


What's so special about speech?

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Humans have long been obsessed with their uniqueness. Early on, it was “man the hunter”. But studies of cooperative hunting in chimpanzees put an end to this view (Boesch, 1994; Goodall, 1986). Then it was “man the tool maker”.

 Once again, studies of chimpanzees, and more recently, several other animals, have shown that humans are by no means unique in their capacity to make and use tools (Alp, 1997; Hauser, 1997; Hunt, 1996; Matsuzawa, 1996; Visalberghi, 1990; reviewed in Hauser, 2000). As recent studies of chimpanzees have clearly shown, the diversity of tools used for solving both social and ecological problems is extraordinary (Whiten, et al., 1999). Then it was “humans, the sexy species”. But observations of bonobos, also known as pygmy chimpanzees, have demonstrated that we are not alone in our sexual extravaganzas (de Waal, 1988; de Waal, 1989; de Waal, 1996; Dixson, 1999). Bonobo females are continuously receptive to the sexual advances of males, as well as females. There are homo- and hetero-sexual encounters, with individuals of all ages, including oral sex and tongue kissing. What, then, of

our verbal abilities, the capacity to speak about quantum mechanics or syntactical structure, the beauty of nature, the passion of romantic love, and the batting record of a Babe Ruth or Sammy Sosa? What, more precisely, is so special about our capacity for speech? My aim in this essay is to explore the “speech-is-special” problem using what I consider to be the only viable empirical approach. It is an approach that Charles Darwin championed, and that I and several colleagues have tapped over the past few years: the comparative method (Kluender et al. in press). Here, I compare human infants and adults on the one hand, with nonhuman animals (hereafter *animals*) on the other, exploring the extent to which the mechanisms underlying speech perception in humans are evolutionarily ancient, inherited from a vertebrate ancestor.

1.1. The speech is special debate: Historical background

First, a brief history. In the 1960s, following Chomsky’s (1957a) famous attack on Skinner’s *Verbal Behavior*, Al Liberman and his colleagues (Liberman et al., 1957, 1967) at the Haskins lab began to explore in detail the mechanisms underlying speech perception in humans. What is particularly interesting about the claims emerging from Haskins at this time is that they were intellectually allied with Chomsky’s (1957b; 1966) position concerning the special nature of human language. In particular, it is clear that Chomsky thought of the “language organ” as a uniquely human organ, and that its capacity for generating syntactical structure evolved for reasons that had nothing to do

with communication. Although one can certainly challenge the veridicality of this claim, what is important for biologists about Chomsky's position is that it sets up a testable hypothesis about the nature of the comparative data base (see Hauser, 1996). Specifically, if humans are truly unique with respect to the language organ, then we should see little to no evidence of a precursor mechanism in other animals. For the past 40 years, biologists, psychologists and anthropologists have been chasing Chomsky's particular version of the human uniqueness claim by looking at the capacities of animals to acquire some form of a human natural language under intensive training environments, or for animals to use their natural, species-typical vocalizations in ways that are similar to spoken language. Thus, for example, studies have focused on the capacity of human-reared apes to string symbols together to form sentences or comprehend them (Gardner et al., 1989; Savage-Rumbaugh & Lewin, 1996; Savage-Rumbaugh, et al., 1993; Terrace, 1979), and of wild monkey populations to use vocalizations to refer to objects and events in the external environment (Fischer, 1998; Gouzoules et al., 1984; Hauser 1998; Marler et al. 1986; Seyfarth et al., 1980; Zuberbuhler et al., 1997). Though these studies have met with mixed success, especially as viewed from the perspective of linguists looking at such comparative data for insights into the evolution of language (Bickerton, 1990; Lieberman 1991; Pinker, 1994), there has been another approach, one that brings us back to Liberman and the Haskins lab. In particular, rather than a focus on the semantics and syntax of language, much of the early work on speech perception was aimed at identifying particular

signatures of an underlying, specialized mechanism. Perhaps one of the most important, and early entries into this problem was Liberman's discovery of the phenomenon of categorical perception.

1.2. Categorical perception: Uniquely human, special to speech?

When we perceive speech, we clearly create categories. Using an artificially created acoustic continuum running from /ba/ to /pa/, human adults show a categorical discrimination and labeling function. More precisely, discrimination of exemplars is excellent for between-category exemplars, but not for within-category exemplars. To determine whether the mechanism underlying categorical perception is specialized for speech, uniquely human, and fine-tuned by the linguistic environment, new methods were required, as were subjects other than human adults. In response to this demand, the phenomenon of categorical perception was soon explored in (1) adult humans using non-speech acoustic signals as well as visual signals, (2) human infants using a non-nutritive sucking technique together with the presentation of speech stimuli, and (3) animals using operant techniques and the precise speech stimuli used to first demonstrate the phenomenon in adult humans. Results showed that categorical perception could be demonstrated for non-speech stimuli in adults (Bornstein, 1987; Remez, 1979), and for speech stimuli in both human infants (Eimas et al., 1971) and nonhuman animals (Kuhl & Miller, 1975; Kuhl & Padden, 1982). Although the earliest work on animals was restricted to mammals (i.e., chinchilla, macaques), more recent studies have

provided comparable evidence in birds (Dent et al., 1997; Kluender et al., 1987). This suggests that the mechanism underlying categorical perception in humans is shared with other animals, and may have evolved at least as far back as the divergence point with birds. Although this finding does not rule out the importance of categorical perception in speech processing, it does indicate that the underlying mechanism is unlikely to have evolved *for* speech.

Categorical perception has also been demonstrated in animals using tasks involving their own, species-typical vocalizations (reviewed in Kuhl, 1989; Hauser, 1996; Wyttenbach & Hoy, 1999). And here, the breadth of species tested is truly extraordinary, including field crickets (Wyttenbach et al., 1996), swamp sparrows (Nelson, 1989), mice (Ehret & Haack, 1981), pygmy marmosets (Snowdon, 1987) and Japanese macaques (May et al., 1989). Perhaps one of the best examples, based on methodological elegance as well as functional and ecological considerations, comes from Wyttenbach and Hoy's work on the field cricket. In this species, individuals emit a contact call of 4-5 kHz. When conspecifics hear this call, they often approach. In contrast, predatory bats produce ultrasonic signals in the 25-80 kHz range, and when crickets hear such sounds, they move away. The perceptual task, therefore, involves a discrimination between two ecologically meaningful acoustic signals, one that elicits approach and a second that elicits avoidance. Laboratory experiments had already indicated a transition between approach and avoidance in the 10-20 kHz range. In the labeling task, crickets were presented with signals that varied from 2.5-40kHz. Results showed an abrupt transition from approach to

avoid between 13-16kHz, providing strong evidence of a categorical boundary. In the discrimination task, crickets were habituated to 20 kHz pulses (i.e., a signal that elicits escape), and a photocell used to measure the movement of the subject's hind leg. Once subjects habituated (i.e., showed little to no escape response), they then received one test stimulus from a different frequency and one 20kHz stimulus. Of the frequencies tested, only stimuli falling below 16 kHz caused dishabituation; no stimuli falling in the ultrasound range caused dishabituation, providing strong evidence of between-category discrimination.

1.3 The speech is special debate: The next generation

The history of work on categorical perception provides an elegant example of the comparative method. If you want to know whether a mechanism has evolved specifically for a particular function, in a particular species, then the only way to address this question is by running experiments on a broad array of species. With respect to categorical perception, at least, we can confidently claim that the underlying mechanism did not evolve for processing speech. A question, however, arises from such work: What, if anything, is special about speech, especially with respect to processing mechanisms? Until the early 1990s, animal scientists pursued this problem, focusing on different phonemic contrasts as well as formant perception (Lotto et al., 1997; Sinnott, 1989; Sinnott & Brown, 1997; Sinnott et al., 1985; Sommers et al., 1992); most of this work suggested common mechanisms,

shared by humans and nonhuman primates. In 1991, however, Patricia Kuhl (1991) published an important paper showing that human adults and infants, but not rhesus monkeys, perceive a distinction between so-to-speak *good* and *bad* exemplars of a phonemic class. The good exemplars, which Kuhl described as *prototypes*, functioned like perceptual magnets, anchoring the category, and making it more difficult to distinguish the prototype from sounds that are acoustically similar; non-prototypes function in a different way, and are readily distinguished from more prototypical exemplars. In the same way that robins and sparrows, but not penguins or storks, are prototypical birds because they consist of the most common or salient visual features (e.g., feathers, beak, wings, flies) within the category bird, prototypical phonemes consist of the most common or salient acoustical features. Although there is controversy in the literature concerning the validity of this work in thinking about the perceptual organization and development of speech (Kluender et al., 1998; Lotto et al., 1998; Sussman & Lauckner-Morano, 1995), my concern here is with the comparative claim. Because Kuhl failed to find evidence that rhesus monkeys distinguish prototypical from non-prototypical instances of a phonetic category, she argued that the perceptual magnet effect represents a uniquely human mechanism, specialized for processing speech. Moreover, because prototypes are formed on the basis of experience with the language environment, Kuhl further argued that each linguistic community will have prototypical exemplars tuned to the particular morphology of their natural language.

To address the comparative claim, Kluender and colleagues (1998) attempted a replication of Kuhl's original findings, using European starlings and the English vowels /i/ and /I/, as well as the Swedish vowels /y/ and /ʉ/; these represent the stimuli used in Kuhl's original work on the prototype effect. Based on a mel scale of the first and second formants, these vowels have distinctive prototypes that are, acoustically, non-overlapping. Once starlings were trained to respond to exemplars from these vowel categories, they readily generalized to novel exemplars. More importantly, the extent to which they classified a novel exemplar as a member of one vowel category or another was almost completely predicted by the F1 and F2 values, as well as by the exemplar's distance from the prototype or centroid of the vowel sound. Because the starlings' responses were graded, and matched human adult listeners' ratings of *goodness* for a particular vowel class, Kluender and colleagues conclude, contra Kuhl, that the perceptual magnet effect is not uniquely human, and can be better explained by general, perceptual learning mechanisms.

In contrast to the extensive comparative work on categorical perception, we have only two studies of the perceptual magnet effect in animals. One study of macaques claims that animals lack such capacities, whereas a second study of starlings claims that animals have such capacities. If starlings perceive vowel prototypes, but macaques don't, then this provides evidence of a homoplasy – a character that is similar between species because of convergent evolution. Future work on this problem must focus on whether the

failure with macaques is due to methodological issues (e.g., would a different testing procedure provide different results?) or to an absence of a capacity.

1.4 The speech is special debate: New approaches

To date, every time a claim has been made that a particular mechanism X is special to speech, animal studies have generally shown that the claim is false. Speech scientists might argue, however, that these studies are based on extensive training regimes, and thus, fail to show what animals spontaneously perceive. Although experiments involving training show what an animal's brain is capable of computing, they do not allow us to understand how animals and humans compare on tasks involving spontaneous methods. Over the past few years, my students and I have been pushing the development of methodological tools that involve no training, and thus, may provide a more direct approach to comparing the behavioral, perceptual, and cognitive mechanisms that are either shared or distinctive across species (Hauser, 1996, 1997, 1998; Santos et al., 1999; Santos & Hauser, 1999); we are certainly not alone in this endeavor (Diamond, 1990; Diamond et al., 1989; Terrace, 1993; Tomasello & Call, 1997; Tomasello et al., 1993). In the remainder of this chapter, I describe several recent results using spontaneous techniques, focusing specifically on how nonhuman primates perceive speech and whether they tap mechanisms that are shared with human primates.

Over the past 15 or so years, my students, colleagues and I have conducted observations and experiments on the vocal behavior of three

nonhuman primate species, each from a different branch of the Primate phylogeny (Figure 1). Specifically, we have conducted studies of cotton-top tamarins (*Saguinus oedipus*) in the laboratory, rhesus monkeys (*Macaca mulatta*) on an island off the coast of Puerto Rico, and chimpanzees (*Pan troglodytes*) in a rainforest in Uganda. A powerful technique for exploring spontaneous perceptual distinctions is the habituation-dishabituation technique (Cheney & Seyfarth, 1988; Hauser, 1998), briefly mentioned above. Given the variety of conditions in which our animals live, each situation demands a slightly different use of this technique. The logic underlying our use of the procedure is, however, the same. In general, we habituate a subject to different exemplars from within an acoustic class and then present them with a test stimulus. A response is scored if the subject turns and orients in the direction of the speaker. We consider the subject to be habituated if it fails to orient toward the speaker on at least two consecutive trials; as such, all subjects enter the test trial having failed to respond on the previous two trials. The advantage of this approach is that we can not only score whether or not they respond to the test stimulus, but in some cases, the magnitude of their response; that is, we can score the amount of time spent looking in the direction of the speaker. In the case of speech stimuli, duration is not a reliable measure, whereas in the case of conspecific vocalizations it is.

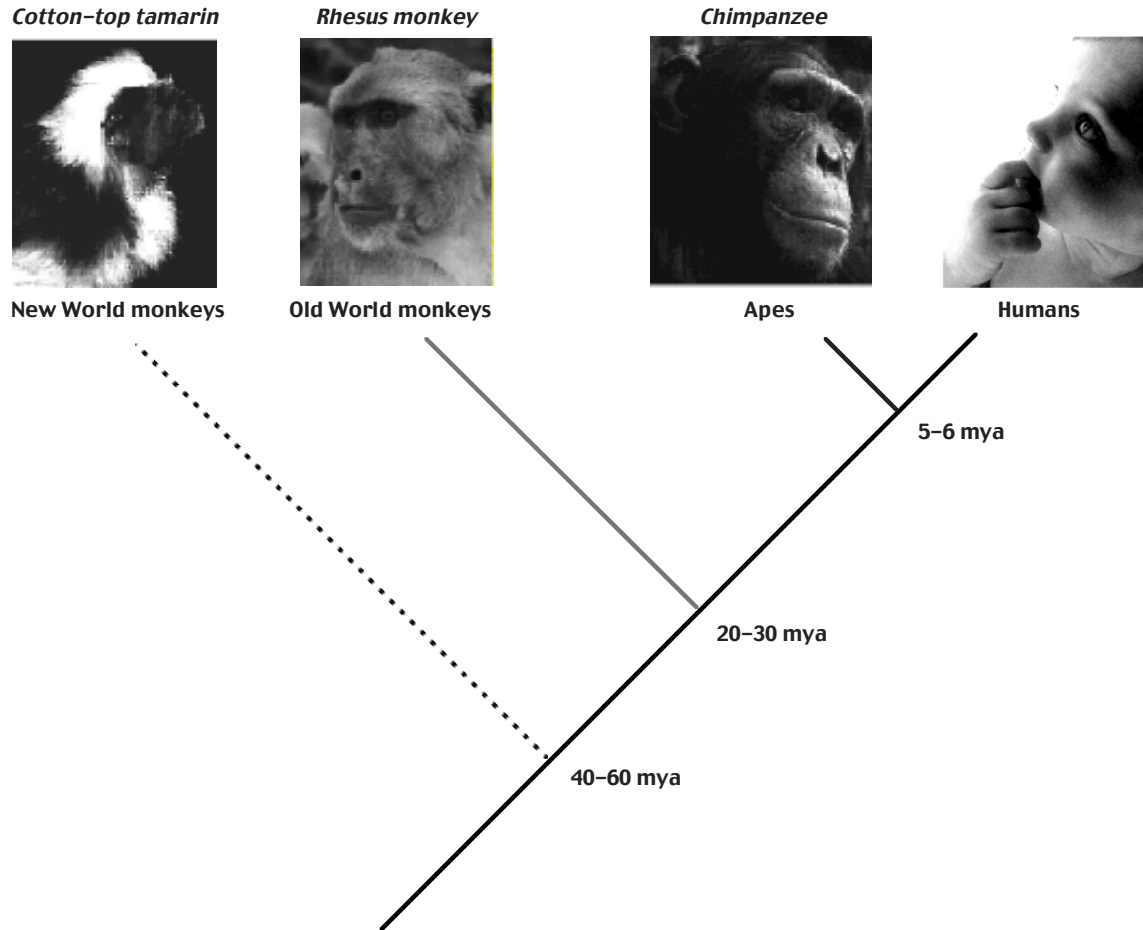


Figure 1. Phylogeny of four of the main primate groups, with approximate divergence times listed at each node.

The first playback experiment on speech perception was run in collaboration with Franck Ramus, Cory Miller, Dylan Morris, and Jacques Mehler (in press). The goal of these experiments was twofold. Theoretically, we wanted to understand whether the capacity of human infants to both discriminate, and subsequently acquire, two natural languages, is based on a mechanism that is uniquely human or shared with other species. Though animals clearly lack the capacity to produce most of the sounds of our natural languages, their hearing system is such (at least for most primates; Stebbins,

1983) that they may be able to hear some of the critical acoustic features that distinguish one language from another. To explore this problem, we asked whether human neonates and other animals can discriminate sentences of Dutch from sentences of Japanese, and whether the capacity to discriminate these two languages depends on whether they are played in a forward (i.e., normal) or backwards direction; given the fact that adult humans process backwards speech quite differently from forward speech, we expected to find some differences, though not necessarily in both species. Methodologically, we wanted to determine whether tests of speech processing could be run on neonates and captive cotton-top tamarins using the same stimuli and procedure. Specifically, would tamarins attend to sentences from a natural language, and could we implement the habituation-dishabituation technique to ask questions about discrimination?

Neonates and adult tamarins were tested in four different conditions involving naturally produced sentences of Dutch and Japanese. In the first language change condition, subjects were habituated to one language played in the normal/forward direction, and then tested with sentences from the second language played in the normal/forward direction. In the second language change condition, all sentences were played backwards, but with the same shift from one language to the other. In the first speaker change condition – run as a control for the language change condition – subjects were habituated to normal/forward sentences of one language spoken by two speakers, and then tested with normal/forward sentences of the same language, but spoken

by two new speakers. The second speaker change condition was the same, but with the sentences played backwards.

There were a few differences in the testing procedures used for neonates and tamarins. The behavioral assay for neonates was a high amplitude sucking response, whereas for tamarins, we used a head orienting response in the direction of the concealed speaker. For neonates, habituation stimuli were played back until the sucking response attenuated to 25% less than the previous minute, and then maintained this level for two consecutive minutes. Once habituated, test stimuli were repeatedly played back. For tamarins, in contrast, we played back exemplars from the habituation category until the subject failed to orient on two consecutive trials. Following habituation, we played back sentences of the test category. If subjects failed to respond in the test trial, we played a post-test stimulus, specifically, a tamarin alarm call. The logic behind the post-test was to ensure that the tamarins had not habituated to the entire playback setup. Thus, if they failed to respond in the post-test, we assumed that they had habituated to the set-up, and reran the entire session a few weeks later.

Neonates failed to discriminate the two languages played forward, and also failed to discriminate the two speakers. Rather than run the backwards condition with natural speech, we decided to synthesize the sentences and run the experiment again, with new subjects. One explanation for the failure with natural speech was that discrimination was impaired by the significant acoustic variability imposed by the different speakers. Consequently, synthetic speech

provides a tool for looking at language discrimination, while eliminating speaker variability. When synthetic speech was used, neonates dishabituated in the language change condition, but only if the sentences were played forward; in the backward speech condition, subjects failed to dishabituate.

In contrast to the data on neonates tested with natural speech, tamarins showed evidence of discrimination in the forward, language change condition, but failed to show evidence of discrimination in any of the other conditions (Figure 2). When the synthetic stimuli were used, the results were generally the same (Figure 2). Only the forward language change condition elicited a statistically significant level of discrimination, though the backward speaker change was nearly significant; thus, there was a non-significant difference between the language and speaker change condition. When the data from the natural and synthetic stimuli are combined, tamarins showed a highly significant discrimination of the forward language change condition, but no other condition.

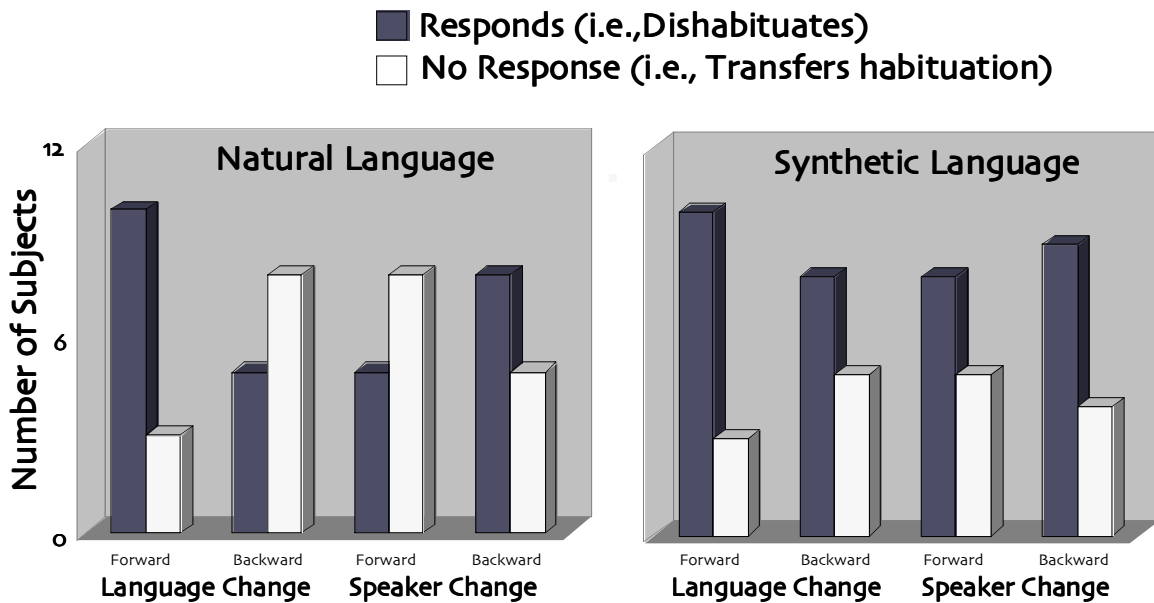


Figure 2. Results from habituation-dishabituation experiments with cotton-top tamarins using natural and synthetic sentences of Dutch and Japanese. The y-axis plots the number of subjects responding (gray bars) by turning toward the speaker, or not responding (white bars), following the habituation series. Each subject was tested in four conditions: Forward sentences with a language change, Backwards sentences with a language change, Forward sentences with a speaker change, and Backwards sentences with a speaker change.

These results allow us to make five points with respect to studying the “speech is special” problem. First, the same method can be used with human infants and nonhuman animals. Specifically, the habituation-dishabituation paradigm provides a powerful tool to explore similarities and differences in perceptual mechanisms, and avoids the potential problems associated with training. Second, animals such as cotton-top tamarins not only attend to isolated syllables as previously demonstrated in studies of categorical perception, but also attend to strings of continuous speech. Consequently, it is now possible to ask comparative questions about some of the higher order properties of spoken languages, including some of the relevant prosodic or

paralinguistic information. Third, given the fact that tamarins discriminate sentences of Dutch from sentences of Japanese in the face of speaker variability, they are clearly able to extract acoustic equivalence classes. This capacity is not present in the human neonate, coming on line a few months after birth (Jusczyk, 1997; Oller, 2000). Fourth, because tamarins fail to discriminate sentences of Dutch from sentences of Japanese when played backwards, their capacity to discriminate such sentences when played forward shows that they must be using specific properties of speech as opposed to low level cues. Fifth, given that the tamarins' capacity to discriminate Dutch from Japanese was weaker in the second test involving synthetic speech, it is possible that newborns and tamarins are responding to somewhat different acoustic cues. In particular, newborns may be more sensitive to prosodic differences (e.g., rhythm) while tamarins may be more sensitive to phonetic contrasts. Future research will explore this possibility.

In addition to our collaborative work with Mehler, we have also begun tests involving other aspects of speech processing. In particular, as several recent papers suggest, a real world problem facing the human infant is how to segment the continuous acoustic stream of speech into functional units, such as phonemes, words, and phrases. Work by Saffran, Newport and Aslin (1996) suggests that infants may be equipped with mechanisms that enable them to extract the statistical regularities of a particular language. Similarly, Marcus and colleagues (1999) have suggested that infants are equipped with the capacity to extract abstract rules that, subsequently, may form the foundation

upon which grammars are constructed. In collaboration with these two groups, we have used our tamarin colony to determine whether other animals are capable of computing transitional probabilities as well as other statistical inferences. Using the original Saffran et al. al material, we have recently replicated the findings with tamarins. Specifically, having been exposed to a continuous acoustic stream of syllables, where the transitional probabilities provide the only relevant information for discriminating words (i.e., three syllable sequences with high transitional probabilities) from non-words (i.e., three syllable sequences with low transitional probabilities), tamarins were able to compute the relevant statistics. Thus, like human infants, tamarins oriented to playbacks of non-words (novel) more often than to words (familiar). This result is powerful, not only because tamarins show the same kind of capacity as do human infants, but because the methods and stimuli are the same, and involve no training.

What can be said about our verbal abilities? Unique or not? If I had to place a wager, I would bet that humans share with other animals the core mechanisms for speech perception. More precisely, we inherited from animals a suite of perceptual mechanisms for listening to speech, ones that are quite general, and did not evolve for processing speech. Whether the similarities across species represent cases of homology or homoplasy can not be answered at present and will require additional neuroanatomical work, tracing circuitry, and establishing functional connectivity. What is perhaps uniquely human, however, is our capacity to take the units that comprise spoken and signed

language, and recombine them into an infinite variety of meaningful expressions. Although much work remains, my guess is that animals will lack the capacity for recursion, and their capacity for statistical inference will be restricted to items that are in close, temporal proximity. With the ability to run animals and human infants on the same tasks, with the same material, we will soon be in a strong position to pinpoint when, during evolution and ontogeny, we acquired our specially designed system for language.

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