

INSIGHTS



PERSPECTIVES

LANGUAGE DEVELOPMENT

Learning from monkey “talk”

Nonhuman primates are capable of several key elements of human language

By Charles T. Snowdon

A fundamental problem for understanding the evolution of human language has been the lack of significant parallels among nonhuman primates. Most researchers have focused on vocal plasticity—that is, the ability to learn novel sounds or modify call structure in response to social or en-

vironmental variables. Although songbirds, whales, dolphins, and some other mammals have this ability, nonhuman primates have appeared not to have it (1). Other studies found that nonhuman primates do not have a vocal tract that would allow them to produce the sounds of human speech (2) and that primates cannot take turns, a critical aspect of human conversation (3). All three points have been challenged by

recent research (see the table), suggesting that nonhuman primates may after all be valuable models for understanding the evolution of speech and language.

The main animal model for vocal learning has been birdsong acquisition. However, there are crucial differences between birdsong acquisition and human language learning. In most temperate-zone songbirds, only males sing, and song typically develops after puberty. Furthermore, song is a sexually selected trait used to attract mates and compete with other males. Its function is thus quite different from most human speech and language. In addition, birds have two vocal organs (syringes) and

Department of Psychology, University of Wisconsin, Madison, WI, USA. Email: snowdon@wisc.edu

Studies of common marmosets (pictured) and other primates can help to explain how human language evolved.

do not have the flexible supralaryngeal structures that facilitate speech. Given these severe limitations of birdsong as a model of speech, there is value in seeking other appropriate parallels among mammals.

During the past decade, research on nonhuman primates has shown evidence of vocal plasticity through population- and group-specific dialects in the wild, vocal changes in response to environmental noise, call structure change as a function of social status, matching the call structure to a new mate or group, and extensive, highly variable infant vocalizations that resemble human babbling (4). Adult nonhuman primates also respond to babbling infants. Infants that are more vocally active early in life show more rapid progression toward adult call structures (4). In a recent study on common marmosets (see the photo), Takahashi *et al.* found that contingent parental vocal feedback—that is, parents responding to infant calls only when the infant produced the appropriately structured call—directly shaped the development of adult-like call structures in infants; greater and earlier parental feedback led to faster development of adult calls (5). This result parallels work showing that human parents stimulate the development of adult-like speech in infants through contingent responses to babbling (6).

An early study on vocal tract structure in nonhuman primates concluded that monkeys and apes did not have the anatomical capacity to produce the full range of vowel sounds of speech (2). This lack has been used to explain why nonhuman primates cannot speak. But recent studies on macaques (7) and baboons (8) have shown that the vocal tracts of these monkeys can produce a full range of human-like vowels.

In the study on macaques, Fitch *et al.* used x-ray videography of vocal tract movement during vocalization, facial displays, and feeding. From these videos, the authors reconstructed the capacity of the vocal tract to produce vowel sounds (as measured by formants, that is, the emphasized frequencies in vowels). The resulting formant space was roughly as large as the human formant vowel space, albeit higher in pitch. In the baboon study, Boe *et al.* evaluated natural vocalizations and constructed a two-formant vowel space through acoustic analysis, measurements of tongue anatomy, and modeling. The range of vowel sounds was similar to those of human children. Thus, these monkeys have a vocal tract capable of human-like speech but appear to lack

the cognitive, motivational, or articulatory mechanisms to create speech.

Turn-taking is a key to fluent human conversation and has been thought to be unique to humans. In one study, captive chimpanzees failed to take turns for a food reward that required collaboration by two animals to succeed, whereas 5-year-old children readily took turns (3). However, another study found that captive chimpanzees increasingly share resources when resources are diminished (9). Collaborative turn-taking for food has been seen in other primates (10). A wide range of nonhuman primates display vocal turn-taking (11), and

different methods and studied marmosets at different ages. Nonetheless, both studies indicate that marmoset parents respond to their offspring and shape both vocal development and turn-taking.

Collectively, these recent studies show that there is value in looking for the evolutionary origins of speech and language in nonhuman primates. The question remains, however, why nonhuman primates do not talk.

Human speech and language are highly complex systems with multiple components. Thus, we should not expect to find a single nonhuman model that will account for all components of human language. To fully

Evidence for language-like behaviors in nonhuman primates

Aspects of primate vocal behavior can serve as models for language evolution and development. Several lines of evidence support each behavior, but no single species shows all behaviors.

LANGUAGE-LIKE BEHAVIOR	EVIDENCE	PRIMATE SPECIES	REFERENCES
Vocal plasticity Vocal structures modified by social and environmental variables	Dialects	Marmosets, chimpanzees, and macaques	4
	Babbling	Marmosets	4, 5
	Contingent vocal response	Marmosets	5
	Social status	Tamarins	4
	Environmental noise	Marmosets, tamarins, baboons, and macaques	4
Vocal tract structure Anatomically possible to produce human-like vowel sounds	X-ray videos	Macaques	7
	Natural vocalizations	Baboons and macaques	7, 8
Turn-taking Coordinated taking of food resources or producing communicative signals	Sharing resources	Tamarins, marmosets, capuchin monkeys, and chimpanzees	9, 10
	Vocal turn-taking	Lemurs, marmosets, titi monkeys, squirrel monkeys, Campbell's monkeys, and siamangs	11
	Gestural turn-taking	Chimpanzees and bonobos	12
	Parental influence	Marmosets	13, 14

gestural turn-taking has been seen in chimpanzees and bonobos (12).

Two studies of common marmoset infants have examined the development of turn-taking with differing conclusions. In the first study, Takahashi *et al.* followed infants longitudinally from birth through 2 months of age and found that parental responses shaped the structure of calls but did not directly influence the development of turn-taking (13). In the second study, Chow *et al.* followed infants from 4 to 12 months and reported that turn-taking was learned, with parental contingent responses shaping turn-taking behavior (14). Parents responded less often when infant calls overlapped adult calls. These results are difficult to reconcile, because they used

explain language origins, researchers must seek multiple models that represent both diverging and converging evolutionary processes. For example, songbirds and humans share a cluster of gene expression profiles not found in other species (15). These shared expressed genes are mainly those involved in rapid articulation and sequencing of sounds. Thus, monkeys may lack the expressed genes that are needed for fluent speech and syntactically complex vocal signals. In contrast, referential signaling—gestures and vocalizations that refer to an external object or event such as a predator or food—have been described in many primate species but not in many songbirds.

There may also be differences among primate species (as there are among birds) in

the developmental processes that parallel human language acquisition. It may be no accident that the main evidence for vocal plasticity and the role of parents in shaping vocal structure and turn-taking has been seen in primates that breed cooperatively (marmosets and tamarins). In these species, most group members assist with infant care, a system thought to parallel human child-care. However, no studies have yet described vowel-like sounds in these monkeys, so marmosets and tamarins may be useful primarily for developmental studies.

It is probable that early humans faced evolutionary pressures that differed from those encountered by other primates and that have made our complex communication system adaptive. Language may have been important for coordinating activities in large cooperative groups in which different individuals played different roles, as was likely among our early ancestors. Neurological and genetic specializations likely allowed humans to develop articulatory and sequencing abilities that are not seen in monkeys and apes. There may also be cognitive and motivational limits: If individuals can thrive without complex vocal signaling, there would be little motivation to push the communication further. Finally, different sensory and motor systems may be important. We tend to evaluate language through a vocal/auditory system, whereas research on apes is beginning to illustrate the complexity of gestural communication (12).

Nonhuman primates do not talk, but we should not expect them to. Each species has its own adaptations for communication. Nevertheless, there is much about language evolution that we can learn from nonhuman primates, provided that we study a variety of species and consider the multiple components of speech and language. ■

REFERENCES

1. V. M. Janik, P. J. B. Slater, *Adv. Stud. Behav.* **26**, 59 (1997).
2. P. H. Lieberman, D. H. Klatt, W. H. Wilson, *Science* **164**, 1185 (1969).
3. A. P. Melis, P. Grocke, J. Kalbitz, M. Tomasello, *Psych. Sci.* **27**, 987 (2016).
4. C. T. Snowdon, *Adv. Stud. Behav.* **40**, 239 (2009).
5. D. Y. Takahashi *et al.*, *Science* **349**, 734 (2015).
6. M. H. Goldstein, A. P. King, M. J. West, *Proc. Natl. Acad. Sci. U.S.A.* **100**, 8030 (2003).
7. W. T. Fitch, V. B. deBoer, N. Mathur, A. A. Ghazanfar, *Sci. Adv.* **2**, e1600723 (2016).
8. L.-J. Boe *et al.*, *PLOS ONE* **12**, e0169321 (2017).
9. S. E. Calcutt, E. V. Lonsdorf, K. E. Bonnie, M. S. Milstein, S. R. Ross, *Behaviour* **151**, 1967 (2014).
10. K. A. Cronin, *Anim. Behav.* **84**, 1085 (2012).
11. S. C. Levinson, *Trends Cogn. Sci.* **20**, 6 (2016).
12. M. Fröhlich *et al.*, *Sci. Rep.* **6**, 25887 (2016).
13. D. Y. Takahashi, A. R. Fenley, A. A. Ghazanfar, *Philos. Trans. R. Soc. B.* **371**, 20150370 (2016).
14. C. P. Chow, J. F. Mitchell, C. T. Miller, *Proc. R. Soc. B.* **282**, 20150069 (2015).
15. A. R. Pfennig *et al.*, *Science* **346**, 125684 (2014).

10.1126/science.aam7443

PLANT BREEDING

Genome editors take on crops

Genome editing technologies may help to enhance global food security

By **Armin Scheben** and **David Edwards**

The global population is expected to rise from 7.3 billion to 9.7 billion by 2050 (1). At the same time, climate change poses increasing risks to crop production through droughts and pests (2). Improved crops are thus urgently needed to meet growing demand for food and address changing climatic conditions. Genome-editing technologies such as the CRISPR (clustered regularly interspaced short palindromic repeat)/Cas (CRISPR-associated protein) system (3) show promise for helping to address these challenges, if the precision of genome editing is improved and the technology is approved and accepted by regulators, producers, and consumers.

From 1981 to 2000, rice, maize, and wheat varieties that had been improved through traditional plant breeding boosted crop yields by 22 to 46% in Asia and Latin America (4). To meet growing demand by 2050, however, a global increase in crop production of 100 to 110% from 2005 levels is required (5). At the same time, climate change is predicted to lower regional crop yields, especially in wheat and maize. In semi-arid developing countries such as Brazil and Argentina, major crop yields may decline by up to 30% by 2030, and in sub-Saharan Africa, yields may decline by 22%, with losses of more than 30% in South Africa and Zimbabwe (6).

Traditional plant breeding is based on crossing germplasm and then selecting individuals with desirable traits (see the figure). Although this approach has been extraordinarily successful, it can take more than 10 years, and in some cases decades, to develop an improved variety. Genomic tools can improve selection efficiency, but breeding remains laborious and dependent on shuffling existing diversity. Given the food security concerns that the human population faces, scientists are turning to genome editing approaches such as CRISPR/Cas (see the figure). Advantages of genome editing over conventional and earlier transgenic approaches are the low cost, ease of use, lack of transgenes permanently introduced

into crop germplasm, and the high level of multiplexing (editing of multiple targets) possible (7). The latter allows rapid trait stacking and editing of gene networks in their native context to improve quantitative traits such as drought tolerance and yield.

Multiplexing is particularly useful in polyploid crops such as wheat (which have more than two sets of chromosomes) because it allows simultaneous editing of multiple gene copies. Furthermore, many simple trait improvements involving few genes have

“Improved crops are ... urgently needed to meet growing demand for food and address changing climatic conditions.”

likely already been made in staple crops, so that trait stacking and more complex modification of gene networks is required to further enhance global yields. The low costs and ease of use of genome editing may also facilitate improvement of subsistence crops such as cassava, with potentially substantial yield increases in sub-Saharan Africa and Latin America.

The CRISPR/Cas system consists of a guide RNA containing a target sequence of usually 20 nucleotides and a Cas nuclease such as the commonly used Cas9, which cleaves double-stranded DNA at the target site. CRISPR/Cas can induce mutations at virtually any genomic site in any organism, functioning like a find-and-replace tool in a word processor. Insertion and/or deletion of nucleotides at the target site occur because of DNA repair errors, whereas specific insertions are achieved by providing template DNA. For plant breeding, this means that scientists can edit the genomes of elite varieties to produce new varieties in a single generation, unconstrained by existing variation and without having to select for favorable combinations of alleles in large populations. However, unlike traditional breeding, such targeted genome editing requires knowledge of the nucleotide sequence and function of the target to design the guide RNA and predict the editing outcome.

School of Biological Sciences and Institute of Agriculture, University of Western Australia, Perth, WA, Australia. Email: armin.scheben@research.uwa.edu.au; dave.edwards@uwa.edu.au

Science

Learning from monkey "talk"

Charles T. Snowdon

Science **355** (6330), 1120-1122.
DOI: 10.1126/science.aam7443

ARTICLE TOOLS

<http://science.sciencemag.org/content/355/6330/1120>

REFERENCES

This article cites 15 articles, 6 of which you can access for free
<http://science.sciencemag.org/content/355/6330/1120#BIBL>

PERMISSIONS

<http://www.sciencemag.org/help/reprints-and-permissions>

Use of this article is subject to the [Terms of Service](#)

Science (print ISSN 0036-8075; online ISSN 1095-9203) is published by the American Association for the Advancement of Science, 1200 New York Avenue NW, Washington, DC 20005. 2017 © The Authors, some rights reserved; exclusive licensee American Association for the Advancement of Science. No claim to original U.S. Government Works. The title *Science* is a registered trademark of AAAS.