

# Mechanisms Underlying Language Acquisition: Benefits From a Comparative Approach

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One of the longstanding issues in language research has been the extent to which the mechanisms underlying language acquisition are uniquely human. The primary goal of this article is to introduce the reader to some of the recent developments in comparative language research that have shed new light on this issue. To appreciate the significance of the new developments, we begin with a brief historical overview of language studies that have adopted a comparative approach, and then discuss a subset of the relevant theoretical accounts that seek to explain why humans are the only species capable of acquiring language. We next focus on findings from behavioral studies comparing the performance of human infants and adults with nonhuman primates on tests that tap the perceptual and learning mechanisms that are fundamental to language acquisition. We argue that in cases where the behavioral data appear similar across populations, there is a need to investigate the underlying computational abilities and units of analysis to correctly specify the degree to which the mechanisms are truly shared or are uniquely specified.

Dogbert: I once read that given infinite time, a thousand monkeys with typewriters would eventually write the complete works of Shakespeare.

Dilbert: But what about *my* poem?

Dogbert: Three monkeys, ten minutes.

Scott Adams's comic strip is amusing because it implies a simple quantitative relationship between humans and nonhumans with respect to language abilities. In fact, this touches on questions that have troubled philosophers and scientists for centuries. Why is it that, in the millions of years since nonhuman primates (hereafter primates) and humans have shared a common ancestor, only humans have developed the capacity for language? Is the difference qualitative or quantitative? What abilities do humans possess that facilitate language, and to what extent are they shared with other species? Despite a wealth of new scientific techniques for addressing these questions, the answers remain elusive. However, behavioral studies that compare performance across species continue to provide crucial data that are fueling current thinking in this area. In recent years a new line of work has appeared, examining the fundamental computational abilities of various species, using a methodology that involves no explicit training. These studies use techniques that can be employed with both human infants and nonhumans, thereby allowing for a more direct assessment of cross-species similarities and differences. In addition, by focusing on basic computational abilities, rather than asking whether primates can acquire a full complex human (or humanlike) communication system, this line of work adds to the literature a growing understanding of how species may be similar and different, particularly with respect to the perceptual and learning mechanisms underlying language acquisition.

The primary goal of this article is to introduce the reader to some of the recent developments in comparative language research, focusing specifically on these perceptual and learning mechanisms that are fundamental to language acquisition. To allow the reader to more fully appreciate the implications of these studies, we begin with a brief background on several relevant theoretical perspectives,<sup>1</sup> and then touch on a variety of comparative approaches that have been used in primate language research. We conclude by speculating on some future directions for this field.

## THE IMPACT OF COMPARATIVE STUDIES

There are a number of reasons why comparative studies can be extremely important for understanding human language acquisition. However, there are two questions that are most often of interest. First, in what ways is human language unique

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<sup>1</sup>An exhaustive account of the many theories surrounding language evolution is beyond the scope of this article. For those interested in a more comprehensive coverage of this topic, see Christiansen and Kirby (2003).

and species-specific? Second, to what degree does human language involve domain-specific abilities? Studies of language-relevant abilities in nonhuman species can provide insight into both of these questions. *Homologies* are shared traits among closely related species that have similar structure and are therefore posited to possess a common evolutionary origin (Campbell, 1988; Hauser, 1996; Owen, 1848). If primates show abilities similar to human infants in speech perception or language processing, we can hypothesize that these abilities are homologous between species and did not evolve specifically for language acquisition. Of course, any claim about shared mechanisms underlying language acquisition usually hinges on a close evolutionary relationship between the species investigated. Demonstrating effects in more distantly related species leaves open the possibility that convergent evolution is at work (although an alternative might be that the mechanism is extremely widespread and inherited from a much earlier common ancestor). For example, many songbird species acquire their species-typical vocalizations through a period of vocal learning that is similar in many ways to human language acquisition (e.g., there are stages of babbling and subsong, auditory feedback is necessary, etc.; see Marler, 1991, for a review). Although it might be tempting on behavioral grounds to view this type of vocal development as an evolutionary precursor for language, the distant relation between human and avian species would suggest that it is actually a *homoplastic* relationship (a shared feature that arises through convergent evolution; see Hodos, 1988). This interpretation is supported by the fact that more closely related species, such as primates, do not exhibit similar types of vocal development (Cheney & Seyfarth, 1990).<sup>2</sup>

A different approach to the question of uniqueness and domain specificity involves demonstrating that humans show comparable abilities in a nonlanguage domain. For example, categorical perception has been demonstrated not only for speech sounds (Liberman, 1970), but also for a variety of visual (Harnad, 1987) and auditory nonlinguistic stimuli (Pisoni, 1977). However, Kuhl (1989) suggested that such evidence is less potent in ruling out language specificity than is demonstrating a homologous effect in a different species. Finding a comparable ability in nonlinguistic and linguistic processing in humans leaves open the possibility that the trait evolved for language but has been coopted or extended for use in another domain. However, finding homologous abilities in nonlinguistic species rules out this alternative account.

An additional opportunity in comparative research is that, once homologous mechanisms are identified, we may begin to understand how natural selection may have shaped them to facilitate language acquisition. In some instances, basic learning mechanisms may be shared across species, but a fine-grained analysis will

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<sup>2</sup>Note that it is important to test multiple species whenever possible to ensure that any behavioral similarities are truly homologous.

reveal differences with respect to the types of computational abilities available to each species or the fundamental units of analysis used for computations (see later for an example of this in the case of statistical learning). Such differences may be very consequential with respect to the ability to acquire language. Thus, in addition to identifying homologous mechanisms across species, the comparative methodology also allows us to generate hypotheses about how existing mechanisms may have been shaped by natural selection to better serve the task of language acquisition. In other instances, comparative studies may help to reveal basic differences in learning between humans and nonhumans, which in turn may elucidate which aspects of learning in humans are critical to language acquisition and how these abilities impact language.

## THEORETICAL APPROACHES

There are a number of ways to conceptualize the underlying differences between species that could result in only humans being capable of acquiring communication systems like language. Here we briefly mention a subset of the broad theoretical positions that have been advanced to account for the striking disparities in communicative abilities between humans and nonhuman primates.

### Broad Differences in Cognition and Language Abilities Across Species

One position suggests that vast differences across species in general cognitive capabilities have resulted in the complex language abilities of humans. There are two versions of this position: One theoretical view asserts widespread qualitative differences between humans and nonhumans, whereas another asserts large quantitative computational differences across species.

Proponents of the qualitative differences view suggest that language arose as an epiphenomenon of other evolutionary developments (e.g., the development of a larger brain and consequently increased cognitive capacity) or as a product of other forces of development that are not yet well understood (e.g., Chomsky, 1982; Gould & Piattelli-Palmarini, 1987, referenced in Pinker & Bloom, 1990). This view is bolstered by the additional claim that the gradual evolution presupposed by natural selection cannot account for elements such as grammatical rules (Bates, Thal, & Marchman, 1991). According to this view, comparative studies might be of limited importance, as the emergence of the language faculty is a uniquely human event, and the relevant cognitive disparities between species are so numerous. Some of the most notable proponents of this view have included the well-known linguist Noam Chomsky and evolutionary biologist Stephen J. Gould (see Pinker & Bloom, 1990).

Another version of this position suggests that the differences between humans and nonhumans may be one of quantity as opposed to quality. Bates claimed that language is “a new machine built out of old parts” (Bates & MacWhinney, 1989). According to this view, the emergence of language in humans is due to changes in the quantity and complexity of information that can be processed. Thus, for example, humans and nonhumans may share rudimentary learning mechanisms that underlie language acquisition, but perhaps only humans use computational units that are appropriate for language acquisition (see later), or only humans may have various types of learning mechanisms coordinated to interact in such a way that language acquisition is facilitated (Bates et al., 1991). Unlike the qualitative view mentioned earlier, this view suggests that we should find broad similarities between humans and nonhumans with respect to the basic mechanisms underlying language acquisition, although humans alone may possess the ability for more sophisticated computations. On this view, then, the comparative method may be extremely useful in identifying the mechanisms underlying language acquisition (the old parts), and also in elucidating how they have been modified and incorporated into supporting language.

### Critical Difference Theories

Another account of the disparity in language abilities suggests that humans and nonhumans share most of the mechanisms underlying language acquisition, save for one or two critical abilities that separate the species. This view suggests that there is a broad range of shared features across species that have been coopted for use by the language faculty, but these features did not specifically evolve for language (as evidenced by their presence in other species). The mechanisms and abilities that are exclusive to humans are candidates for explaining the crucial disparity in language abilities.

For example, a recent model by Hauser, Chomsky, and Fitch (2002; hereafter HCF) proposes that humans and nonhumans share a wide range of mechanisms that facilitate language, but differ in their ability to learn recursive grammars. Their model proposes that the language faculty is split between the faculty of language in the broad sense (FLB), and the faculty of language in the narrow sense (FLN). The FLB consists of a number of subsystems such as a sensorimotor system, a conceptual-intentional system, and the FLN. With the exception of the FLN, the systems comprising the FLB are thought to be mostly, if not entirely, shared across species. The FLN, however, is posited to be a uniquely human component of the faculty of language. Recursion—the ability to combine and recombine elementary units to form an infinite set—has been proposed to be the sole feature of the FLN. That is, according to HCF, recursion is the major difference between species that has facilitated the emergence of language abilities in humans.

Another version of a critical difference hypothesis points to other specific cognitive factors that are crucial to the evolution of language and that differ between species. For example, Terrace (2005) suggested that before the evolution of language, it was necessary to evolve nonverbal skills dedicated to understanding other individuals' minds (theory of mind). According to this view, possessing these skills simplifies the task of learning language, and thus may represent the key component that facilitated language evolution.

### Uniquely Human Language Module

A third theoretical position suggests that the crucial difference between humans and nonhumans pertinent to language is the appearance of a new, modular function that has evolved in humans and is absent in nonhumans. This idea is consistent with the notion that human language is a complex adaptation that has evolved specifically for purposes of communication of knowledge and intentions (Pinker & Bloom, 1990). This view is in many ways compatible with the FLB and FLN framework proposed by HCF. However, the difference between these theories is that, in the present position, the language faculty has many unique features, absent in other species, all of which are crucial to language. Proponents of this position point to a broad number of differences between humans and nonhumans with respect to speech perception, word learning, and other language capacities (see later) as candidates for uniqueness. On this view, all of these differences may deserve equal status with recursion as part of the FLN in the HCF theory.

These three positions are not an exhaustive list of the positions proposed in the literature, but rather a sample of the ways in which researchers may conceptualize the gulf in language abilities between humans and primates. Just as there have been a variety of theoretical positions, so too a variety of methods have been employed to determine empirically the extent to which our language abilities differ from those found in primates.

## METHODOLOGICAL APPROACHES

One of the earliest notions about why primates and humans differ with respect to language was an extreme version of shared mechanisms across species. It was thought that perhaps humans and primates were entirely similar, but only humans are raised in a rich environment conducive to language development. This notion was tested in early ape language projects in which researchers raised chimpanzees in a human environment, providing them with most of the experiences that human infants receive over the course of development (Hayes & Hayes, 1951; Kellogg & Kellogg, 1933). These studies found that chimps were unable to

learn to produce human speech (interestingly, one chimpanzee named Vicki did manage to produce four words with a heavy chimp accent). However, subsequent research demonstrated that the chimpanzee vocal tract (or the chimpanzee brain) may not provide the articulators with enough degrees of freedom to articulate many human speech sounds (Lieberman, 1984). Following these discoveries, ape language projects moved away from teaching spoken languages and instead turned to teaching sign languages (because chimpanzees have dexterous hands). One of the initial studies reported remarkable successes, noting that the chimpanzees were even creative in combining known signs to form novel words such as water bird as a sign for duck (Gardner & Gardner, 1969). However, claims of success were tempered by criticisms of the methods used for collecting and analyzing data (e.g., Seidenberg & Pettito, 1979; Terrace, Petitto, Sanders, & Bever, 1979; Wallman, 1992). Subsequent work has demonstrated that some Great Apes are capable of mastering certain language-related abilities such as analogical reasoning (Premack & Premack, 1983) and comprehending some syntactic constructions (e.g., Savage-Rumbaugh & Brakke, 1996). Although this type of research has been informative, ultimately this paradigm disadvantages primates in that it requires them to acquire a heterospecific (another species') system of communication. However, with respect to theorizing about the language faculty, this type of research has eliminated the most extreme possibility for shared mechanisms, demonstrating that the gulf between humans and primates in linguistic abilities is not merely a by-product of environmental differences.

Another approach to investigate comparative abilities has been to employ psychophysical techniques for assessing speech perception across species. These studies have typically employed an operant training paradigm, testing species (primates and nonprimates) on a variety of important phenomena of human speech perception, such as the perception of phonetic contrasts (e.g., Kuhl & Miller, 1975; Sinnott & Brown, 1997) and formant perception (Sommers, Moody, Prosen, & Stebbins, 1992). The majority of such studies have demonstrated that there are many similarities in the way that humans and primates perceive speech stimuli. For example, categorical perception, once thought to be a unique property of humans (Lieberman, 1970), has been shown to be ubiquitous across many species, both primates and nonprimates (Kuhl, 1986, 1989).

However, although many perceptual studies have reported species similarities, a number of studies have identified important differences in speech perception across species. For example, some primates perceive phonetic contrasts with different perceptual boundaries than humans (Sinnott & Brown, 1997) and do not exhibit identical patterns of trading relations (Sinnott & Saporita, 2000). Analyses have revealed that the vowel space for primates may differ from humans (Sinnott et al., 1997; see Pinker & Jackendoff, 2005, for a review). In addition, the perceptual magnet effect, a phenomenon in which prototypical vowels are harder to discriminate from each other than nonprototypical exemplars, has been claimed

to be unique to human speech perception (Kuhl, 1991).<sup>3</sup> The overall state of this literature thus seems to be somewhat mixed. There are many studies demonstrating that the primate auditory system is the same as that of humans in processing speech sounds. This suggests that many basic mechanisms are indeed shared across species. However, a few studies show that finer analyses reveal subtle differences. This issue is further complicated by the fact that some of the reported differences are in abilities known to be shaped by linguistic experience in humans (e.g., categorical boundaries), leaving open the possibility that the initial state of such abilities in humans may be like that of other species. The importance of these differences has been a source of contention between proponents of critical difference theories and modular language theories (see earlier).

A possible critique of this work concerns the fact that the methods depend on extensive training. There may thus be a trade-off between experimental control and the ability to assess the natural abilities of the species in question. Although these studies demonstrate the animals' abilities under tightly controlled conditions, they do not speak to spontaneous processing, a component crucial for human language learning. One of the hallmarks of human language development is that it proceeds in the absence of explicit training (Chomsky, 1955). To provide a more transparent comparison with human data, a number of recent behavioral studies have used methods developed for field research that do not involve any explicit training or reward, but rather use spontaneous looking techniques (e.g., Hauser, Newport, & Aslin, 2001; Hauser, Weiss, & Marcus, 2002; Ramus, Hauser, Miller, Morris, & Mehler, 2000). Experiments typically consist of a familiarization phase, in which participants are passively exposed to a stimulus set for a predetermined amount of time, followed by a test phase in which participants hear isolated units and their response is gauged by whether they turn and look toward a speaker hidden out of view. One important benefit of these studies is that they are quite compatible with looking time experiments commonly run with human infants. One of the strengths of this paradigm is therefore that it permits close comparisons of perceptual and cognitive abilities between humans and nonhumans in the absence of any explicit training.

A second benefit of using a methodology that requires no explicit training is that it allows for comparison with the earlier psychophysical studies. Because it is quite challenging to pose perceptual questions to subjects with whom we cannot communicate (either human infants or nonhumans), to correctly assess an ability it is important to triangulate results using multiple methodologies (Hauser, 1996). Finally, an additional benefit of this type of research is that it lends itself to determining just meaningful differences, as opposed to psychophysical measures that

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<sup>3</sup>There may be some counterevidence in starlings (see Kluender, Diehl, & Killeen, 1987). On that basis some argue that this phenomenon has not been studied enough in nonhumans to support a uniqueness claim (Hauser, 2003).

may lend themselves more easily to determining just noticeable differences (Hauser, 1996). Although psychophysical methodologies can be tightly controlled, the results obtained with training may reflect perception only under ideal conditions. Using a method that requires no explicit training may tap into differences that are spontaneously perceived and therefore reflect perceptual biases that are a priori meaningful to the subject.

## RESULTS OF THE NONTRAINED BEHAVIORAL APPROACH

The first studies using this methodology for speech perception asked whether non-human primates, like human infants, could perceive language differences based on rhythmic classes (Ramus et al., 2000; also see Tincoff et al., 2005). Subsequent studies have investigated a variety of topics including speech segmentation (Hauser et al., 2001; Newport, Hauser, et al., 2004), rudimentary rule learning (Hauser, Weiss, & Marcus, 2002), and recursive computational abilities (Fitch & Hauser, 2004). The majority of the research in this field has been conducted with cotton-top tamarins, a New World monkey that possesses a large vocal repertoire (Cleveland & Snowden, 1982) and a complex social structure (Neyman, 1977). Like studies using operant conditioning, the results from these studies have uncovered some remarkable similarities and differences across species. Human infants and primates share a proficiency for discriminating languages based on rhythmic classes (Ramus et al., 2000; Tincoff et al., 2005), for acquiring rudimentary rules (Hauser, Weiss, & Marcus, 2002), and for using the statistics of adjacent speech sounds to segment words from a stream of speech (Hauser et al., 2001).

The use of this looking methodology has also produced studies reporting important species differences with respect to language abilities. A recent study by Fitch and Hauser (2004) claims that humans, but not primates, are capable of learning recursive phrase structure grammars, a computational ability necessary for language acquisition. This study found that human adults, but not tamarins, could acquire a recursive grammar with the structure  $A^nB^n$  (which can be thought of as  $S \Rightarrow AXB$ , where  $X = AB$ ). However, this study has been criticized on several grounds, including the suggestion that no natural human language grammars actually follow this particular center-embedded structure (Pinker & Jackendoff, 2005) and the claim that humans may learn the patterns in  $A^nB^n$  strings by non-recursive methods (Perruchet & Rey, 2005).

There have also been studies of statistical learning that point to another potentially important difference between humans and primates. The original finding that both humans (Saffran, Aslin, & Newport, 1996; Saffran, Newport, & Aslin, 1996) and nonhumans (Hauser et al., 2001) can compute statistical dependencies between adjacent speech sounds to parse a running speech stream suggests that at least some aspects of a statistical learning mechanism may be phylogenetically

preserved, and may in fact be a general learning mechanism available to all mammals (Hauser et al., 2001; see Toro & Trobalon, 2005, for evidence of some limited aspects of statistical learning in rats). In fact, for humans there is evidence that this mechanism operates on both tones (Creel, Newport, & Aslin, 2004; Saffran, Johnson, Aslin, & Newport, 1999) and visual patterns (Fiser & Aslin, 2002), showing that at least some basic aspects of the statistical learning mechanism are domain general and not specific to language. However, despite similarities across species for computing adjacent speech sound statistics, recent findings suggest that the abilities of humans and primates to parse running speech streams are not entirely the same. Newport, Hauser, Spaepen, and Aslin (2004) found differences between humans and primates with respect to the processing and computation of nonadjacent regularities in speech sounds. Human adults can learn miniature languages containing nonadjacent consonant and vowel dependencies (like patterns found in natural languages such as Hebrew and Turkish, respectively), but cannot learn to parse speech streams containing only nonadjacent syllable dependencies (a pattern that does not commonly occur in natural languages; cf. Pena et al., 2002, for a different view). In contrast, cotton-top tamarins can parse languages that require computing nonadjacent vowel and nonadjacent syllable dependencies, but cannot parse languages that rely on nonadjacent consonant dependencies (Newport, Hauser, et al., 2004). These findings raise an important question about the primate work: In speech stream segmentation tasks, are the units of analysis and computation performed by primates similar to those found in humans?

One hypothesis put forward by Newport, Hauser, et al. (2004) is that human infants, adults, and tamarins may be computing statistical regularities using different units of analysis. To address this question, Newport, Weiss, Wonnacott, and Aslin (2004) began a research project designed to determine the computational primitives of these different types of learners, by presenting them with languages in which phonetic segment<sup>4</sup> and syllable dependencies are manipulated separately. In one experimental condition, learners are presented with languages that contain congruent dependencies at both the segmental and syllabic level (i.e., both syllable and segment information indicate the same word boundaries). A second experimental condition presents languages that contain information about word boundaries only at the syllabic level (segmental information is distributed evenly throughout the language). A final experimental condition tests whether either segment or syllable information alone is sufficient for word boundaries, or whether information must be congruent at the syllable and segment levels. In this condition, languages were constructed in which segmental statistics indicate the word boundaries to be at one location, whereas the syllabic statistics indicate word boundaries at a different location; if learners require that

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<sup>4</sup>The term *segment* (or *phonetic segment*) refers to individual consonants and vowels.

the two types of statistics are congruent, they should not parse words successfully at either location.

Thus far, results have shown that adult humans are capable of parsing languages in Condition 1, but not in Condition 2 or 3. That is, adults compute statistics for words based on phonetic segments (both consonants and vowels), and also on the alignment of these segments into syllables. However, this complex and hierarchically organized approach to speech perception may not be shared by infants or by tamarins, even though the three types of subjects look quite similar in simpler tasks. Currently infants and (in collaboration with Hauser) tamarins are being tested with this paradigm. Based on the results of the nonadjacent studies (Newport & Aslin, 2004; Newport, Hauser, et al., 2004), the prediction is that tamarins may show a different pattern than human adults, with tamarins computing statistics based on syllables or vowels, but not based on fully separable consonant and vowel segments. Infants may behave like adults, or may show changes from a tamarin-like pattern to an adult pattern over development.

This work has broad implications for interpreting behavioral results across species. One implication is that similar behaviors (e.g., the results of the original adjacent transitional probabilities experiments) can emerge as a product of different computations, or even different mechanisms. To identify the extent to which mechanisms are truly homologues, one must probe how the computations are being performed and identify the underlying units of analysis for computation. These subtle differences may have profound repercussions for real-world language acquisition. It is possible that there are developmental changes in humans, in computation or units of analysis, that may affect the ability to solve real-life segmentation tasks at different developmental stages. Likewise, the statistical learning mechanism in primates may differ significantly from that in humans, with only the most basic aspects of this mechanism shared across species. As a result of such differences, primates may not be able to parse human languages effectively, even though they can perceive some of the basic elements and can perform some of the basic computations that human languages utilize. There may also be significant species differences (or similarities) in how such learning is generalized to other elements in the language (Maye, Weiss, & Aslin, 2005). Overall, such research may reveal how a general learning mechanism can be exploited for language, and also how such a basic mechanism might have been altered or adapted to the needs imposed by language. In this way additional comparative data may provide important insights into the ways in which the language faculty has become uniquely human.

As previously mentioned, studies using the nontrained behavioral approach have also addressed computations beyond speech segmentation. The work on speech segmentation asks about primates' ability to acquire statistical regularities among specific speech sounds. However, one of the hallmarks of human language acquisition is the ability not only to learn about specific exemplars, but also to

extract more abstract patterns from the input, patterns that generalize to novel instances and to categories of items (Marcus, 2001). Hauser, Weiss, and Marcus (2002) demonstrated that tamarins are capable of generalizing simple rules. In this experiment, monkeys were habituated to sequences of consonant–vowel syllables that followed a simple pattern, such as AAB (e.g., la la gi). Following habituation, the monkeys were presented with novel test items that either reflected the same pattern as that during habituation (e.g., ti ti ga) or that did not follow this pattern (e.g., li na na). Like human infants (Marcus, Vijayan, Bandi Rao, & Vishton, 1999), the tamarins more often dishabituated to test items containing a different pattern. This suggests that tamarins can extract simple rules from patterned input and are not restricted to learning the properties of specific exemplars.

However, because human languages contain much more complex grammatical structures than these, an important question is whether primates possess the computational abilities to extract anything beyond such simple rules. There is a growing body of evidence suggesting that they cannot. One example, mentioned earlier, is the study involving recursive phrase structure. In these types of computations, the tamarins' learning does not match that of their human counterparts (Fitch & Hauser, 2004). Similarly, a more recent comparative study involving tamarins and 12-month-old infants found that both tamarins and infants were capable of using statistically predictive dependencies among words to acquire structured word strings. However, only human infants were capable of using dependencies among classes of words to acquire structured phrases (Saffran et al., 2005). As in the Fitch and Hauser (2004) study, the authors suggested that although nonhumans may be able to master very simple rules and finite state grammars, there may be some forms of phrase structure organization that only humans can master. However, the authors also considered an alternative account, suggesting that tamarins may simply be limited by complexity of the language to be learned, and not by any particular type of organizational structure. In fact, this explanation could apply as well to the tamarins' failure in the Fitch & Hauser (2004) study. One of the difficult tasks ahead will be to design experiments that can tease apart these alternative accounts, to determine whether the constraints on learning in primates arise from their inability to control specific types of structures and operations (e.g., phrase structure or recursion) or rather whether they arise from quantitative limits on processing complexity.

## TOWARD THE FUTURE

As mentioned at the outset of this article, there is still active debate as to whether, and how, human language is facilitated by specialized mechanisms. There are some, like Bates, who have argued that, at the core, the basic mechanisms underlying language acquisition are shared, but there is a quantitative difference between humans and primates that permits only humans to process sufficient complexity of

information necessary for supporting language acquisition (Bates & MacWhinney, 1989). Others, like Hauser, Chomsky, and Fitch (2002), argue for a qualitative difference. On this view, although most abilities underlying language acquisition involve mechanisms that are shared across species, recursion (and the notion of discrete infinity) are uniquely human. Still others, such as Pinker, argue for an even more extensive version of qualitative differences across species, contending that the language faculty is a complex adaptation with many components shaped by natural selection specifically for supporting language (Pinker & Jackendoff, 2005). Determining which view is correct will ultimately involve many fields, including biology, psychology, linguistics, and philosophy. We believe that the comparative behavioral approach will be a central source of evidence, providing important insights regarding the extent to which mechanisms are shared or distinct.

Thus far, the picture that has emerged from the comparative behavioral literature is that humans and primates share much of the machinery underlying speech perception, and perhaps even some basic aspects of the machinery underlying language learning. However, closer investigation reveals that there may be a number of subtle but important differences across species in how these mechanisms are instantiated. Thus, for example, we seem to share categorical perception of speech sounds, but differ with respect to category boundaries (Sinnott, Brown, Malik, & Kressley, 1987). The perceptual magnet effect is claimed to be a phenomenon completely absent in other species (although this point is disputed; see Kluender et al., 1987). Studies are needed of other phonological phenomena, such as whether primates, like humans, show an asymmetry in vowel perception, preferring peripheral vowels as anchors for discrimination (see Polka & Bohn, 2003). Likewise, we share a basic statistical learning mechanism, but differ with respect to the more complex types of computations we are able to perform (and perhaps the computational primitives). Thus the comparative research program will continue to inform theories by elucidating the similarities and differences across species, comparing the abilities of primates, who cannot acquire true language, with human infants who are in the process of acquiring language.

The issues that are addressed by the comparative studies just reviewed are important not only for informing us about the origins of human language, but also as a critical component to studying primate communication. Why does a primate (or any other species) have a learning mechanism that is capable of operating on human speech input? Only humans and songbirds are known to go through extensive vocal learning during development; what utility does a primate vocal learning mechanism serve? One suggestion is that statistical and rule-learning mechanisms did not originally evolve to operate on auditory stimuli and might serve, for example, to support foraging (Gallistel, Brown, Carey, Gelman, & Keil, 1991; Hauser & Fitch, 2003) or some other patterned noncommunicative behavior. However, there is also evidence of some sequence learning in natural vocalizations. For example, some primate species track the ordering of conspecific vocalizations, either between individuals

(e.g., Cheney, Seyfarth, & Silk, 1995) or within individuals (e.g., Robinson, 1984; Zuberbuhler, 2002). Likewise, numerous studies demonstrate that although vocal development may not be plastic in primates, adult vocal learning and modification is quite prevalent across many species (e.g., Crockford, Herbinger, Vigilant, & Boesch, 2004; Marshall, Wrangham, & Arcadia, 1999; Mitani & Brandt, 1994; Sugiura, 1998; Snowdon & Elowson, 1999; Weiss, Garibaldi, & Hauser, 2001; see also Egnor & Hauser, 2004). It is possible that tracking some of the statistical properties of calls is an essential component to this type of vocal learning. Future studies, using a range of species, will ultimately need to address these issues to complete our understanding of the origins and functions of these mechanisms.

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### REFERENCES

- Bates, E., & MacWhinney, B. (1989). Functionalism and the competitive model. In B. MacWhinney & E. Bates (Eds.), *The crosslinguistic study of sentence processing* (pp. 3–73). Cambridge, UK: Cambridge University Press.
- Bates, E., Thal, D., & Marchman, V. (1991). Symbols and syntax: A Darwinian approach to language development. In N. Krasnegor, D. Rumbaugh, M. Studdert-Kennedy, & R. Schiefelbusch (Eds.), *Biological and behavioral determinants of language development* (pp. 29–65). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Campbell, C. B. G. (1988). Homology. In L. N. Irwin (Ed.), *Comparative neuroscience and neurobiology: Readings from the encyclopedia of neuroscience* (pp. 44–45). Boston: Birkhauser.
- Cheney, D. L., & Seyfarth, R. L. (1990). *How monkeys see the world: Inside the mind of another species*. Chicago: University of Chicago Press.
- Cheney, D. L., Seyfarth, R. M., & Silk, J. B. (1995). The responses of female baboons (*Papio cynocephalus ursinus*) to anomalous social interactions: Evidence for causal reasoning? *Journal of Comparative Psychology*, *50*, 249–257.
- Chomsky, N. (1955). *The logical structure of linguistic theory*. Unpublished manuscript, Harvard University, Cambridge, MA.
- Chomsky, N. (1982). Discussion of Putnam's comments. In M. Piattelli-Palmarini (Ed.), *Language and learning: The debate between Jean Piaget and Noam Chomsky*. Cambridge, MA: Harvard University Press.
- Christiansen, M. H., & Kirby, S. (2003). *Language evolution*. New York: Oxford University Press.
- Cleveland, J., & Snowdon, C. T. (1982). The complex vocal repertoire of the adult cotton-top tamarin, *Saguinus oedipus oedipus*. *Zeitschrift für Tierpsychologie*, *58*, 231–270.
- Creel, S. C., Newport, E. L., & Aslin, R. N. (2004). Distant melodies: Statistical learning of non-adjacent dependencies in tone sequences. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *30*, 1119–1130.

- Crockford, C., Herbinger, I., Vigilant, L. & Boesch, C. (2004). Wild chimpanzees produce group-specific calls: A case for vocal learning? *Ethology*, *110*, 221–243.
- Egnor, R., & Hauser, M. D. (2004). A paradox in the evolution of primate vocal learning. *Trends in Neurosciences*, *27*, 649–654.
- Fiser, J., & Aslin, R. N. (2002). Statistical learning of higher order temporal structure from visual shape sequences. *Journal of Experimental Psychology: Learning, Memory & Cognition*, *28*, 458–467.
- Fitch, W. T., & Hauser, M. D. (2004). Computational constraints on syntactic processing in nonhuman primates. *Science*, *303*, 377–380.
- Gallistel, C. R., Brown, A., Carey, S., Gelman, R., & Keil, F. (1991). Lessons from animal learning for the study of cognitive development. In S. Carey & R. Gelman (Eds.), *The epigenesis of mind: Essays on biology and cognition* (pp. 3–36). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Gardner, R. A., & Gardner, B. T. (1969). Teaching sign language to a chimpanzee. *Science*, *165*, 664–672.
- Gould, S. J., & Piattelli-Palmarini, M. (1987). *Evolution and cognition*. Course taught at Harvard University, Cambridge, MA.
- Harnad, S. (Ed.). (1987). *Categorical perception: The groundwork of cognition*. New York: Cambridge University Press.
- Hauser, M. D. (1996). *The evolution of communication*. Cambridge, MA: MIT Press.
- Hauser, M. D. (2003). Primate cognition. In R. J. Nelson & M. Gallagher (Eds.), *Handbook of psychology: Biological psychology* (Vol. 3, pp. 561–574). New York: Wiley.
- Hauser, M. D., Chomsky, N., & Fitch, W. T. (2002). The faculty of language: What is it, who has it, and how did it evolve? *Science*, *298*, 1569–1579.
- Hauser, M. D., & Fitch, W. T. (2003). What are the uniquely human components of the language faculty? In M. H. Christiansen & S. Kirby (Eds.), *Language evolution: The states of the art* (pp. 158–181). New York: Oxford University Press.
- Hauser, M. D., Newport, E. L., & Aslin, R. N. (2001). Segmentation of the speech stream in a non-human primate: Statistical learning in cotton-top tamarins. *Cognition*, *78*, B53–B64.
- Hauser, M. D., Weiss, D. J., & Marcus, G. (2002). Rule learning by cotton-top tamarins. *Cognition*, *86*, B15–B22.
- Hayes, K. J., & Hayes, C. H. (1951). The intellectual development of a home-raised chimpanzee. *Proceedings of the American Philosophical Society*, *95*, 105–109.
- Hodos, W. (1988). Homoplasy. In L. N. Irwin (Ed.), *Comparative neuroscience and neurobiology: Readings from the encyclopedia of neuroscience* (p. 47). Boston: Birkhauser.
- Kellogg, W. N., & Kellogg, L. A. (1933). *The ape and the child*. New York: McGraw-Hill.
- Kluender, K. R., Diehl, R. L., & Killeen, P. R. (1987). Japanese quail can learn phonetic categories. *Science*, *237*, 1195–1197.
- Kuhl, P. K. (1986). Theoretical contributions of tests on animals to the special-mechanisms debate in speech. *Experimental Biology*, *45*, 233–265.
- Kuhl, P. K. (1989). On babies, birds, modules, and mechanisms: A comparative approach to the acquisition of vocal communication. In R. J. Dooling & S. H. Hulse (Eds.), *The comparative psychology of audition: Perceiving complex sounds* (pp. 397–419). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Kuhl, P. K. (1991). Human adults and human infants show “a perceptual magnet effect” for the prototypes of speech categories, monkeys do not. *Perception and Psychophysics*, *50*, 93–107.
- Kuhl, P. K., & Miller, J. D. (1975). Speech perception by the chinchilla: Voiced–voiceless distinction in alveolar plosive consonants. *Science*, *190*, 69–72.
- Liberman, A. M. (1970). Some characteristics of perception in the speech mode. In D. A. Hamburg (Ed.), *Perception and its disorders, Proceedings of A. R. N. M. D.* (pp. 238–254). Baltimore: Williams & Wilkins.
- Lieberman, P. (1984). *The biology and evolution of language*. Cambridge, MA: Harvard University Press.

- Marcus, G. (2001). *The algebraic mind: Integrating connectionism and cognitive science*. Cambridge, MA: MIT Press.
- Marcus, G., Vijayan, S., Bandi Rao, S., & Vishton, P. M. (1999). Rule learning by seven-month-old infants. *Science*, 283, 77–80.
- Marler, P. (1991). The instinct to learn. In S. Carey & R. Gelman (Eds.), *The epigenesis of mind: Essays on biology and cognition* (pp. 37–66). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Marshall, A. J., Wrangham, R. W., & Arcadia, A. C. (1999). Does learning affect the structure of vocalizations in chimpanzees? *Animal Behaviour*, 58, 825–830.
- Maye, J., Weiss, D. J., & Aslin, R. N. (2005). *Statistical phonetic learning in infants: Facilitation and feature generalization*. Manuscript submitted for publication.
- Mitani, J. C., & Brandt, K. (1994). Social factors influence the acoustic variability in the long-distance calls of male chimpanzees. *Ethology*, 96, 233–252.
- Newport, E. L., & Aslin, R. N. (2004). Learning at a distance: I. Statistical learning of non-adjacent dependencies. *Cognitive Psychology*, 48, 127–162.
- Newport, E. L., Hauser, M. D., Spaepen, G., & Aslin, R. N. (2004). Learning at a distance: II. Statistical learning of non-adjacent dependencies in a non-human primate. *Cognitive Psychology*, 49, 85–117.
- Newport, E. L., Weiss, D. J., Wonnacott, E., & Aslin, R. N. (2004, November). *Statistical learning in speech: Syllables or segments?* Paper presented at the Boston University Conference on Language Development, Boston.
- Neyman, P. F. (1977). Aspects of the ecology and social organization of free-ranging cotton-top tamarins (*Saguinus Oedipus*) and the conservation status of the species. In D. G. Kleiman (Ed.), *The biology and conservation of the Callitrichidae* (pp. 39–71). Washington, DC: Smithsonian Institution Press.
- Owen, R. (1848). *On the archetype and homologies of the vertebrate skeleton*. London: John van Voorst.
- Pena, M., Bonatti, L. L., Nespor, M., & Mehler, J. (2002). Signal-driven computations in speech processing. *Science*, 298, 604–607.
- Perruchet, P., & Rey, A. (2005). Does the mastery of center-embedded structures distinguish humans from non-human primates? *Psychonomic Bulletin & Review*, 12, 307–313.
- Pinker, S., & Bloom, P. (1990). Natural language and natural selection. *Behavioral and Brain Sciences*, 13, 707–784.
- Pinker, S., & Jackendoff, R. (2005). The faculty of language: What's special about it? *Cognition*, 95, 201–236.
- Pisoni, D. B. (1977). Identification and discrimination of the relative onset time of two-component tones: Implications for voicing perception in stops. *Journal of the Acoustical Society of America*, 61, 1352–1361.
- Polka, L., & Bohn, O. S. (2003). Asymmetries in vowel perception. *Speech Communication*, 41, 221–231.
- Premack, D., & Premack, A. (1983). *The mind of an ape*. New York: Norton.
- Ramus, F., Hauser, M. D., Miller, C. T., Morris, D., & Mehler, J. (2000). Language discrimination by human newborns and cotton-top tamarin monkeys. *Science*, 288, 349–351.
- Robinson, J. G. (1984). Syntactic structures in the vocalizations of wedge-capped capuchin monkeys, *Cebus nigrivittatus*. *Behaviour*, 90, 46–79.
- Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science*, 274, 1926–1928.
- Saffran, J. R., Hauser, M. D., Seibel, R., Kapfhamer, J., Tsao, F., & Cushman, F. (2005). *Cross-species differences in the capacity to acquire language: Grammatical pattern learning by human infants and monkeys*. Manuscript in preparation.
- Saffran, J. R., Johnson, E. K., Aslin, R. N., & Newport, E. L. (1999). Statistical learning of tonal sequences by human infants and adults. *Cognition*, 70, 27–52.
- Saffran, J. R., Newport, E. L., & Aslin, R. N. (1996). Word segmentation: The role of distributional cues. *Journal of Memory and Language*, 35, 606–621.

- Savage-Rumbaugh, S., & Brakke, K. E. (1996). Animal language: Methodological and interpretive issues. In D. Jamieson & M. Bekoff (Eds.), *Readings in animal cognition* (pp. 269–288). Cambridge, MA: MIT Press.
- Seidenberg, M. S., & Pettito, L. A. (1979). Signing behavior in apes: A critical review. *Cognition*, 7, 177–215.
- Sinnott, J. M., & Brown, C. H. (1997). Perception of the American English liquid /ra-la/ contrast by humans and monkeys. *Journal of the Acoustical Society of America*, 102, 588–602.
- Sinnott, J. M., Brown, C. H., Malik, W. T., & Kressley, R. A. (1997). A multidimensional scaling analysis of vowel discrimination in humans and monkeys. *Perception and Psychophysics*, 59, 1214–1224.
- Sinnott, J. M., & Saporita, T. A. (2000). Differences in American English, Spanish, and monkey perception of the say–stay trading relation. *Perception and Psychophysics*, 62, 1312–1319.
- Snowdon, C. T., & Elowson, A. M. (1999). Pygmy marmosets modify call structure when paired. *Ethology*, 105, 893–908.
- Sommers, M. S., Moody, D. B., Prosen, C. A., & Stebbins, W. C. (1992). Formant frequency discrimination by Japanese macaques. *Journal of the Acoustical Society of America*, 91, 3499–3510.
- Sugiura, H. (1998). Matching of acoustic features during the vocal exchange of coo calls by Japanese macaques. *Animal Behaviour*, 55, 673–687.
- Terrace, H. S. (2005). Metacognition and the evolution of language. In H. S. Terrace & J. Metcalfe (Eds.), *The missing link in cognition* (pp. 84–115). New York: Oxford University Press.
- Terrace, H. S., Pettito, L. A., Sanders, R. J., & Bever, T. G. (1979). Can an ape create a sentence? *Science*, 206, 891–902.
- Tincoff, R., Hauser, M., Tsao, F., Spaepen, G., Ramus, F., & Mehler, J. (2005). The role of speech rhythm in language discrimination: Further tests with a nonhuman primate. *Developmental Science*, 8, 26–35.
- Toro, J. M., & Trobalon, J. B. (2005). Statistical computations over a speech stream in a rodent. *Perception and Psychophysics*, 67, 867–875.
- Wallman, J. (1992). *Aping language*. New York: Cambridge University Press.
- Weiss, D. J., Garibaldi, B. T., & Hauser, M. D. (2001). The production and perception of long calls by cotton-top tamarins (*Saguinus oedipus*): Acoustic analyses and playback experiments. *Journal of Comparative Psychology*, 15, 258–271.
- Zuberbuhler, K. (2002). A syntactic rule in forest monkey communication. *Animal Behaviour*, 63, 293–299.

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