna go in here
DS	don't cos be a good bird	DUW
DS	look wanna kiss KS	i love you
WBI	betty kiss	WBI
DW	NWM	NWM
DW	ID ID	DS
PH	go up cosmo be a good bird	DUW
PH	go up	WBI
PH	OOO	where are you
RI	NWM	i'm here
wanna peanut	wanna peanut	DS
peanut in cage	cosmo wanna be a good bird	DS
DUW	cosmo go up here	DS
DOS	cosmo go up	DS
NWM	go up ID okay	WBI
NWM	wanna come	hello cosmo
hello cosmo	cosmo go up	i love you
what's that	ID be good bird	cosmo wanna be a good bird
PH	cos don't bite okay	okay go up
PH	wanna go up	cosmo be a good bird
WBI	wanna peanut	go up
we're gonna go to kitchen	cosmo wanna peanut o	be a good bird okay go up
PH	cosmo wanna be a good bird	okay go up
DW	DUW	step up
NWM	okay	PH
DW	wanna kiss KS KS	PHS
wanna be a	NWM	hi tom

good		
WBI	DUW	i'm ID
NWM	wanna	WBI
DW	cosmo wanna be a good bird	DUW
PH	cosmo go up	i'm here
hello cosmo	okay	ID i'm here
we'll be back	cosmo wanna go up	WW
NWM	DUW	i love you
RI	DUW	i love you
NWM	i'm here	WBI
NWM	cosmo wanna go up	WW
DS	no peanut	DUW
DUW	okay go up	i'm here
DUW	cosmo wanna kiss	i love you
NWM	KSS	i love you
that's wanna grape	i'm here	KS
peanut for	DUW	WBI
DO	wanna gonna	where cosmo where are you
there you are	cos	LA here
i'm here	wanna be a good bird	NWM
DO	NWM	WW
ID tom	okay cosmo	wanna come here
okay bye	cosmo go up	i love you
PH	cosmo wanna	NWM
DSS	wanna go up	NWM
DO	cosmo don't bite okay	NWM
hello cosmo	come here	WBI
squirrel	DUW	WBI
be back soon be back	DUW	that's birdie
AM	DUW	come here
DW	DUW	DUW
WBI	i'm here	WBI
DO	come here	we're gonna go
come here	KS KS	hi tom
we're gonna go for a walk	okay	hi tom
WBI	cosmo be a go	okay

	up	thanks bye
WBI	DUW	PH
WBI	DUW	PH
PH	WW	PH
PHS	DUW	WBI
hi tom	LS	OOO
hi tom ID walk	DUW	NWM
RI	wanna go bed	NWM
what's bye	no cos	DUW
betty jean have to leave	ID	DUW
NWM	cos no	WBI
NWM	DUW	DUW
NWM	DUW	DUW
NWM	i'm here	betty jean have go in a car
NWM	ID kiss	oh ID
NWM	KS KS KS KS	goodbye cosmo
WBI	KS KS	ID
hi tom	cosmo go back cage	DO
alright thanks bye	DUW	MWH
PH	DUW	MWH
hello	i'm here	LS
hi hep how are you	LS	fine thanks how are you
DS	how are OOO	DO
DS	KS	cosmo wanna water
DS	cosmo	i love you
DW	wanna be a good bird	we're gonna go in a car
DW	cosmo go up	MWH
WBI	MWH	DUW
DS	DUW	WBI
WBI	WW	DUW
WBI	LS	DUW
DS	fine thank	DUW
DS	ID KS KS	DUW
that's bark	DUW	that's birdie
OOO	DUW	hi
woof	DUW	WBI
DS	DUW	MWH
DS	i'm here	DUW

DW	there you are	hello
DW	i'm here	hi how are you
DS	WBI	cosmo wanna go in a car
PH	DUW	cosmo's a bird
CR	DUW	no
LS	DUW	cosmo wanna water
OOO	DUW	WF
fine	i'm here	what's that
RI	i'm here	WF
PH	MWH	hi
hello	DUW	DUW
hi jeff how are you	DUW	DUW
bye	WW	LSW
PH	wanna kiss	fine thanks how are you
WBI	DUW	i love you
cosmo wanna showe	DUW	NWM
NWM	okay	MWH
step up here	wanna	DUW
step up	cosmo be a good bird	NWM
step up	ID cosmo be a good	DUW
up up up up up up	LA	DO
PH	cos	goodbye
PH	NWM	i love you
PH	DS	okay we'll be back soon okay
DW	NWM	MWH
dogs wanna go for walk	cosmo wanna talk	DUW
NWM	NWM	DUW
DW	NWM	WBI
NWM	WW	DUW
LSW	WW	DUW
NWM	WW	DUW
WBI	WW	DUW
that's woof	WW	DUW
DW	WW	betty jean have to go

		in a car
what's bach	NWM	LSW
DUW	look	NWM
PH	NWM	where are you
KS	that's tele	ID thanks how are you
LSW	telephone for bird	NWM
woof	LA	DUW
DUW	ID	LSW
PH	telephone for betty jean	cosmo is a bird
PHS	hi	cosmo wanna water
hi tom	goodbye	DS
hi tom how are you	NWM	LS
DS	goodbye	DS
DS	NWM	i love you
DS	that's cosmo	we're gonna go LA
DW	goodbye	WBI
NWM	NWM	DUW
MWH	look	WBI
DS	NWM	DUW
DW	ID wanna cuddle	KS goodbye
NWM	don't bite	cosmo betty jean gonna go in a car
LSW	NWM	DO
AM	KS	MWH
PH	WBI	DUW
look wanna grape	DO	ID i love you
a peanut for cage	MWH	hi kerri
here you are	DUW	cosmo wanna water
KS	DUW	MWH
WBI	cosmo time for shower and peanut	DS
DS	no	DW
PH	okay step	LSW

DS	ID ID cosmo	that's ID bark DS
OOO	LA	WF
DS	no	PH
DW	look	WBI
NWM	NWM	DUW
MWH	cosmo	cosmo gonna go in a car
KS	LA	no betty kiss KS KS KS KS
OOO	cos let go	i love you
DS	OOO what a bird	ple let go please
DW	don't bite don't wanna cuddle	let go no LA
DS	ID have feathers MWH	cosmo
MWH	what a good	i love you
NWM	cosmo wanna cuddle	okay OOO
what's bach	don't bite don't	DUW
how are you	o	NWM
what's bach	OU	LSW
cosmo poop	wanna cuddle	ID thank you
PH	don't bite	DUW
RI	don't bite	DUW
NWM	DUW	i'm here
DS	cosmo wanna whi	there you are
DW	DUW	cosmo stay okay go in a car
DS	DUW	cosmo wanna talk
WBI	cosmo wanna shower	NWM
what's bach	here step up	MWH
i love you	step up up up up up up	DUW
cosmo's a birdie	let go	DUW
mary has	let go	betty jean have to go in a
cosmo has feathers MWH	LA	goodbye
betty jean has gla	OOO what a bird	DS

AM	let go	DS
AM	let go	DS
NWM	let go LA	DW
DS	let	LS
DW	let go	WBI
DWS	let go please	MWH
DS	let go	hi
WBI	LA	ID
WBI	let go	MWH
WBI	let go	DUW
NWM	LA	DO
FR	cosmo	DUW
NWM	NWM	DUW
DS	NWM	DUW
FR	MWH	goodbye
DS	MWH	cosmo betty jean have go in a car
OOO	NWM	ID be back soon okay
WBI	MWH	i love you
FR	NWM	MWH
DS	look	DUW
DW	cosmo wanna peanut	DO
DW	KS	goodbye
DSS	MWH	i wanna go in a car
DW	DUW	ID be back soon
DS	KS	MWH
DS	DUW	DUW
DS	DUW	WBI
DS	wow	NWM
ODS	cosmo wanna shower	DUW
that's bark	wow	goodbye
woof	DS	WBI
PH	ID has feathers MWH	WBI
RI	cosmo wanna cuddle	WBI
hi tom	no ID	WBI
WBI	OU don't bite	DUW
WBI	WBI	DUW
WBI	here you are	alright
DS	i'm here	NWM
DSS	wanna kiss	DUW
DS	DUW	DUW
DWS	KS	DUW

DSS	wanna go to	WW
DWS	NWM	goodbye
that's doggie bark	LS	i love you
mary's a doggie	fine thanks	cosmo stay home we're gonna have
OOO	cosmo wanna be a good bird	okay
RI	okay cosmo don't bite	cosmo's gonna go in a car
telephone ID telephone	cosmo wanna go up here step up	DO
five four nine six two four three	ID ID please	MWH
telephone	please	DUW
what's that	let go	DUW
what's bach	LA	goodbye
DW	OOO	betty jean have go in a car
NWM	NWM	step okay
LSW	wanna ID feathers MWH	i love you
woof	okay	cosmo we're gonna go in a car
NWM	PH	DO
time	hello	DUW
wanna peanut	PH	DUW
peanut for peanut	PHS	goodbye
what's bach	hi tom	DSS
woof	hi tom how are you	DS
NWM	goodbye	DSS
ID	NWM	DS
woof	look cosmo	DS
woof	okay	DSS
where are you	want kiss	DS
there you are	DUW	CR
cosmo wanna go back cage	KS	DO
here step up	NWM	MWH
doggies wanna	wanna kiss	goodbye

go		
squirrel	KSS	betty jean have
that's squirrel	ID ID	WBI
that's squirrel	cosmo wanna go up	WW
okay we're gonna go to betty	no	DUW
NWM	DUW	DUW
DS	NWM	NWM
that's woof	NWM	goodbye
that's woof	NWM	i love you
NWM	wanna be a good birdie	goodbye kerri
LS	okay cos	WBI
OOO	cosmo go be a good bird please	hi
fine thank you how are	please step up	that's ID how are you
cosmo back in cage	NWM	MWH
wanna step up	you have reached betty jean	DUW
we're gonna have company	goodbye	DUW
NWM	NWM	DUW
NWM	DSS	DO
NWM	don't bite	goodbye
NWM	OU	betty jean have go in a car
that's squirrel	OOO	DS
squirrel	wanna ID wanna cuddle	DS
that's squirrel	ID feathers MWH	oh goodbye
oh goodbye	step up	DUW
i love you	okay time for shower peanut	DUW
we're gonna have company	okay don't bite	DO
goodbye	come here	goodbye
let go	wanna towel	cosmo betty jean have go in a car
let go please	towel for	DO

	cosmo	
LA	here you are	MWH
MWH	LS	DUW
NWM	DUW	DO
DUW	NWM	DO
what's bach	oh	goodbye i love you
that's bye	LS	goodbye ID bye
that's beak	DUW	MWH
that's beak	DUW	MWH
okay step up	DW	WBI
let go	OU	DUW
DS	ID feathers MWH	DUW
DS	cosmo wanna shower	RI
DS	NWM	hello
DS	NWM	ID ID LA
DS	WBI	OOO
DS	WBI	tele for bet jean
DWS	WBI	goodbye NWM
woof	WBI	DO
what's bach	WBI	goodbye
that's beak	NWM	DSS
cosmo has beak	what a bird	ID be back soon
that's beak	cosmo has feathers MWH	DS
NWM	okay time for shower peanut	DO
DS	LA	goodbye
KS	no	MWH
betty jean wanna kiss the beak	NWM	oh goodbye
DS	cos	betty jean have to go in a car
NWM	wanna be a good bird	DO
DW	DUW	DUW
that's squirrel	i'm here	DUW
NWM	no	goodbye
here step up here	cosmo go back cage	good ID ID
that's squirrel	cosmo	DO
that's squirrel	okay be a good bird cos	MWH

okay goodbye	go up here	WBI
i love you	what	goodbye
let go	here MWH step up	betty go in a car
LA	okay cosmo	DO
OOO	what's that	NWM
let go	that's clo	NWM
LA	cosmo wanna go for a walk	NWM
that's a doggie bark	no	DO
that's beak	cosmo wanna go	goodbye
please	no	DO
DS	DUW	MWH
DS	MWH	goodbye
wanna peanut	LS kiss	betty jean have go in a car
peanut in cage	KSS	DO
NWM	wow	good byelove you
NWM	cosmo ID cos	WBI
wanna peanut	what's	DUW
peanut for cage	that's cosmo	DUW
woof	there you are	MWH
that's wanna water	NWM	DUW
water in cage	jean wanna kiss	ID ID
NWM	KS	DO
OW	DS	MWH
OW	WBI	DUW
NWM	WW	NWM
NWM	no cosmo	goodbye
WBI	no	good byelove you
DS	be a good bird please	betty go in a car
WBI	DUW	WBI
NWM	DUW	MWH
what's bach	okay hurt	DUW
NWM	hi	DUW
NWM	hello	WBI
what's that	cosmo don't bite	where are y
that's woof	cosmo wanna go up	DUW
woof	okay go up	DUW

i love you	wanna be a good	NWM
what a bird	DUW	WBI
cosmo has feet	NWM	cosmo ID
that's feet	DUW	wanna be a good bird
that's	DUW	ID up here
cosmo has feet	LS	cosmo wanna talk
NWM	MWH	DUW
wanna good kiss feathers MWH	DUW	WBI
betty jean have to leave	DUW	MWH
NWM	DUW	NWM
KSS	NWM	DUW
good kiss	there you are	DUW
that's wanna water	i'm here	DUW
that's bark	MWH	LS
woof	WBI	OOO
woof	WBI	what that
ID what a good bird kiss	WBI	we're
NWM	WBI	ID we're gonna have company
KS	WBI	DS
come here	WBI	DS
cosmo wanna water	WBI	DS
want it	WBI	hi
NWM	WBI	how are thank
NWM	WBI	how are you
NWM	WBI	DS
we're gonna have	look want a kiss	DS
what's bach	MWH	want kiss KS
here step up	KS KS KS	i love you
step up	hello	ID ID
please	LS	KS
please step up	OOO	i love you
OW	how are you OOO	KS KS KS
ID	KS	i love you

what's bach	that's cosmo want kiss	WW
here step	cosmo wanna talk	DUW
cosmo wanna water	cosmo wanna DUW	there
OU	DUW	there you are
NWM	DUW	DO
ID wanna water	WBI	MWH
wanna go back cage	here	DO
okay step up	okay	DUW
step on	cosmo be a good bird	DUW
okay go back cage	okay	DO
wanna come here	cosmo go up	DO
LA	cosmo be a good bird please	goodbye
LA	no	i love you
let go	go up	cos bet jean have go in a car
OOO	okay good bird please	okay be back soon
cosmo more water	please	goodbye
NWM	ID	i love you
here step up	PH	NWM
up up up	PH	we're gonna car
cosmo wanna water	PH	okay ID ID
NWM	PH	let go LA
NWM	okay ID	let go LA
NWM	okay bye	cosmo LA
KSS	PH	you have reached five four LA bird
good kiss	PH	what that
NWM	PHS	what
KS	PH	cosmo betty jean wanna whistle DUWS

what a bird	telephone	i love you
here step up	cosmo ID betty jean here	we're gonna have company
NWM	PH	cosmo let go
wanna peanut	RI	okay OOO LA OOO
peanut ID cosmo	telephone	don't no let go
that's water	cosmo	cosmo LA
DS	goodbye	let go
NWM	NWM	let go please LA
NWM	telephone phone for bird	let go oh no LA
NWM	no	you have reached cosmo
NWM	what's that	i love here
NWM	you have reached betty jean ID	DO
here step up	goodbye	DUW
we're gonna have	NWM	DO
DS	look cosmo wanna water	ID goodbye
WBI	no	ID here
that's squirrel	ID	i love you
squir	cosmo wanna kiss	DO
that's squirrel	cosmo wanna water	DUW
okay let's go betty jean have to go in a car	cosmo wanna be a good bird	DO
goodbye	DO	goodbye
DSS	DO	goodbye
DS	DUW	NWM goodbye
DS	DUW	goodbye
here step up	okay	goodbye kerri
okay step up on here	we'll be back soon	DS
squirrel	MWH	ID goodbye
cosmo wanna water	LS	want kiss

we're gonna have company	OOO	KS
NWM	i love you	i love you
DS	NWM	ID ID
DS	telephone for bird	WBI
ID more water	cosmo	DUW
DS	here step up	DUW
DS	what's that	DUW
DW	PH	DUW
DW	that's tele	where are
DS	what's that	ID here
DS	what's	want kiss
DW	that's bye	KS
OOO	ID	i love you
WBIS	PH	NWM
DS	kiss	MWH
OW	KS	DUW
DS	betty jean wanna kiss	oh goodbye
MWH	KS	DSS
MWH	KS KS	WBI
DW	look	ID that
NWM	betty kiss	DO
NWM	please	goodbye
here step up	no	oh here
we're gonna have	WBI	there you are
cosmo water	NWM	DUW
DS	WBI	DO
wanna peanut	what's that	goodbye
NWM	that's clothes	why thank
DS	WBI	DUW
NWM	WBI	DO
wanna go back cosmo poop	WBI	good ID bye
no	NWM	ID here
OU that's hurt	LS	WBI
OOO	OOO	DUW
okay step up wanna go to kitchen	fine thank you	DUW
here step up	DUW	DO
up up up up up up up	okay	come here
LA	be back soon be back	ID love ID
cosmo we've got company	DO	DO
DS	DUW	goodbye
DS	DUW	goodbye

		kerri
DS	okay goodbye	goodbye
DS	cosmo wanna peanut o	i love you KS
DS	cosmo wanna be a good bird	cosmo we're gonna go in a car
DS	DUW	we're ID okay
WBI	okay	okay
NWM	wanna kiss KS KS	cosmo wanna talk
NWM	NWM	cosmo stay home we're gonna have company
DW	DUW	okay let go
wanna poop	wanna	NWM
cosmo wanna water	cosmo wanna be a good bird	why thank
water for cage	cosmo go up	DUW
ID	okay	DUW
ID	cosmo wanna go up	DUW
wanna step up	DUW	DS
DS	DUW	DS
LA	i'm here	DS
hello	cosmo wanna go up	DS
where cosmo	no peanut	what that
LA	okay go up	WBI
OOO cosmo wanna shower	cosmo wanna kiss	wanna peanut
shower for cosmo	KSS	i love you
okay step up we're gonna go for a walk	i'm here	ID ID ID
cosmo poop	DUW	look cosmo
where are you	wanna gonna	you have reached five hello
LA	cos	hello hi how are you
cosmo wanna water	wanna be a good bird	ID

ID	NWM	okay goodbow
cosmo wanna shower	okay cosmo	LA OOO
OOO	cosmo go up	WBI
OOO	cosmo wanna	WBI
cosmo	wanna go up	WBI
here step up	cosmo don't bite okay	NWM
wanna go to kitchen	come here	NWM
wanna go to kitchen	DUW	NWM
hello	DUW	NWM
wanna go to cosmo room	DUW	DUW
LA	DUW	LS
OOO	i'm here	OOO
OOO	come here	fine thank you
DSS	KS KS	NWM
okay time to go back	okay	that's tele
betty jean have to ID	cosmo be a go up	that's televil
DS	DUW	that's tele
DS	DUW	OOO
DS	WW	that's televi
DS	DUW	NWM
DS	LS	that's WF
heygov	DUW	WF
wanna peanut	wanna go bed	WF
DS	no cos	WF
OOO	ID	WF
heygov	cos no	WF
heygov	DUW	WF
WBI	DUW	WF
hey cosmo	i'm here	what that
WBI	ID kiss	WF
WBI	KS KS KS KS	what that
wanna peanut	KS KS	WF
ID peanut ID cosmo	cosmo go back cage	WF
that's water	DUW	what good bird
DS	DUW	cosmo
DS	i'm here	DUW
NWM	LS	DUW
NWM	how are OOO	DS
that's water	KS	DS

DS	cosmo	DS
DS	wanna be a good bird	LS
DS	cosmo go up	OOO
DS	MWH	WF
NWM	DUW	NWM
NWM	WW	that cosmo
NWM	LS	wanna talk
NWM	fine thank	tel for bird
wanna peanut	ID KS KS	LA
no more peanut	DUW	you have reached
here wanna peanut	DUW	okay goodbye
OU	DUW	NWM
bad bird	DUW	DS
DS	i'm here	DS
DS	there you are	DS
LA	i'm here	DS
WBI	WBI	DW
DS	DUW	we're gonna have
LS	DUW	NWM
OOO	DUW	NWM
fine thanks how are you	DUW	NWMS
that's bark woof	i'm here	NWMS
woof	i'm here	NWM
NWM	MWH	NWM
NWM	DUW	WW
NWM	DUW	thank
that's woof	WW	WWS
NWM	wanna kiss	that's cosmo
woof	DUW	MWH
that's woof	DUW	DUW
what a good bird i love you	okay	DS
KS	wanna	DS
DS	cosmo be a good bird	DS
DS	ID cosmo be a good	WBI
DS	LA	DS
NWM	cos	DS
LS	NWM	DS
OOO	DS	DS
fine how are you	NWM	DS

that's woof	cosmo wanna talk	DS
NWM	NWM	DS
what's bye	NWM	MWH
NWM	WW	DO
NWM	WW	DO
that's poop	WW	NWM
what a good kiss	WW	NWM
DUW	WW	NWM
KSS	WW	betty jean have
what a	NWM	NWM
cosmo has feet	look	DO
that's the beak	NWM	DO
NWM	that's tele	DS
that woof	telephone for bird	DS
DUW	LA	DS
NWM	ID	DS
what's bye	telephone for betty jean	DS
cosmo has feet	hi	NWM
cos ID has	goodbye	NWM
WBI	NWM	NWM
WBI	goodbye	DUW
WBI	NWM	DUW
WBI	that's cosmo	hello
WBI	goodbye	LS
WBI	NWM	OOO
WBI	look	betty jean have go to work
WBI	NWM	NWM
WBI	ID wanna cuddle	NWM
KS	don't bite	NWM
WBI	NWM	oh goodbye
DUW	KS	NWM
what's bye	WBI	DUW
hello	DO	KS
cosmo's a birdie	MWH	NWM
hello cosmo	DUW	DUW
KS	DUW	WBI
LSW	cosmo time for shower and peanut	WBI
what's bye	no	NWM
LA	okay step	WBI

you have reached betty jean	ID ID cosmo	WBI
DS	LA	WBI
DS	no	MWH
NWM	look	i'm here
that bark woof	NWM	DUW
woof	cosmo	here i are
woof	LA	come here
hi	cos let go	DUW
ID you are	OOO what a bird	DUW
RI	don't bite don't wanna cuddle	cosmo wanna go up
RI	ID have feathers MWH	okay
RI	what a good	DUW
DS	cosmo wanna cuddle	i'm here
DS	don't bite don't	WBI
DS	o	WBI
DW	OU	DUW
DWS	wanna cuddle	i'm here
NWM	don't bite	there you are
NWM	don't bite	WBI
cosmo has feak	DUW	DUW
that's beak	cosmo wanna whi	DUW
step up here	DUW	WBI
NWM	DUW	hi
KS	cosmo wanna shower	hello
OU	here step up	cosmo be a good bird
that's bad bird back in cage	step up up up up up up	okay go up
WBI	let go	PH
WBI	let go	DUW
WBI	LA	i'm here
WBI	OOO what a bird	cosmo wanna
WBI	let go	cosmo wanna be a good bird
NWM	let go	DUW
NWM	let go LA	DUW
OU	let	DUW

OU that's bad dog bite	let go	i'm here
KS	let go please	here you are
NWM	let go	i'm here
DS	LA	cosmo
DWS	let go	cosmo wanna be a good
NWM	let go	oh cosmo back cage
NWM	LA	DUW
NWM	cosmo	i'm here
what's bye	NWM	okay
DUW	NWM	here you are
NWM	MWH	cosmo wanna go to kitchen
NWM	MWH	step up please
WBI	NWM	there you are
WBI	MWH	i'm here
WBI	NWM	cosmo wanna go to kitchen
WBI	look	DUW
WBI	cosmo wanna peanut	i'm here
what's that	KS	here i
that's bach	MWH	here you are
that's	DUW	okay
that's ID	KS	i'm here
MWH	DUW	i'm here
that's wanna grape	DUW	here you are
i love you	wow	where are i'm here
ID work	cosmo wanna shower	i'm here
what a good bird	wow	okay i'm here
cosmo has	DS	hello cosmo
NWM	ID has feathers MWH	cosmo wanna go up
DS	cosmo wanna cuddle	DUW i'm here

NWM	no ID	okay
DS	OU don't bite	i'm here
DS	WBI	DUW
MWH	here you are	WBI
NWM	i'm here	DUW i'm here
NWM	wanna kiss	here i are
NWM	DUW	cosmo wanna ID ID
what's that	KS	okay
that's paper OOO	wanna go to	here i are
that's wanna poop	NWM	DUW
NWM	LS	NWM
NWM	fine thanks	there you are
NWM	cosmo wanna be a good bird	i'm here
NWM	okay cosmo don't bite	here you
WBI	cosmo wanna go up here step up	DUW i'm here
WBI	ID ID please	ID here
WBI	please	DUW
WBI	let go	DUW
NWM	LA	i'm here
DS	OOO	there you are
DS	NWM	DUW
DS	wanna ID feathers MWH	i'm here
WBI	okay	here you are
NWM	PH	DUW
what's bye	hello	okay
that's bye	PH	WBI
NWM	PHS	WBI
hello cosmo poop	hi tom	DUW
betty jean have to go in a ca	hi tom how are you	okay
we're gonna have company	goodbye	DUW
NWM	NWM	DUW
NWM	look cosmo	i'm here
NWM	okay	here i are
DS	want kiss	i'm here
NWM	DUW	DUW

NWM	KS	DUW
NWM	NWM	here you are
NWM	wanna kiss	where are you
NWM	KSS	i'm
NWM	ID ID	i'm here
NWM	cosmo wanna go up	okay let's go to kitchen
NWM	no	PH
what's bye	DUW	PH
NWM	NWM	PH
WBI	NWM	WBI
WBI	NWM	WBI
WBI	wanna be a good birdie	WBI
NWM	okay cos	WBI
NWM	cosmo go be a good bird please	WBI
hello	please step up	WW
squirrel	NWM	okay
we'll be back s be back soon	you have reached betty jean	here you are
we'll be back s	goodbye	let's go to kitchen
DUW	NWM	come
NWM	DSS	PH
WBIS	don't bite	RI
AM	OU	PH
AM	OOO	hello
AM	wanna ID wanna cuddle	hello
NWM	ID feathers MWH	tele for bird
DS	step up	LA
NWM	okay time for shower peanut	you have reached
DS	okay don't bite	five four nine
DS	come here	six two four three
DS	wanna towel	LA
NWM	towel for cosmo	hello
NWM	here you are	okay
NWM	LS	cosmo wanna go up

NWM	DUW	DUW
NWM	NWM	i'm here
NWM	oh	there you are
LS	LS	want up here
OOO thank	DUW	i love you
NWM	DUW	cosmo wanna go to bed
NWM	DW	DUW
here step up here	OU	i'm here
cosmo wanna go up	ID feathers MWH	here you are
no	cosmo wanna shower	DS
cosmo please	NWM	DS
please	NWM	DS
up cosmo	WBI	DS
please	WBI	DS
let go	WBI	WBI
DS	WBI	DS
DS	WBI	DS
DS	NWM	WBI
DS	what a bird	WBI
DS	cosmo has feathers MWH	WBI
DO	okay time for shower peanut	WBI
WBI	LA	WBI
WBI	no	WBI
WBI	NWM	NWM
WBI	cos	NWM
WBI	wanna be a good bird	NWM
WBI	DUW	WBI
NWM	i'm here	WBI
NWM	no	CR
LS	cosmo go back cage	WBI
OOO	cosmo	NWM
fine thanks how are you	okay be a good bird cos	WBI
DS	go up here	WBI
WBI	what	WBI
WBI	here MWH step up	i love you
NWM	okay cosmo	NWM
what's bye	what's that	WBI
don't don't bite	that's clo	WW

be a good bird	cosmo wanna go for a walk	i'm here
go up	no	here i are
step up	cosmo wanna go	DUW
please	no	DUW
let go	DUW	WBI
please	MWH	WW
PH	LS kiss	there you are
PHS	KSS	DS
PH	wow	DW
PHS	cosmo ID cos	CR
hello	what's	DUW
hi tom	that's cosmo	i'm here
hi ID ID ID	there you are	there you
oh okay	NWM	here i are
PH	jean wanna kiss	i'm here
PH	KS	cosmo wanna talk
RI	DS	come here
RI	WBI	okay
telephone	WW	MWH
hi	no cosmo	MWH
how are you	no	MWH
KS KS	be a good bird please	DS
hi cosmo	DUW	WBI
KS KS KS KS KS KS	DUW	WBI
hello	okay hurt	WW
WW	hi	okay
WWS	hello	there you are
we're gonna go to betty jean room	cosmo don't bite	DUW
DW	cosmo wanna go up	wanna be a good bird
NWM	okay go up	okay
NWM	wanna be a good	DUW
what's bye	DUW	there you are
NWM	NWM	wanna be a good bird
hello	DUW	okay
okay step up	DUW	here i are

here step up		
squirrel	LS	cosmo wanna be a good bird
that's squirrel	MWH	oh cosmo wanna go up
we're gonna have	DUW	good
betty jean have to go in a car	DUW	WW
okay	DUW	i'm here
goodbye	NWM	there you are
let go	there you are	cosmo wanna be a bird
let go please	i'm here	DUW
let go	MWH	okay
let go please	WBI	i'm here
DS	WBI	DUW
OOO	WBI	i'm here
NWM	WBI	there you are
KS	WBI	DUW
WBI	WBI	DUW
OOO	WBI	cosmo wanna go to kitch
WBI	WBI	DUW
DS	WBI	i'm here
OOO	WBI	there you are
OOO	WBI	DUW
wanna peanut	look want a kiss	i'm here
ID ID peanut cage	MWH	there you are
DS	KS KS KS	DUW
OOO	hello	i'm here
hi tom	LS	there you are
OOO	OOO	DUW
PH	how are you OOO	DUW
PH	KS	DUW
PHS	that's cosmo want kiss	DUW
hi tom	cosmo wanna talk	DUW

that's ID ID MWH	cosmo wanna DUW	okay
aww	DUW	cosmo wanna go up
okay ID ID ID thanks bye	DUW	DUW
PH	WBI	DUW
PH	here	i'm here
PHS	okay	DUW
hi tom	cosmo be a good bird	here you are
that's birdie	okay	DUW
aww MWH here step up	cosmo go up	okay
okay	cosmo be a good bird please	there you are
hi tom	no	DUW
LA	go up	there you are
OOO	okay good bird please	where are you
LA	please	wanna come
ID ID ID ID birdie	ID	i'm here
okay	PH	DUW
thanks bye	PH	DUW
PH	PH	i'm here
PH	PH	cosmo wanna go up here
PHS	okay ID	okay
hi tom	okay bye	DUW
LA walk	PH	here i are
aww	PH	DUW
betty has feathers MWH hair	PHS	okay
NWM	PH	DUW
DO	telephone	MWH i'm here
WBI	cosmo ID betty jean here	here you are
WBI	PH	DUW
WBI	RI	okay
WBI	telephone	there you are
WBI	cosmo	DUW
hi tom	goodbye	here you

		are
ID ID walk	NWM	i'm here
aww LA	telephone phone for bird	DUW
OOO how ID ID MWH	no	okay
hi tom LA	what's that	here i are
OOO	you have reached betty jean ID	i'm here
PH	goodbye	DUW
PHS	NWM	here you are
hi tom that's tele for MWH ID	look cosmo wanna water	okay
oh LA birdie	no	cosmo wanna
hi tom	ID	DUW
OOO LA	cosmo wanna kiss	DUW
okay dogs go for a walk	cosmo wanna water	i'm here
that's rain	cosmo wanna be a good bird	here you are
hi tom i can't i ID ID back back bye	DO	DUW
PH	DO	i'm here
PH	DUW	DUW
NWM	DUW	here i are
LA	okay	okay
NWM OOO	we'll be back soon	i'm here
ID ID ID ID	MWH	WW
ID ID ID ID tele	LS	here you are
DUW	OOO	DUW
WBI	i love you	DUW
no	NWM	i'm here
that's squirrel	telephone for bird	here you are
cosmo wanna go up	cosmo	i'm here
that's squirrel	here step up	DUW
that's birdie	what's that	DUW
s	PH	i'm here
hello cos	that's tele	okay
NWM	what's that	here you are
NWM	what's	i'm here

MWH	that's bye	there you are
MWH	ID	DUW
MWH	PH	i'm here
MWH	kiss	DUW
MWH	KS	i'm here
MWH	betty jean wanna kiss	there you are
hello	KS	cosmo wanna be a good bird
NWM	KS KS	okay
s	look	cosmo go up
NWM	betty kiss	DUW
DS	please	i'm here
NWM	no	here you are
NWM	WBI	okay
NWM	NWM	cosmo wanna go to kitchen
NWM	WBI	DUW i'm here
NWM	what's that	there you are
WBI	that's clothes	hello
WBI	WBI	PH
MWH	WBI	PH
MWH	WBI	PH
DS	NWM	PH
DO	LS	MWH
NWM	OOO	i'm here
NWM	fine thank you	WBI
that's tele	DUW	i'm here
hello	okay	here you are
NWM	be back soon be back	i'm here
betty jean wanna	DO	here you are
NWM	DUW	DUW
we're gonna have	DUW	i'm here
that's squirrel	okay goodbye	here you are
that's tele	wanna peanut	WW
DS	look	MWH
woof	look	i'm here
NWM	LS	here you

		are
ID ID ID ID	OOO	where are you
	want kiss	DUW
	betty jean wanna kiss	okay
	KS	hi here
	love you	here you are
	wanna cuddle	WW
	cosmo wanna be a bird	okay
	NWM	i'm here
	wanna be a	here you are
	KS	PH
	betty jean wanna kiss ID okay	RI
	NWM	PH
	wanna come here	hello
	ID ID up here	hi ID how are you
	cosmo don't bite okay	MWH
	NWM	i'm here
	cosmo go back in cage	cosmo wanna go to bed
	no cos	no
	cosmo back in cage step up	LA
	here step up here	LS
	LS	DUW
	OOO	here you are
	cosmo wanna be a good bird	i'm here
	don't bite okay	PH
	cosmo wanna cuddle	RI
	DUW	WW
	cosmo wanna cuddle	NWM
	no peanut	NWM
	cosmo be a good bird	WBI
	that's don't bite okay	that's birdie

	cosmo wanna	bark
	okay	WF
	cosmo wanna go up	doggie bark
	NWM	WF
	come here cosmo step	WF
	what a bird	cosmo's a bird
	betty jean wanna kiss	LA
	LS	WBI
	OOO	what's that
	WBI	DUW
	DO	PH
	wanna come	LS
	here	OOO
	cosmo go back cage	how are thank you
	go here	where are you
	here step up	there you are
	NWM	PH
	what a bird	PH
	betty jean wanna	PHS
	NWM	WBI
	KS KS KS	that birdie
	that's you wanna kiss the beak please	OOO
	DUW	ID
	cos betty jean wanna whistle	PH
	DUW	WBI
	what's bach	that's birdie
	that's bark WF	MWH
	cosmo wanna talk	i'm here
	how are you	WBI
	that's cosmo wanna kiss	i'm here
	NWM	ID i'm here
	KS	here you are
	KS	ID be a good bird
	what a bird	okay go up

	cosmo has feathers MWH	come here
	what's bach	oh wanna stay here
	WF	PH
	hello kerri	WBI
	betty kiss	DS
	DUW	DS
	KS KS	WBI
	NWM	WBI
	that's bark	that's bark WF
	WF	WF
	NWM	WBI
	LS	MWH
	OOO	DUW
	fine thank how are you	PH
	what's bach	DUW
	WF	i'm here
	that's WF	here you are
	i love you	i love you
	cosmo poop	i love you
	does betty jean wanna talk	KS
	wanna whistle	what a bird
	DUW	we're gonna go in bet
	KS	WBI
	betty jean wanna kiss	OU
	KS	LA
	what a bird	no
	oh it has feathers MWH	PH
	NWM	WBI
	what bach	that's birdie
	mary has feathers MWH	OOO bad bird
	cosmo poop	cosmo
	LS	telephone
	OOO	you LA
	how are you	WBI
	cosmo has feathers MWH	WBI
	want kiss	that's birdie

	cosmo wanna talk	WF
	what's bach	WF
	WF	what's that
	NWM	WF
	NWM	PH
	DUW	RI
	LS	tele
	OOO	telephone betty jean
	want kiss	hi
	KS	fine
	how are you	wanna shower and peanut
	i love	WBI
	DUW	DS
	DUW	DS
	want kiss	WBI
	KS	i'm here
	KS	there you are
	how are you	WW
	that's cosmo what bach	NWM
	ID wanna come here	here you are
	cosmo wanna cuddle	wan go to bed
	no betty jean wanna	PH
	cosmo don't bite	RI
	okay cosmo be a good bird	DUW
	okay wanna go up	DSS
	cosmo wanna be a good bird	WBI
	wanna be a good bird	i'm here
	cosmo don't bite okay	wow
	cosmo wanna be a bird	DUW
	go up here	here here
	okay wanna stay here	i'm here
	cosmo don't be good cosmo	cosmo wanna come here

	here wanna come here	here i are
	NWM	ID i'm here
	ID be a good bird	i'm here
	cosmo wanna kiss	ID i'm here
	KS	WBI
	cosmo wanna shower a peanut	RI
	look cosmo wanna kiss	te
	what's bach	RI
	WF	cosmo
	how are you	hello cosmo
	what's bach	thank
	ID ID wanna	goodbye
	KS	NWM
	NWM	NWM
	how are you	hello
	that's cos a good good good bird	DO
	that's birdie	DO
	WBI	i'm here
	NWM	WBI
	NWM	NWM
	NWM	DUW
	DUW	i'm here
	NWM	there you are
	wanna cuddle	PH
	cosmo don't bite	RI
	wanna be a bird	hello
	cosmo don't bite okay	DUW
	NWM	i'm here
	ID be a good bird	okay
	don't bite okay	cosmo wanna go to kit
	wanna be a good bird	DUW
	don't bite okay don't bite	i'm here

	NWM	DUW
	cosmo be a good bird	okay
	wanna peanut	WBI
	DUW	WBI
	NWM	i'm here
	no peanut	DUW
	cosmo don't bite okay	DO
	cosmo wanna be a good bird	WBI
	cosmo don't bite okay	NWM
	okay cosmo go back	NWM
	wanna come	NWM
	DUW	PH
	betty jean wanna kiss	RI
	NWM	hello
	KS KS KS	how are you
	cosmo wanna whistle	cos
	cosmo ID betty jean wanna whi	wanna be a good bird
	DUW	oh
	okay time for shower	cosmo wanna peanut
	NWM	okay
	NWM	here i are
	that's poop	MWH
	NWM	i'm here
	that's WF	here you are
	what's bach	hi
	what	here you are
	NWM	DUW
	don't bite	we're ID here
	hello kerri	LA
	hello kerri	here you are
	KS	here you are
	cosmo wanna talk	where are you
	we're gonna go	i'm here

	ID	i love you
	NWM	WW
	NWM	here i
	LS	here you are
	OOO	i'm here
	NWM	cosmo wanna cuddle
	WF	no more peanut
	that's bark	come here
	WF	here i are
	NWM	DUW
	look	i'm here
	betty jean wanna kiss feather	here you are here
	KS	i'm here
	ID wanna kiss feathers MWH	DUW
	KS	cosmo wanna kiss
	how are you	okay
	that's betty kiss	here i are
	KS	DUW
	cosmo's a good bird LA	DUW
	you have reached betty jean	i'm here
	you have reached betty jean	here you are
	cosmo's good bird	i'm here
	what's bach	here you are
	WBI	DUW
	wanna come here	DUW
	wanna come here	DUW
	KS	WBI
	cosmo wanna cuddle	here you are
	okay	NWM
	come here	RI
	betty jean wanna kiss	hello
	KS	RI

	wanna kiss	telephone
	wanna come here	PH
	cos be a good bird	ID LA
	cosmo go up	WBI
	wanna be a bird	WBI
	wanna	WBI
	okay	WW
	wanna kiss	there you are
	KS	okay
	wanna come kiss	cosmo wanna bed
	come here	here you are
	please	ID
	KS KS	here i are
	no	NWM
	wanna step up here	DO
	wanna ID ID okay NWM	WBI
	NWM	DUW
	OU that's bad bird	okay
	wanna cuddle	ID
	NWM	WBI
	NWM	RI
	go up	MWH
	no	i'm here
	no	here i are
	wanna cuddle	no ID here
	betty kiss	here i are
	KS	WBI
	please	WBI
	KS	WBI
	NWM	WBI
	mary has feathers	DS
	MWH	DUW
	LSW	PH
	NWM	i'm here
	that's feathers	here you are
	MWH	WBI
	kiss	RI
	please	DUW
	cosmo wanna talk	DUW

	cosmo and betty jean wanna whi DUW	here you are
	DUW	okay
	KS KS	i wanna talk
	wanna come here	cosmo wanna go up
	no	here i are
	ID wanna cuddle	DS
	come here	DW
	NWM	WBI
	KS	that's birdie
	i love you	here you are here
	cosmo's a good good bird	MWH
	how are you	i'm here
	mary has feathers	DSS
	MWH	WBI
	wanna go to kiss	WF
	KS	WF
	come here	DS
	betty kiss	DS
	KS KS	DO
	NWM	what's that
	wanna cosmo	that's
	betty kiss KS	doggie bark
	wanna come here	WF
	no	PH
	wanna go back cage	PHS
	ID wanna	KS
	KS	MWH
	KS	what's that
	wanna come here	that's OOO
	DUW	that's squirrel
	wanna kiss KS KS KS KS	that's cosmo
	wanna go to bed	you LA

	cosmo wanna go to bed	WBI
	no	WBI
	wanna go to betty jean	WBI
	ID wanna	WBI
	no	WBI
	betty jean ID	NWM
	KS	WBI
	KS	NWM
	betty please	LS
	please	OOO
	KS KS KS	fine thank you
	ID wanna talk	how are you
	what's ID ID ID	KS
	what a bird	KS
	KS	MWH
	come here please	LS
	KS KS KS KS	OOO
	oh what a bird	fine thank you
	that's doggie has feathers	how are you
	MWH	WBI
	mary has feathers	that's birdie
	MWH	OOO
	NWM	that's bird
	KS	NWM
	betty kiss	PH
	come here	NWM
	wanna kiss a beak	i love
	what a bird	LA
	cosmo ID go	NWM
	mary	WBI
	cosmo's ID birdie	what that
	cosmo has feathers	that's birdie
	MWH	OOO
	no	wow LA
	mary has	tel for bird
	doggie has	LA
	wanna come	what a bird
	wanna kiss	yeah

	KS KS KS	PH
	OU that's cos don't bite	RI
	wanna cuddle	i'm here
	no	there you are
	betty kiss	i love
	KSS	WBI
	come here please	what that
	KS KS KS KS	OU
	ID	DS
	cosmo wanna cuddle	KS
	DUW	MWH
	DUW	WBI
	cos	WF
	wanna come here	DUW
	no	PH
	i wanna stay here	WBI
	work	WBI
	no	NWM
	it's rain	DOS
	wanna kiss KS KS KS	what's that
	KSS	that clothes
	what a good bird	ID cosmo wanna go to ID
	hello kerri	come here
	KS	ID here
	KS KS	PH
	cosmo's a good bird	WBI
	cos feathers MWH	LS
	no	OOO
	mary has feathers MWH	DUW
	step up here	i'm here
	how are you	DUW
	cosmo's a birdie	DUW
	cosmo wanna whi DUW	wanna talk
	cosmo wanna whistle	we're gonna have

		company
	FR	tel for bird
	cosmo wa whi cuddle	LA
	no	DO
	betty kiss KS KS KS KS KS KS	NWM
	NWM	NWM
	come here please	NWM
	betty i wanna kiss on the beak KS KS	WBI
	ID	WBI
	wanna come here	NWM
	no	NWM
	KS	NWM
	betty kiss ID ID	WBI
	KS	NWM
	come here	NWM
	KS	WW
	come here cosmo wanna cuddle	WW
	no	PH
	betty kiss	wanna shower and peanut
	KS KS KS KS	wanna ID ID ID
	that's birdie	here you are
	hello kaylee	okay let's go to kitchen
	that's doggie has	NWM
	FR	NWM
	KS	WBI
	cosmo wanna talk	DS
	cosmo wanna go to betty	DS
	come here	NWM
	KS	PH
	betty wanna kiss feathers MWH	NWM

	okay come here	NWM
	KS	WBI
	cosmo wanna come here	WBI
	no	WBI
	wanna stay here	WBI
	DUW	NWM
	WBI	NWM
	bark	NWMS
	LS	WBI
	fine thank you	WBI
	how are you	NWM
	we're	NWM
	cosmo wanna talk	WW
	cosmo wanna whi DUW	KS
	want kiss KS KS KS	MWH
	please	wanna shower peanut
	KS	okay
	cosmo's a bird	time for shower for cosmo
	no	LA
	wanna ID kiss	here i i'm here
	KS KS KS	NWM
	ID kiss KS KS	NWM
	what a bird	NWM
	cos wan whi	NWM
	NWM	DUW
	that's doggie	DUW
	DUW	PH
	DUW	a beak
	wanna come	ID ID
	please	hello
	KSS	DOS
	KS KS	what that
	ID kiss	that's close
	please KS KS	PH
	cosmo wanna step up here	PH
	we're gonna go in betty jean ID gonna talk	WBI
	ID ID kiss	WBI

	KSS	NWM
	wow	DSS
	betty kiss	ID cosmo wanna go up
	KS	cos don't bite
	that's cosmo wanna talk	wanna be a good bird
	telephone for bird	cosmo go up here step up
	cosmo wanna talk	PH
	wanna whi DUW	PH
	DUW	PH
	DUW	DUW
	DUW	DUW
	what's that	DUW i'm here
	mary has feathers MWH	there you are
	no	i'm here
	KS	i'm here
	want kiss KS KS KS	here i are
	KS	i love you
	KS	DUW
	ID birdie kiss	DUW
	KS	i'm here
	come here	here you are
	that's wanna go bed	i'm here ID
	no wanna ID	DUW
	WBI	DUW
	FR	DUW
	NWM	DUW
	you have reached five four nine	i'm here
	you've	cosmo go up
	five four nine	okay come here
	telephone for bird	please
	cosmo poop	thank you
	KS	DUW

	betty wanna	i'm here
	wanna kiss KSS	wanna go up here
	wow	KS KS
	NWM	KS KS KS
	NWM	cosmo wanna be a bird
	kiss KS	DUW i'm here
	hello kerri	okay
	that's	WBI
	wanna go to bed	i'm here
	DUW	cosmo be a good bird
	NWM	i'm here
	what's that	okay go up
	that's doggie	thank you
	mary has feathers MWH	DUW
	no	DW
	good dog kerri	here you ar
	KS	LS
	mary feathers MWH	fine thanks how are you
	no	WBI
	DUW	that bird
	DUW	WBI
	NWM	DUW
	wanna cuddle	DUW
	how are you	wow
	fine thank you	aww
	how are you	PH
	wanna kiss KSS	RI
	good kiss	you have reached
	KS KS	telephone for bird LA
	good bird	you have reached five four nine LA
	cos and betty jean wanna whi DUW	DUW

	DUW	here you are
	DUW	i love you
	WBI	i love you
	that's birdie	WBI
	bark	cosmo wanna kiss
	WF	KS KS
	what's that	WBIS
	tele ID	i'm here
	ID how are you	here you are
	hello kerri KS KS	i'm here
	what's that	DUW
	wanna kiss KS KS	i'm here
	NWM	PH
	go up	PH
	be good cosmo	DUW
	ID ID ID	DUW
	go up here	DUW
	wanna go back cage	MWH
	no	DUW
	NWM	MWH
	go up here	MWH
	cosmo poop	WW
	go up	MWH
	step up here	NWM
	no ID don't bite	okay cosmo betty jean have to go to work
	that's bad bird	betty jean have
	bad bird	MWH
	cosmo be a good bird	LS
	go up	MWH
	cosmo wanna whi DUW	WBI
	kiss	DUW
	KS KS	WBI
	OU don't bite	WBIS
	ID don't bite	WBIS
	FR	NWM
	wanna cuddle	WBI
	DUW	WBI
	DUW	WBI

	what's that	WBI
	that's doggie	NWM
	ID	WBI
	kiss	DS
	DUW KS KS	DS
	what's bar	DSS
	wanna come here	DWS
	DUW	DS
	DUW	DS
	LS	DS
	fine thank you	that's doggie
	how are you	mary has bark
	telephone for	that's doggie has
	you have reached	DS
	five four nine NWM OOO	DS
	okay goodbye	DW
	NWM	DS
	NWM	what's bark
	cosmo wanna go up	DUW
	no	PH
	how are you	PHS
	cosmo's a good good bird	hi tom
	cosmo and wanna whi DUW	hi ID ID walk LA aww
	wow	okay ID ID ID MWH
	DUW	thanks bye PH
	DUW	WBI
	DUW	WBI
	wow	NWM
	DUW	DO
	cosmo wanna cuddle	HA
	i love you	HA
	NWM	NWM
	ID kiss KS KS	DUW
	KS	WBI
	KS	WBI
	KS	DUW

	cosmo wanna talk	DUW
	do you wanna talk	what a bird
	no	i love you
	DO	what a bird
	that's birdie	KS
	that's doggie has feathers MWH	ID wanna kiss
	ID doggie has feathers MWH	NWM
	no	NWM
	ID what a good bird	DUW
	cosmo has feathers	WBI
	DUW	DUW
	NWM	DUW
	that's birdie	DUW
	bark	WBI
	WF	what's bark
	what's that	WF
	WF	bark
	WF	WF
	WF	WF
	WF	WF
	what's that	PH
	wanna cuddle don't bite wanna cuddle	PHS
		hi tom
		hi tom LA
		ID ID back
		ID for walk
		PH
		PHS
		hi tom LA
		oh where are you
		DUW
		WBI
		DUW
		DUW
		WBI
		DUW
		DUW

		WBI
		wanna ID
		come up here
		DS
		DSS
		WBI
		i'm here
		KS KS
		WBI
		WBI
		WBI
		WBI
		NWM
		DUW
		DUW
		WBI
		WBI
		WBI
		ID
		hi
		how are you
		how are you
		PH
		PHS
		okay how are you
		LA we're gonna walk
		gonna walk ID ID
		WBI
		WBI
		HA
		WBI
		DUW
		DUW
		fine
		i'm here
		WBI
		WBI
		WBI
		DUW
		DUW
		WBI
		WBI
		WBIS

		DUW
		DUW
		WBI
		DUW
		i'm here
		there you are
		wanna go to bed
		WBI
		HAS
		HAS
		WBI
		DUW
		DUW
		i'm here
		there you are
		DUW
		yoohoo
		where are you
		okay
		let's go to betty jean room
		DUW i'm here
		DUW
		DUW
		DUW
		DUW
		i'm DUW
		okay
		here step up here
		PH
		cosmo wanna go up
		ID kiss
		NWM
		NWM
		i wanna kiss
		i love you
		KS
		what
		bark WF
		that's doggie

		bark
		WF
		PH
		PHS
		WBI
		DUW
		DUW
		ID mary
		five four nine six two four three
		thanks ID AM
		NWM ID ID ID
		AM
		PH
		hello
		WBI
		WBI
		DUW
		WW
		DUW
		WBI
		DUW
		DUW
		what hello cosmo
		what a bird
		WBI
		bark
		fine thanks how are you
		i love you
		KS KS KS
		WBIS
		DUW
		WBI
		LS
		fine thanks how are you
		how are you
		how are you
		DUW
		DUW

		HA
		HA
		WBI
		WBIS
		WBIS
		that's bark
		DS
		WBI
		DUW
		i'm here
		KS i'm here
		where are you cosmo where
		kiss KS KS KS KS KS
		i love you
		what's ID
		bark WF
		DUW
		WBI
		DUW
		WBI
		what's bark
		bark WF
		bark WF
		WF
		what's that
		i love you KS
		don't bite don't bite
		hello
		how are you
		WBI
		WBI
		WBI
		ID ID no
		no ID no
		no that's ID no no no ID ID
		no
		DW
		PH
		PHS
		hi tom

		ID ID ID walk
		LA
		aww ID ID ID ID walk bye
		PH
		PHS
		hi ID LA
		ID ID ID ID
		NWM
		DUW i'm here
		here you are
		PH
		PHS
		WBI
		DUW
		DUW
		WBI
		what ID LA
		WBI
		DUW
		HA
		HA
		HA
		DUW
		cosmo be a go up
		cosmo wanna go up
		i wanna kiss okay
		KS thank you
		NWM
		NWM
		NWM
		NWM
		NWM
		ooh i love
		i wanna kiss okay
		KS
		NWM
		NWM
		MWH

		HA HA
		HA HA
		WBI
		DUW
		hi
		how are you
		DS
		DS
		DS DS
		WBI
		WBI
		WBI
		WBI
		WBI
		DUW
		WBI
		WBI
		WBI
		WBI
		WBI
		MWH
		WBI
		WBI
		DUW
		DUW
		WBI
		DUW
		WBI
		DUW
		WBI
		DUW
		DUW
		WBI
		what
		WBI
		NWM
		DUW
		i wanna ID
		WBI
		NWM
		WBI
		WBI
		MWH
		WBI
		what's bark
		bark WF
		CR
		CR
		CR

		WBI
		WBI
		NWM
		DW
		DS
		PH
		ID step up don't bite don't bite
		no
		DS
		DW
		WBI
		DUW
		WBI
		WBI
		WBI
		WBI
		MWH
		WBI
		DS
		WBI
		NWM
		DUW
		DS
		what is bark
		NWM
		NWM
		NWM
		NWM
		NWM NWM
		WBI
		WBI
		what's bark
		yoohoo
		WW
		DUW
		NWM
		bark
		DS
		CR
		CR
		CR
		CR
		CR
		CR
		DUW
		DUW

		WBI
		DUW
		DUW
		WBI
		WBI
		DUW
		DUW
		WBI
		oh cosmo
		oh
		DUW
		DUW
		WBI
		ID bark
		NWMS
		WBI
		DUW
		HA DUW
		DUW
		DUW
		that's rain
		NWM
		NWM
		WBI
		WBI
		WBI
		WBI
		ID
		DUW
		MWH
		wanna water
		that's bark WF
		how are you
		fine thank you
		how are you
		MWH
		DUW
		WBI
		WW
		WBI
		WBI
		we're gonna go for a walk
		DS
		DSS

		DW
		DS DW
		DW
		NWM
		mary
		no
		no
		no mary
		that's ID ID ID ID
		hi cosmo
		how are you
		WBI
		WBI
		NWM
		CR
		CR
		CR
		CR
		WBI
		WBI
		want kiss KS KS KS
		ID ID ID
		ID no no no
		NWM
		DUW
		WBI
		DUW
		WBI
		ID ID
		ID ID ID
		ID ID ID
		NWM
		ID ID that
		WBI
		NWM
		NWM
		ID
		aww
		ID ID ID ID kay
		LA ID ID walk ID ID okay
		ID ID ID ID ID
		okay ID ID ID

		ID well thank you
		thanks bye PH
		NWM
		ID ID ID ID ID
		ID ID
		WBI
		ID ID ID
		aww
		WBI
		okay ID ID bye PH
		WF
		aww
		ID ID MWH ID
		aww
		LA
		LA ID ID ID
		okay ID ID bye PH
		PH
		PHS
		ID ID ID MWH ID ID
		WF
		LA ID ID ID girl
		okay ID thank you
		oh thank you bye
		PH
		PH
		PHS
		hi tom
		ID
		Aww

APPENDIX B

Humpback whale vocalizations, by song. PR = Puerto Rico, TC = Turks and Caicos, LA = Lesser Antilles.

PR '70	**PR '70**	**PR '70**	**PR '75**	**TC '74**	**TC '74**	**TC '74**	**LA '73**	**LA '73**	**LA '76**	**LA '76**
117770	**117774**	**117775**	**128296**	**118102**	**118118**	**118119**	**110847**	**110858**	**118171**	**118172**
unit13	unit16	unit15	unit20	unit6	unit12	unit8	unit15	unit21	unit7	unit1
unit1	unit22	unit10	unit25	unit11	unit12	unit8	unit19	unit8	unit10	unit18
unit17	unit16	unit24	unit24	unit6	unit6	unit2	unit15	unit21	unit13	unit1
unit22	unit22	unit20	unit20	unit11	unit12	unit8	unit15	unit8	unit10	unit12
unit6	unit16	unit4	unit20	unit5	unit12	unit3	unit15	unit21	unit7	unit13
unit1	unit16	unit24	unit20	unit2	unit21	unit8	unit19	unit8	unit10	unit7
unit17	unit16	unit15	unit20	unit5	unit5	unit3	unit7	unit21	unit13	unit6
unit21	unit17	unit10	unit25	unit5	unit3	unit9	unit15	unit8	unit10	unit13
unit17	unit22	unit18	unit20	unit5	unit5	unit3	unit13	unit21	unit13	unit1
unit17	unit1	unit19	unit20	unit3	unit5	unit5	unit15	unit8	unit10	unit13
unit17	unit24	unit6	unit19	unit5	unit3	unit3	unit9	unit21	unit13	unit7
unit21	unit17	unit6	unit19	unit3	unit8	unit5	unit19	unit8	unit10	unit1
unit13	unit22	unit1	unit19	unit5	unit3	unit8	unit19	unit21	unit7	unit7
unit17	unit16	unit18	unit19	unit3	unit5	unit5	unit19	unit15	unit10	unit1
unit17	unit22	unit10	unit19	unit5	unit11	unit3	unit8	unit21	unit13	unit17
unit16	unit16	unit9	unit19	unit5	unit5	unit5	unit17	unit8	unit10	unit17
unit17	unit1	unit1	unit19	unit5	unit11	unit8	unit8	unit21	unit7	unit8
unit17	unit22	unit18	unit19	unit5	unit5	unit5	unit17	unit9	unit10	unit13
unit16	unit16	unit10	unit19	unit3	unit2	unit3	unit9	unit21	unit13	unit7
unit16	unit21	unit1	unit19	unit5	unit11	unit5	unit21	unit9	unit10	unit13
unit16	unit19	unit23	unit19	unit3	unit12	unit3	unit8	unit21	unit13	unit13
unit22	unit22	unit10	unit19	unit5	unit5	unit9	unit21	unit9	unit10	unit3
unit17	unit16	unit1	unit19	unit10	unit2	unit9	unit15	unit21	unit7	unit9
unit17	unit22	unit18	unit19	unit5	unit11	unit3	unit21	unit8	unit7	unit7
unit6	unit6	unit4	unit19	unit3	unit5	unit8	unit9	unit21	unit10	unit9
unit6	unit6	unit1	unit19	unit5	unit6	unit16	unit21	unit15	unit8	unit11
unit7	unit1	unit18	unit19	unit10	unit5	unit6	unit19	unit9	unit9	unit9
unit13	unit24	unit4	unit19	unit5	unit2	unit6	unit21	unit9	unit8	unit13
unit16	unit21	unit14	unit19	unit3	unit12	unit6	unit8	unit9	unit10	unit10
unit17	unit17	unit4	unit19	unit5	unit5	unit22	unit21	unit9	unit9	unit7
unit17	unit21	unit18	unit19	unit8	unit2	unit6	unit9	unit9	unit8	unit10
unit17	unit19	unit10	unit19	unit3	unit11	unit13	unit21	unit15	unit10	unit13
unit16	unit19	unit14	unit19	unit5	unit5	unit7	unit8	unit9	unit8	unit3
unit16	unit17	unit4	unit19	unit5	unit11	unit7	unit21	unit8	unit15	unit14
unit13	unit24	unit14	unit19	unit10	unit8	unit22	unit9	unit3	unit8	unit10
unit16	unit1	unit3	unit24	unit5	unit11	unit11	unit21	unit10	unit3	unit23
unit16	unit23	unit18	unit19	unit3	unit10	unit11	unit14	unit14	unit15	unit10
unit16	unit6	unit3	unit24	unit5	unit11	unit16	unit21	unit8	unit9	unit7
unit16	unit12	unit18	unit19	unit3	unit11	unit22	unit5	unit10	unit8	unit10

unit22	unit1	unit3	unit19	unit5	unit2	unit16	unit21	unit9	unit9	unit13
unit16	unit25	unit14	unit19	unit3	unit11	unit16	unit5	unit15	unit8	unit10
unit22	unit23	unit3	unit19	unit5	unit8	unit11	unit21	unit8	unit9	unit12
unit16	unit9	unit14	unit20	unit3	unit2	unit22	unit9	unit15	unit9	unit10
unit22	unit21	unit3	unit19	unit5	unit11	unit16	unit21	unit15	unit9	unit13
unit16	unit25	unit14	unit15	unit3	unit9	unit22	unit8	unit15	unit9	unit10
unit22	unit21	unit3	unit19	unit5	unit11	unit11	unit21	unit9	unit8	unit22
unit22	unit8	unit8	unit19	unit5	unit6	unit11	unit9	unit15	unit3	unit9
unit11	unit17	unit11	unit19	unit5	unit11	unit12	unit21	unit15	unit10	unit13
unit22	unit17	unit11	unit25	unit8	unit6	unit1	unit5	unit15	unit9	unit10
unit6	unit22	unit18	unit19	unit3	unit22	unit22	unit21	unit14	unit20	unit13
unit1	unit6	unit3	unit19	unit8	unit11	unit12	unit8	unit15	unit8	unit10
unit17	unit6	unit18	unit19	unit5	unit5	unit12	unit21	unit8	unit20	unit13
unit17	unit1	unit3	unit19	unit2	unit6	unit12	unit9	unit3	unit3	unit10
unit17	unit22	unit15	unit19	unit10	unit2	unit22	unit8	unit14	unit4	unit13
unit17	unit22	unit3	unit19	unit2	unit11	unit11	unit15	unit3	unit23	unit13
unit17	unit4	unit9	unit19	unit10	unit12	unit6	unit9	unit8	unit20	unit10
unit22	unit23	unit9	unit19	unit2	unit8	unit12	unit9	unit3	unit18	unit12
unit6	unit18	unit11	unit19	unit5	unit3	unit11	unit9	unit9	unit3	unit4
unit6	unit4	unit23	unit19	unit8	unit6	unit22	unit9	unit3	unit18	unit23
unit1	unit23	unit16	unit20	unit9	unit11	unit12	unit9	unit8	unit3	unit10
unit22	unit20	unit11	unit25	unit8	unit8	unit12	unit8	unit3	unit20	unit13
unit16	unit17	unit18	unit20	unit4	unit5	unit1	unit9	unit14	unit15	unit10
unit17	unit18	unit3	unit19	unit8	unit3	unit7	unit9	unit3	unit10	unit13
unit17	unit3	unit18	unit19	unit5	unit2	unit13	unit8	unit3	unit3	unit10
unit16	unit6	unit3	unit20	unit8	unit5	unit13	unit9	unit14	unit20	unit13
unit22	unit1	unit20	unit19	unit3	unit2	unit13	unit9	unit3	unit20	unit10
unit16	unit22	unit9	unit19	unit2	unit5	unit7	unit15	unit3	unit15	unit13
unit17	unit16	unit11	unit19	unit5	unit2	unit3	unit20	unit14	unit3	unit7
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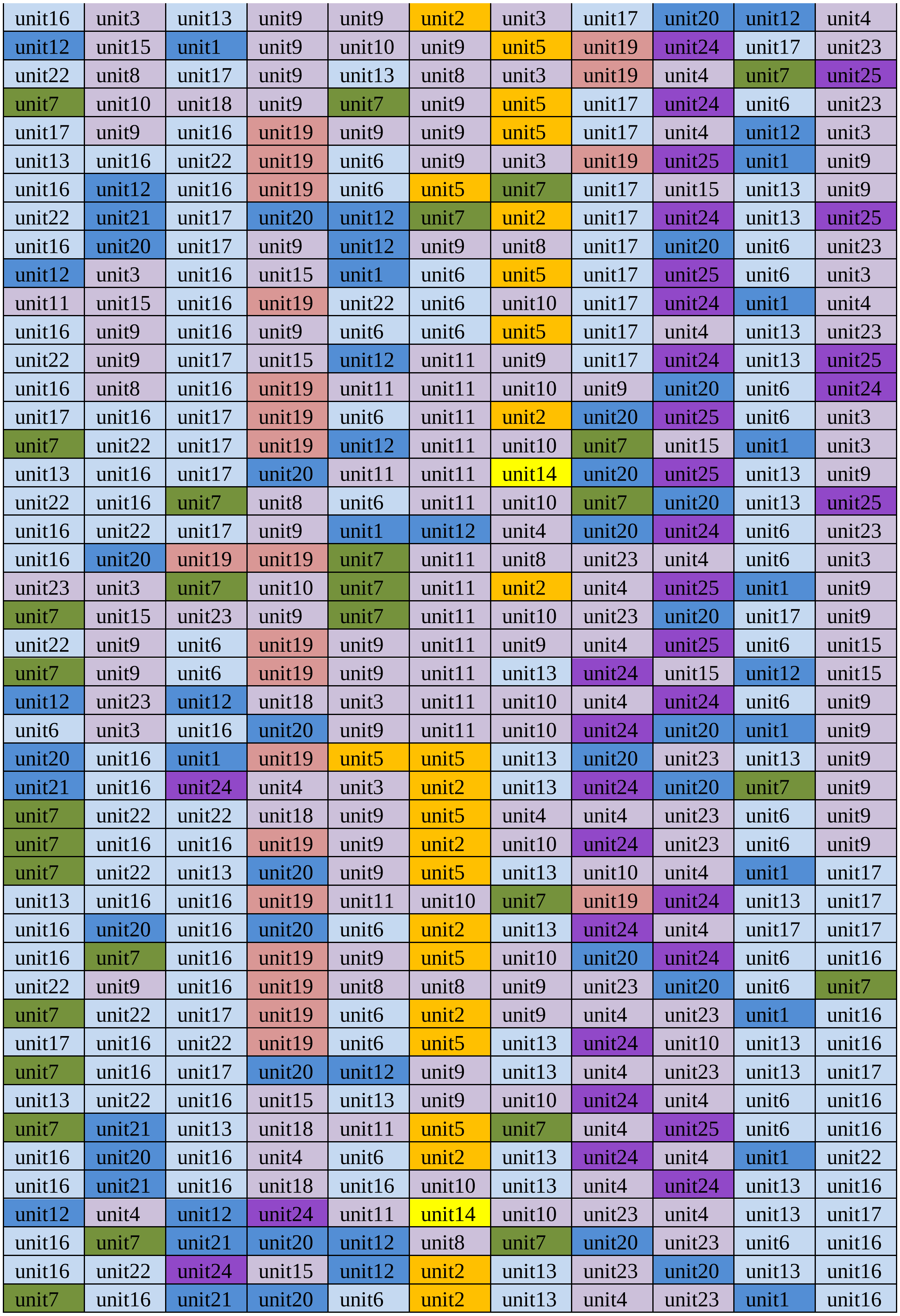

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		unit15					unit9	unit10	unit13	unit6
		unit15					unit21	unit23	unit7	unit13
		unit17					unit8	unit10	unit6	unit6
		unit21					unit16	unit18	unit7	unit12

		unit20					unit23	unit20	unit1	unit12
		unit15					unit8	unit13	unit13	unit6
		unit13					unit9	unit15	unit15	unit17
		unit15					unit9	unit19	unit13	unit12
		unit23					unit8	unit15	unit1	unit6
		unit19					unit8	unit15	unit15	unit7
		unit6					unit7	unit15	unit13	unit6
		unit9						unit19	unit7	unit6
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		unit22						unit15	unit17	unit6
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		unit16						unit15	unit17	unit6
		unit12						unit15	unit7	unit1
		unit11						unit15	unit15	unit9
		unit12						unit3	unit17	unit6
		unit11						unit19	unit17	unit6
		unit22						unit15	unit15	unit6
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		unit11						unit15	unit7	unit6
		unit11						unit3	unit13	unit12
		unit12						unit18	unit7	unit6
		unit11						unit3	unit20	unit13
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		unit23						unit15	unit18	unit6
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		unit11						unit4	unit7	unit17
		unit1						unit17	unit20	unit6
		unit24						unit7	unit7	unit12
		unit21						unit21	unit3	unit1
		unit19						unit9		unit13
		unit21						unit21		unit17
		unit19						unit19		unit6
		unit23						unit21		unit17
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		unit11						unit9		unit17
		unit23								unit18
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		unit24								

APPENDIX C

Wild Type mice corpuses, coded with classes. Numbers are identifiers for individual mice.

14	15	21	22	23	24	25	26	27	35	36	44	45
c4	c1	c9	c10	c9	c10	c4	c4	c9	c3	c4	c7	c1
c4	c21	c9	c1	c1	c4	c4	c4	c4	c1	c4	c18	c12
c5	c15	c9	c4	c12	c4	c4	c11	c4	c23	c4	c23	c1
c4	c7	c4	c8	c8	c9	c4	c4	c9	c23	c4	c19	c6
c9	c4	c4	c4	c12	c4	c4	c12	c4	c23	c1	c19	c1
c9	c6	c9	c9	c5	c11	c1	c4	c1	c11	c4	c1	c1
c9	c1	c4	c4	c12	c4	c1	c4	c12	c23	c5	c1	c5
c1	c1	c9	c1	c12	c9	c1	c1	c12	c23	c5	c1	c1
c1	c1	c9	c9	c4	c4	c6	c6	c12	c23	c1	c1	c4
c4	c1	c9	c1	c4	c4	c4	c4	c11	c23	c12	c1	c8
c4	c4	c5	c4	c12	c4	c12	c12	c12	c23	c12	c1	c10
c4	c4	c5	c12	c9	c4	c4	c1	c4	c11	c6	c1	c9
c5	c4	c4	c3	c4	c4	c4	c4	c4	c1	c6	c12	c1
c9	c13	c4	c1	c4	c9	c12	c1	c5	c20	c9	c1	c9
c4	c15	c1	c9	c4	c9	c5	c12	c4	c23	c4	c1	c8
c4	c1	c4	c10	c9	c5	c11	c4	c12	c23	c18	c1	c9
c4	c15	c4		c9	c12	c5	c1	c1	c23	c1	c11	c12
c5	c1	c4		c1	c1	c6	c11	c5	c23	c12	c19	c1
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c4	c15	c12		c1	c4	c1	c4	c9	c23	c12	c1	c2
c5	c21	c12		c12	c4	c15	c4	c11	c23	c12	c1	c8
c4	c12	c1		c1	c4	c11	c9	c4	c23	c12	c1	c9
c5	c6	c4		c5	c4	c12	c4	c4	c1	c12	c1	c12
c12	c1	c11		c1	c4	c12	c9	c6	c1	c1	c1	c12
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c9		c4		c9	c1	c12	c1	c4	c1	c1	c1	c1
c5		c4		c4	c1	c12	c3	c9	c12	c1	c1	c4
c9		c4		c9	c4	c12	c1	c1	c23	c17	c1	c4
c4		c9		c1	c4	c4	c1	c1	c1	c17	c1	c9
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c4		c4		c10	c1	c1	c22	c9	c6	c4	c1	c1
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c4		c1			c4	c4	c12	c9	c23	c9	c1	c1
c9		c4			c4	c4	c1	c4	c23	c12	c23	c4
c4		c5			c4	c4	c1	c6	c23	c1	c23	c4
c4		c4			c4	c4	c4	c1	c23	c4	c23	c9
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c4		c5			c9	c12	c13	c9	c23	c4	c11	c1
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c4		c4			c1	c1	c4	c4	c23	c12	c19	c12
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c4		c12			c1	c9	c1	c1	c4	c5	c1	c5
c4		c12			c9	c9	c23	c6	c2	c5	c12	c1
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c9		c12			c6	c3	c4	c1	c23	c1	c1	c9
c5		c12			c1	c1	c1	c9	c1	c21	c1	c12
c9		c1			c12	c4	c4	c12	c5	c1	c12	c12
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c4		c1			c4	c4	c12	c12	c11	c1	c1	c5
c4		c1			c1	c4	c5	c4	c23	c1	c19	c12
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c1		c4			c4	c4	c4	c23	c23	c1	c4	c1
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c18		c11			c1	c4	c4	c18	c23	c12	c1	c1
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Knockout mice corpuses, coded with classes. Numbers are identifiers for individual mice. Ten particularly short songs (< 40 calls) have been removed due to space restrictions.

1	3	4	5	8	9	10	13	16	17	20	28	29	30	31	32	33	34	37	42
c9	c1	c13	c18	c10	c4	c1	c6	c5	c9	c9	c4	c9	c12	c11	c9	c11	c1	c11	c1
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APPENDIX D

Frequency counts for all corpuses

COSMO:

Frequency	Phrase
561	NWM
519	DUW
474	WBI
316	DS
157	PH
133	MWH
122	DW
115	I'M HERE
108	KS
87	OOO
78	WF
75	NO
70	DO (DOOR SOUND)
67	OKAY
66	I LOVE YOU
55	HELLO
53	LS
50	RI
48	WW
47	HERE YOU ARE
43	GOODBYE
41	THERE YOU ARE
40	HOW ARE YOU
40	LA
36	CR
36	PHS
34	HI
33	WHAT'S THAT
29	HI TOM
26	COME HERE
26	WANNA COME HERE
25	WANNA BE A GOOD BIRD
23	KS KS

22	DSS
21	COSMO WANNA GO UP
21	COSMO WANNA TALK
21	DWS
21	HA
20	LET GO
19	HERE I ARE
19	WHAT'S BACH
18	PLEASE
18	THAT'S SQUIRREL
18	WANNA PEANUT
18	WE'RE GONNA GO FOR A WALK
17	AM
17	THAT'S BIRDIE
15	COSMO
15	WHAT A BIRD
14	COSMO WANNA BE A GOOD BIRD
14	HERE STEP UP
14	THAT'S WF
13	COSMO GO UP
13	FINE THANK YOU
13	LOOK
13	TELEPHONE FOR BIRD
13	THAT'S TELEVI
13	WHAT'S BYE
12	COSMO BE A GOOD BIRD
12	DUW I'M HERE
12	GO UP
12	HELLO COSMO
12	LSW
12	MARY
12	OKAY GO UP
12	WANNA CUDDLE
12	YOU HAVE REACHED
11	COSMO WANNA WATER
11	KS KS KS
11	WANNA KISS
11	WBIS

11	WE'RE GONNA HAVE COMPANY
11	WHERE ARE YOU
10	BETTY JEAN WANNA KISS
10	BETTY KISS
10	COME HERE PLEASE
10	COSMO DON'T BITE OKAY
10	COSMO WANNA CUDDLE
10	DOGGIES WANNA GO FOR A WALK
10	DOS
10	KSS
10	THAT'S BARK
9	OU
9	THAT'S TELE
9	WANT KISS
9	WOW
8	AWW
8	FINE THANKS HOW ARE YOU
8	SQUIRREL
8	TELEPHONE
8	WHAT
8	WHAT THAT
7	BARK
7	COME ON
7	COSMO POOP
7	DON'T BITE
7	FR
7	HELLO KERRI
7	KISS
7	MARY HAS FEATHERS
7	OH GOODBYE
7	OKAY GOODBYE
7	STEP UP
7	YOU HAVE REACHED BETTY JEAN
6	COS
6	KS KS KS KS
6	OKAY WE'RE GONNA GO FOR A WALK
6	THAT'S BEAK

6	THAT'S RAIN
6	WANNA BE A BIRD
6	WANNA COME
6	WE'RE GONNA HAVE
5	BARK WF
5	COSMO WANNA KISS
5	DON'T BITE OKAY
5	NO PEANUT
5	STEP UP HERE
5	THAT'S
5	THAT'S BARK WF
5	WANNA GO UP
5	WANNA TALK
5	WE'LL BE BACK SOON
5	WHAT A GOOD BIRD
5	WHAT'S BARK
4	BE BACK SOON BE BACK
4	BETTY JEAN HAVE GO IN A CAR
4	COS DON'T BITE OKAY
4	COSMO DON'T BITE
4	COSMO HAS FEATHERS MWH
4	COSMO HAS FEET
4	COSMO WANNA
4	COSMO WANNA BE A BIRD
4	COSMO WANNA GO FOR A WALK
4	COSMO WANNA GO TO BED
4	COSMO WANNA SHOWER
4	COSMO WANNA WHI DUW
4	COSMO'S A BIRDIE
4	FINE
4	GO UP HERE
4	HERE STEP UP HERE
4	HI TOM HOW ARE YOU
4	LET GO PLEASE
4	MARY HAS FEATHERS MWH
4	NWMS
4	OKAY BYE
4	OW

4	THANK YOU
4	THAT'S COSMO
4	THAT'S DOGGIE
4	WANNA
4	WANNA BE A
4	WANNA BE A GOOD
4	WANNA WHISTLE
4	WE'LL BE BACK SOON BE BACK
4	WE'RE GONNA GO
4	WWS
3	BE A GOOD BIRD OKAY GO UP
3	BETTY JEAN HAVE
3	BETTY JEAN HAVE TO GO IN A CAR
3	BETTY JEAN HAVE TO LEAVE
3	BETTY JEAN WANNA
3	BETTY JEAN WANNA KISS KS
3	COME MARY
3	COSMO GO BACK CAGE
3	COSMO WANNA COME HERE
3	COSMO WANNA GO TO KITCHEN
3	COSMO WANNA GO UP HERE
3	COSMO'S A BIRD
3	FIVE FOUR NINE
3	FIVE FOUR NINE SIX TWO FOUR THREE
3	GOOD KISS
3	GOODBYE KERRI
3	HEYGOV
3	HI COSMO
3	HI TOM LA
3	I LOVE
3	I LOVE YOU KS
3	KISS OKAY
3	LET GO LA
3	MARY HAS
3	NO MORE PEANUT
3	OH

3	OKAY COSMO
3	OKAY STEP UP
3	PEANUT'S IN CAGE
3	TEL FOR BIRD
3	TELEVI
3	THAT'S BYE
3	THAT'S DOGGIE BARK
3	THAT'S WANNA GRAPE
3	THAT'S WATER
3	WANNA GO BACK CAGE
3	WANNA GO TO BED
3	WANNA GO UP HERE
3	WANT KISS KS KS KS
3	WANT PEANUT
3	WE'LL BE BACK
2	BAD BIRD
2	BETTY GO IN A CAR
2	BETTY KISS KS
2	BYE
2	COS DON'T BITE
2	COSMO AND BETTY JEAN WANNA WHISTLE
2	COSMO BACK IN CAGE
2	COSMO BE A GO UP
2	COSMO BETTY JEAN HAVE GO IN A CAR
2	COSMO GO UP HERE
2	COSMO HAS FEATHERS
2	COSMO LA
2	COSMO PLEASE
2	COSMO WANNA GO BACK CAGE
2	COSMO WANNA PEANUT
2	COSMO WANNA WHISTLE
2	COSMO WE'RE GONNA GO IN A CAR
2	COSMO'S A GOOD GOOD BIRD
2	DOGGIE BARK
2	GOOD BYELOVE YOU
2	HA HA
2	HAS (HAWK SOUND

	SEQUENCE)
2	HELLO KAYLEE
2	HERE
2	HERE I
2	HERE YOU ARE HERE
2	HOW ARE THANK YOU
2	I WANNA KISS OKAY
2	KS KS KS KS KS KS
2	LET'S GO TO BETTY JEAN ROOM
2	LOOK COSMO
2	MARY COME ON
2	NO COS
2	OH THANK YOU BYE
2	OKAY COME HERE
2	OKAY COS
2	OKAY DOGS WE'RE GONNA GO FOR A WALK
2	OKAY GOODBYE NWM
2	OKAY LET'S GO TO KITCHEN
2	OKAY TIME FOR SHOWER PEANUT
2	OOO WHAT A BIRD
2	OU DON'T BITE
2	PEANUT
2	PEANUT IN CAGE
2	PLEASE STEP UP
2	S
2	STEP UP PLEASE
2	TELE FOR BETTY JEAN
2	TELE FOR BIRD
2	TELEPHONE FOR
2	THANK
2	THANKS BYE PH
2	THAT'S COSMO'S A BIRDIE
2	THAT'S DOGGIE HAS
2	THAT'S KISS
2	THAT'S PAPER
2	THAT'S POOP
2	THAT'S WANNA WATER

2	THERE YOU
2	TIME
2	WAN GO TO BED
2	WANNA GO FOR A WALK
2	WANNA GO TO
2	WANNA GO TO KITCHEN
2	WANNA KISS KS KS
2	WANNA KISS KSS
2	WANNA PEANUT OKAY
2	WANNA SHOWER AND PEANUT
2	WANNA STEP UP
2	WANNA WHI DUW
2	WE'RE
2	WE'RE GONNA GO FOR WALK
2	WE'RE GONNA GO IN A CAR
2	WHAT A GOOD
2	WHAT'S
2	WHERE COSMO
2	WHY THANK
2	WOW LA
2	YOOHOO
2	YOU HAVE REACHED COSMO
2	**YOU LA**

HUMPBACK SONG:

By song. PR = Puerto Rico, TC = Turks and Caicos, LA = Lesser Antilles.

	PR '70	**PR '70**	**PR '70**	**PR '75**	**TC '74**	**TC '74**	**TC '74**	**LA '73**	**LA '73**	**LA '76**	**LA '76**
	117770	**117774**	**117775**	**128296**	**118102**	**118118**	**118119**	**110847**	**110858**	**118171**	**118172**
unit 1	30	12	56	0	5	8	2	0	0	50	51
unit 2	0	1	4	0	65	112	34	2	1	0	0
unit 3	14	36	48	4	70	41	57	71	82	46	49
unit 4	5	14	73	2	3	16	6	90	104	24	28
unit 5	0	0	0	0	177	121	77	7	15	0	1
unit 6	41	14	45	0	45	33	34	0	14	93	124
unit 7	105	32	15	1	32	28	52	12	13	61	117
unit 8	7	16	19	1	47	64	31	69	57	43	36
unit 9	5	28	46	22	35	33	27	91	82	63	73
unit 10	8	15	46	3	38	44	34	33	33	87	56
unit 11	4	0	86	0	38	85	89	0	0	11	3
unit 12	13	15	56	0	12	44	40	3	7	61	46
unit 13	54	23	21	0	17	22	45	2	6	78	94
unit 14	6	4	49	0	6	4	4	51	62	14	14
unit 15	10	28	30	46	1	1	0	56	77	43	43
unit 16	97	168	118	0	1	4	15	2	2	71	35
unit 17	157	64	82	0	0	1	0	15	12	40	55
unit 18	32	27	116	6	3	0	0	13	16	32	24
unit 19	8	3	32	147	0	0	0	101	62	13	26
unit 20	7	49	81	30	0	0	0	41	53	20	14
unit 21	33	52	57	0	1	3	4	57	58	4	11
unit 22	63	128	79	0	3	27	12	0	0	18	14
unit 23	22	28	46	1	1	2	2	63	59	32	43
unit 24	2	3	35	6	0	0	0	87	59	18	14
unit 25	0	2	31	22	0	0	0	54	80	25	26
	723	**762**	**1271**	**291**	**600**	**693**	**565**	**920**	**954**	**947**	**997**

MICE:

	WT	**KO**
c1	1492	2113
c2	70	26
c3	80	138
c4	1188	824
c5	262	111
c6	120	105
c7	39	36
c8	29	94
c9	411	420
c10	85	129
c11	337	277
c12	727	343
c13	53	54
c15	153	127
c17	8	36
c18	27	93
c19	99	33
c20	6	156
c21	9	91
c22	10	30
c23	818	141