EVOLUTION OF LANGUAGE

Experiments Probe Language's Origins and Development

In a new twist for an old field, language researchers are heading to the laboratory to test hypotheses

KYOTO AND TOKYO—Playing slide whistles. Learning fictitious "alien" languages. Making Stone Age tools. Those all sound more like hobbies than scientific pursuits. But such activities are at the heart of recent efforts to understand the emergence and evolution of language. And the trend shows how much the field is changing.

Theorizing once dominated work on the origins of language. More recently, researchers have gone into the field to study how songbirds learn to sing and into nurseries to observe the vocalizations and gestures of children for hints of how language may have emerged. Now researchers are testing their hypotheses under experimental conditions. "Five or 6 years ago, it seemed an odd idea that we could do experiments in language evolution, but that has changed," says Simon Kirby, an evolutionary linguist at the University of Edinburgh in the United Kingdom.

The experiments, observations, and even some theorizing were on the agenda at the Evolang9 conference in Kyoto and a follow-up forum in Tokyo last month.* By design, these meetings bring diverse views together to unravel questions not likely to be answered by work within one discipline (*Science*, 21 May 2010, p. 969).

Cognitive tools

Evo-devo, or evolutionary developmental, theorists as far back as Charles Darwin in *The Descent of Man* have speculated that there may be a connection between language and stone toolmaking (*Science*, 6 February 2009, p. 709). "There is a rich line of people who tried to look at the archaeological record of the making of stone tools and the evolution of language," says Michael Arbib, a neuroscientist at the University of Southern California in Los Angeles. "You look at the archaeological relics," he says, and "try to infer the behavior involved" in making them.

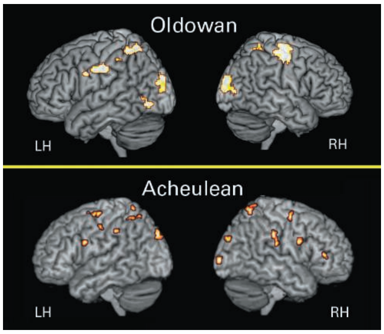
The inferences start with the earliest known examples of human technology, Oldowan cutting tools. Dating back 2.6 million years, they are simple stone flakes with sharp edges knapped off crude "cores" using "hammerstones." Such tools gradually became more refined, achieving a high level of sophistication about 700,000 years ago with Late Acheulean handaxes. High-tech by comparison, these were deliberately crafted into oval or teardrop shapes in multistep manufacturing processes that required planning and significant skill. One hypothesis is that the cognitive capabilities that supported toolmaking gave the toolmakers language-ready brains; then the benefits of instructing succeeding generations in how to make tools drove the emergence of language.

Evidence supporting this hypothesis began accumulating in the past decade as brain imaging found overlaps in the neural areas associated with language and those involved in tool use. More recently, groups led by Dietrich Stout, an archaeologist at Emory University in Atlanta, and Thierry Chaminade, a cognitive neuroscientist at Aix-Marseille University in Marseille, France, have taken to actually reproducing stone tools while tracking neural activity with positron emission tomography. In a series of experiments reported over the past 5 years, they showed that Oldowan toolmaking activates the left ventral premotor cortex, a region previously shown to be involved in both manual grip coordination and phonological processing. Late Acheulean tool production relies on those same regions, they found, plus other areas of the brain, including the inferior frontal gyrus, which is associated with abstraction and hierarchical organization (needed for executing subgoals along the way to a final product, for example), as well as larger scale discourse and language processing.

Follow-up experiments in which Bruce Bradley, an archaeologist at the University of Exeter in the United Kingdom, wore a data glove to record left hand finger movements suggested that it was the cognitive demands of making Acheulean tools—not left hand manipulation—that lit up the right brain.

The results "establish plausible evolutionary links" between specific toolmaking skills and language processing, Stout and Chaminade concluded in a review that appeared in *Philosophical Transactions of the Royal Society B* in January 2012.

But another step was needed to go from a language-ready brain to language. To see if teaching tool-



Knapping know-how. Archaeologist Bruce Bradley reproduces Late Acheulean stone axes similar to one from 500,000 years ago (*top right*). Brain imaging (*right*) shows that stone toolmaking activates areas also involved in language.

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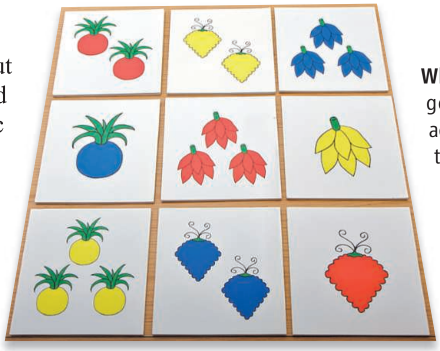

Whatchamacallit? Randomly generated syllable strings acquired languagelike properties as subjects used them to pick images from an array.

making had a role, Stout and colleagues used functional magnetic resonance imaging to capture brain activity of subjects as they watched an accomplished knapper at work. When observing Late Acheulean toolmaking, only those observers themselves skilled at toolmaking activated the intention-reading areas of the brain. They understood the ultimate goal of the craftsman, while the neophytes did not. The drive to bridge this gap in understanding "could have provided an adequate scaffold for the evolution of intentional vocal communication," Stout and Chaminade wrote in their review.

Although neither Stout nor Chaminade attended the recent meetings, their work was at the center of many discussions. The co-opting of existing capabilities for new uses "is the way that evolutionary biologists typically explain major evolutionary innovations," said evolutionary biologist Russell Gray of the University of Auckland in New Zealand during his talk. Gray and others gave tantalizing glimpses of work under way that builds on the Stout-Chaminade work to suggest that, among other things, the origins of abstraction and syntax might lie in toolmaking pedagogy.

But not everyone was convinced. Massimo Piattelli-Palmarini, a biolinguist at the University of Arizona in Tucson, later told *Science* that a more genetic basis for language "will one day be discovered." For now, evo-devo thinkers seem to have the upper hand.

The cultural factor

Those working on the cultural side of language evolution are also embracing experiments. Kirby argues that our modern use of language results from a dual inheritance. On one side, genetics gave us the cognitive and physiological capabilities for language. But language itself is passed from generation to generation by teaching and learning, a cultural process. "The language faculty evolved biologically, but languages themselves evolved culturally," Kirby says. Kirby is particularly interested in the structure of language, specifically how meaningless syllables can be combined to make meaningful words, what he calls combinatoriality; and how words combine into phrases, compositionality. Thanks to these two properties, "I can produce sentences I've never said before and you've never heard before and yet you can understand me," Kirby says.

Kirby and colleagues wanted to investigate how language acquired these structural aspects. Or, as his University of Edinburgh collaborator Hannah Cornish puts it, "What happens when you have some loose ideas of concepts and some ability to produce signals, but no preexisting system of combining these things together." They hypothesized that the transmission of a language from generation to generation played a critical role. To test this idea, they recruited volunteers to learn a fictitious "alien" language. (Calling it "alien" attracted participants.) Working at computer terminals, they were shown a series of words and the images they referred to. The words were actually randomly generated strings of syllables. Each of the images had a unique combination of color, shape, and patterning. The participants were then shown images and asked to type in the appropriate words. They were also asked to produce words for images with color, shape, and patterning combinations they hadn't specifically learned. The words as given by one participant were used to train the next in line, a process called iterated learning that resembles the cultural transmission of a language among generations.

Researchers tested different scenarios of that basic approach. In one, instead of individuals in each generation, there were pairs of participants who used the alien language to "communicate," picking images from an array. (The pairs were separated and interacted via computer terminals so they could not point or gesture.) The words they recalled after the communication exercise were used to train the next pair in the chain. Other pairs simply did the communication task, again via computer terminals, over and over without the "language" being passed to a new generation.

When pairs of humans learned the words, used them to communicate, and then passed them on through several generations, a compositional structure emerged. Parts of the words—the prefix, for example—consistently corresponded to color, and other parts became associated with shape or pattern. Succeeding pairs found the language progressively easier to learn and use accurately. Pairs at the ends of the chains could even recombine the parts of the words to accurately label images they had not specifically learned. When the language passed through a chain of individuals, thus skipping the communication step, it became ambiguous, with one "word" having multiple meanings. The pairs that worked just on the communication task eventually agreed on linking words with images, but the language remained an idiosyncratic pairing of syllables and meaning with no standardization or compositional structure. To get structural properties and improve learnability, "what is really crucial [is] a combination of naive learners and communication," Kirby says.

Tuning up. By passing through a succession of learners playing slide whistles, random notes became musical phrases.

Kirby admits that the linguistic structure they're seeing may be an artifact from people who already have language. But Tessa Verhoef and Bart De Boer of the University of Amsterdam in the Netherlands, devised an experiment that avoided language altogether: Participants use slide whistles to produce whistling sounds unconnected to any meaning. The whistles produced by one participant were used to train the next. Again, structural elements—down-up and up-down whistles, repeated notes—emerged that were systematically reused and combined in various ways. And after several iterations, the whistles "become more learnable [and] more reproducible," Verhoef says.

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In addition to experiments with human subjects, Kirby and his colleagues ran computer simulations of populations acquiring language through iterated learning. Their computer model allowed them to test whether the tendency toward structure was likely to be innate—that is, genetically hard-wired—or the result of cultural transmission. Their work suggests that the structural properties seen in languages are more likely produced by the dynamics of cultural transmission. (The group's computer simulations were reported in the *Proceedings of the National Academy of Sciences* in 2007, and the results of the initial laboratory experiments appeared in the same journal in 2008. More recent work has yet to be published.)

The Kirby and Verhoef–De Boer experiments were "quite impressive and clever," says Robert Van Valin, a linguist at Heinrich Heine University in Düsseldorf, Germany. That the computer simulations and human experiments agreed is significant, he says; it argues for the importance of cultural factors

Name that tune. Domesticated Bengalese finches (*left*) outsing wild white-rumped munias (*right*).

in the evolution of language. But there were still questions about what the experiments say about an ancient phenomenon. "It demonstrates one plausible path" for the emergence of language structure, says Sotaro Kita, a psychologist at the University of Birmingham in the United Kingdom.

Kirby says certain of his group's hypotheses are bolstered by other studies. They have done some experiments using spoken words and have gotten the same results—with structure emerging after passage through several generations. Also, he says their experimental findings suggest that languages used by larger and more diverse groups, with more transmission to naïve learners, tend to be simpler. More complex languages appear to arise when user groups are smaller and more cohesive. That is consistent with what Gary Lupyan of the University of Wisconsin, Madison, and Rick Dale of the University of California, Merced, found in a survey of 2000 languages reported in *PLoS ONE* in 2010. "The analyses suggest that languages spoken by large groups have simpler inflectional morphology than languages spoken by smaller groups as measured on a variety of factors," the pair wrote. Like organisms, language structures appear to adapt to their environment.

More evidence that complex language arises in close-knit, stable communities comes from a study of songbirds presented at the Tokyo Evolutionary Linguistics Forum by biopsychologist Kazuo Okanoya of the University of Tokyo. He reported that long-domesticated Bengalese finches have much more complex songs than their close cousins that live in the wild, white-rumped munias. Okanoya says that in the wild, the song needs to be simple and distinct so females can find males of their own species. But in a birdcage full of Bengalese finches, females take mastery of a complex song as a sign of male fitness. "Domestication freed songs from the function of species identity and female choice promoted complexity in Bengalese finches," Okanoya concludes in a paper now in press at *Interaction Studies*. By extension, Okanoya says human self-domestication could have set the stage for human language to gain complexity.

No one line of investigation is going to answer all the questions, Kirby says. Understanding the evolution of language "requires a convergence of evidence from an extraordinarily diverse set of disciplines," he says.

That conciliatory tone echoed throughout Evolang9. People spoke of fitting together the pieces of a very complex puzzle. A new generation of language researchers "is more interested in an interdisciplinary approach and more tolerant of complexity," says Rafael Núñez, a cognitive scientist at the University of California, San Diego. That bodes well for the Evolang conferences, which were founded on the notion that all those studying language evolution should have something to say to one another.

–DENNIS NORMILE

Where Time Goes Up and Down

In Western cultures, the future lies ahead; the past is behind us. These notions are embedded in both gestures and spoken metaphors (looking forward to next year or back over the past year). A forward hand motion typically accompanies talk of the future; references to the past often bring a wave over the shoulder.

It is hard for most Westerners to conceive of other ways of conceptualizing time. But in 2006, Rafael Núñez, a cognitive scientist at the University of California, San Diego, reported that for the Aymara, an ethnic group of about 2 million people living in the Andean highlands, in both spoken and gestural terms, the future is unseen and conceived as being behind the speaker; the past, since it has been witnessed, is in front. They point behind themselves when discussing the future. And when talking about the past, Aymara gesture farther in front of them the more distant the event (*Science*, 23 June 2006, p. 1723).

Heads up. This Yupno man of Papua New Guinea points downhill when speaking of the past, whether facing uphill (*left*) or downhill (*right*).

At the Tokyo Evolutionary Linguistics Forum, Núñez presented another example of unusual thinking—and gesturing—about time: The Yupno people, who inhabit a remote valley in Papua New Guinea, think of time topographically. No matter which way a speaker is facing, he or she will gesture uphill when discussing the future and point downhill when talking about the past. "It can only occur in small societies that share an ecological niche," Núñez says of their finding, in press at *Cognition*. These different abstractions of time, including gestures, indicate the importance of the cultural aspects of language evolution, he contends.

Núñez's "very interesting" Yupno study "provides a tiny glimpse into the way one group of people relates to their world linguistically and cognitively," says Erica Cartmill, a psychologist at the University of Chicago in Illinois who studies the use of gesture by great apes and children. She says more such comparative studies would help clarify the relationship between gesture, speech, and cognition in different cultures. **–D.N.**

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