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Did Working Memory Spark Creative Culture?

A provocative model suggests that a shift in what and how we remember may have been key to the evolution of human cognition

COLORADO SPRINGS, COLORADO—About 32,000 years ago, a prehistoric artist carved a special statuette from a mammoth tusk. Holding the abstract concepts of "human" and "animal" in his or her mind, the artist created an imaginary beast with the body of a human and the head of a lion. Archaeologists found the 28-centimeter-tall figurine in hundreds of pieces in the back of Germany's Hohlenstein-Stadel cave in 1939, and after World War II, they put the fragments back together, reconstructing the ancient artwork.

Today, archaeologists hail the "Lion Man" as one of the earliest unambiguous examples of artistic expression, a hallmark of modern human behavior. The figurine "has acquired an iconic status for modern archaeologists as profound as it must have been for the original artisan," wrote Thomas Wynn and Frederick Coolidge, both of the University of Colorado, Colorado Springs, in a paper last year. Wynn and Coolidge argue that the figurine's creation—as well as its subsequent reconstruction by archaeologists—is an excellent example of something unique to our species: an enhanced capacity to hold and manipulate information in one's conscious attention while carrying out specific tasks, an ability psychologists call working memory.

Right now you are using working memory as you read this story: You are holding the concept of the figurine, or its image from the illustration above, in your mind. As you go from sentence to sentence, you are also remembering the meaning of each bit of text. And you must pay active attention, shutting out extraneous thoughts such as how your grant application is doing.

We use our working memory for tasks as trivial as remembering a telephone number while we dial it, as technically challenging as designing an airplane, and as imaginative as creating works of art and music. Psychologists and neuroscientists consider working memory essential to the capacity for language, planning, and conscious experience. "Any symbolic processing, such as language, requires it," says David Linden, a psychologist at Bangor University in Gwynedd, U.K. Working memory is "the blackboard of the mind," as the late Patricia Goldman-Rakic of Yale University put it.

In the view of Wynn and Coolidge—an archaeologist and a psychologist who form an unusual scientific partnership—a stepwise increase in working memory capacity was central to the evolution of advanced human cognition. They argue that the final steps, consisting of one or more genetic mutations that led to "enhanced working memory," happened sometime after our species appeared nearly 200,000 years ago, and perhaps as recently as 40,000 years ago. With enhanced working memory, modern humans could do what their ancestors could not: express themselves in art and other symbolic behavior, speak in fully grammatical language, plan ahead, and make highly complex tools.

"The enhancement of working memory opened up a whole load of new possibilities

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Blackboard of the mind. Working memory is key to conscious thought.

for hominids," says anthropologist Dwight Read of the University of California, Los Angeles. "It was a qualitative shift."

However, others question how well the archaeological record supports Wynn and Coolidge's ideas. The pair argue that the final boost in working memory capacity came late in human evolution, whereas many archaeologists see the stirrings of complex behavior thousands of years earlier (see p. 164)—and some say, even in other species. "Enhanced working memory capacities can be observed in both modern humans and Neandertals," insists Anna Belfer-Cohen, an archaeologist at The Hebrew University of Jerusalem. "Working memory does not appear to be the major shift" in human evolution.

Despite the critics, Wynn and Coolidge's ideas are increasingly popping up in scientific journals. The pair "have made a really big splash," says Philip Barnard, a cognition researcher at the University of Cambridge in the U.K. This month, *Current Anthropology* devotes a special online supplement to the topic, and later in April, Wynn and Coolidge will update their ideas at a major meeting on the evolution of language in the Netherlands. The theory makes sense to many. "It is the most impressive, explicit, and scientifically based model" so far, says archaeologist Paul Mellars of the University of Cambridge.

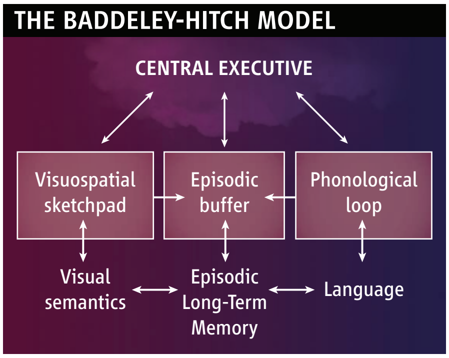
Memorable pair. Thomas Wynn (*left*) and Frederick Coolidge hypothesize that working memory shaped human evolution.

Thanks for the memory

For as long as anyone can remember, researchers have been debating how many kinds of memory there are. In the late 19th century, American psychologist William James proposed two types of information storage: a temporary store that James called "the trailing edge of consciousness" and a more durable and even permanent store. His model was not immediately adopted, but by the 1960s, experiments with human subjects, including patients with amnesia or brain damage, had convinced many researchers that there are two types of memory: short-term and long-term.

It soon became clear that short-term memory was not just a passive, temporary storehouse. Experiments showed that retaining information in conscious memory required active "rehearsal" to keep it there, as we do when we repeat a telephone number in our minds until we have the chance to write it down. Temporary memory is a dynamic part of the conscious mind, engaged in all sorts of work, including processing and manipulating information. In 1974, psychologists Alan Baddeley and Graham Hitch of the University of York in the U.K. proposed a new model, replacing the concept of short-term memory with what they called working memory.

Baddeley and Hitch argued that working memory had three components: a "phonological loop," which stores and processes words, numbers, and sounds; a "visuospatial sketchpad," which stores and processes visual and spatial information; and a "central executive," which focuses the mind's attention on the information in the other two systems and controls how it is used. In 2000,



Memory modules. This view of working memory remains influential.

Baddeley added a fourth component, an "episodic buffer," which serves as an interface between the other three systems and long-term memory (see diagram, above).

Central to the model's experimental approach were so-called dual-task exercises, in which subjects had to do more than one memory-taxing thing at a time. Such experiments showed that some tasks interfere with each other: You memorize a list of words less efficiently when you are also reciting a series of numbers. But other tasks are apparently separate: You can remember the colors of items while reciting numbers.

This research convinced Baddeley, Hitch, and many others that words and numbers are stored in one kind of temporary memory buffer while visual information goes into another. Meanwhile, the central executive is thought to control the flow of information between working memory's temporary storage buffers, long-term memory, and other cognitive functions. Indeed, although the Baddeley model now has competitors (see sidebar, p. 162), most researchers agree that dynamic concepts of working memory, rather than passive storage, best explain sophisticated human cognition, which requires that we be masters and not slaves of our memories.

Working memory allows us to juggle the past and the present in our conscious minds, says Jackie Andrade, a psychologist at the University of Plymouth in the U.K., and so is critical to complex behavior. We can "aim for future goals rather than just being driven by our current goals or environment," she says. Or, as psychologist Nelson Cowan of the University of Missouri, Columbia, puts it, "Working memory holds the plan until we can execute it."

Wynn and Coolidge acknowledge that earlier hominins, and even apes, had enough working memory to carry out certain skilled tasks. The difference was one of degree, they say, and came in evolutionary stages. For example, the 1.8-million-year-old *Homo erectus*, creator of the first known bifacial tools, probably had more working memory than apes and australopithecines. The first big jump in working memory capacity, Wynn and Coolidge contend, came with the 650,000-year-old *H. heidelbergensis*, which made highly symmetrical hand axes—a talent that probably required holding a mental template of the tool in the mind while making it (*Science*, 6 February 2009, p. 709).

A meeting of minds

Wynn and Coolidge note that working memory has two key features that could make it subject to natural selection: It varies among individuals, and that variation may have a genetic basis. Numerous studies have found a close correlation between working memory capacity and performance in cognitive tasks such as language learning and reasoning ability. In a 2004 review, psychologist Randall Engle of the Georgia Institute of Technol-

CREDITS (TOP TO BOTTOM): EMILY WYNN; ADAPTED FROM ALAN BADDELEY

ogy in Atlanta and his co-workers identified nearly 40 cognitive tasks significantly correlated with working memory capacity. Some researchers have proposed that intelligence tests actually measure working memory capacity, although this is controversial. And a number of studies conclude that variances in working memory capacity, for example those linked to learning disabilities, could have a genetic component.

It was evidence for such genetic variation that first brought Coolidge and Wynn together. In 2000, Coolidge published a twin study suggesting a strong genetic correlation between attention deficit hyperactivity disorder and deficits in what researchers call "executive functions"—a range of mental abilities such as forming goals and planning ahead.

Coolidge, who had long been interested in archaeology, went to see Wynn, whom he then knew only casually. Wynn, known for analyzing the mental steps in hominin toolmaking, was attracted by Coolidge's suggestion that executive functions were key to modern human evolution.

In their first paper together in 2001, the pair focused solely on executive functions. But not long afterward, Wynn recalls, "Fred walked into my office and said, 'It's working memory.' " Coolidge had realized that there was considerable overlap between "executive functions" and the "central executive" in Baddeley's model. The best way to explore the evolution of modern human cognition, the pair decided, was to adopt the Baddeley model and see where it led them. "[It's] probably the most cited cognitive model of the past 30 years," Wynn says. "It gave us a theoretical model that had punch."

They scoured the archaeological record and began to spin out a series of papers contending that modern humans had greater working memory capacity than earlier hominins. For example, they argued in 2004 in the *Journal of Human Evolution* that Neandertals fell short mainly in areas such as complex hunting strategies and symbolic expression, which required enhanced working memory. They point out that for 200,000 years, Neandertal stone-tool technology, although skillful, changed little. And even when it did shift, it was "on a scale and at a rate that would appear to rule out conscious experimentation and creativity, the stuff of enhanced working memory," Wynn and Coolidge wrote.

The pair also cited the relative lack of evidence for Neandertal symbolic behavior, such as the elaborate burials and artistic expression typical of modern humans, as support for their conclusion. Neandertal cognition, they contended in another 2004

Sticking to his model. Alan Baddeley of the University of York.

CREDIT: LINDSEY BOWES

Does 'Working Memory' Still Work?

The idea that a better working memory made *Homo sapiens* smarter than its ancestors is attracting attention from psychologists, archaeologists, and neuroscientists alike (see main text, p. 160). The architects of the hypothesis, Thomas Wynn and Frederick Coolidge of the University of Colorado, Colorado Springs, base their idea on a model of working memory proposed 35 years ago by two British psychologists. That model, devised by Alan Baddeley and Graham Hitch of the University of York in the United Kingdom, "was seminal" in memory research, says psychologist Randall Engle of the Georgia Institute of Technology in Atlanta. But now he and other researchers are challenging some of its basic tenets. "The Baddeley model has pretty stiff competition now" from alternative models, says psychologist Jackie Andrade of the University of Plymouth in the U.K.

Baddeley proposed that working memory includes separate, temporary storage areas for verbal and visual information, plus a central executive to direct information flow. Today, a key issue is whether our temporary memories are actually stored in buffers separate from long-term memory or if these simply represent "activated" parts of long-term memory.

The latter model is "more neurologically feasible," says psychologist Nelson Cowan of the University of Missouri, Columbia, who cites recent brain-imaging studies that he says contradict Baddeley's model. "The neural data don't support a buffer model of working memory," agrees Mark D'Esposito, a cognitive neuroscientist at the University of California, Berkeley, whose lab has done such experiments. Different parts of the brain are activated depending on what kind of working-memory task is being done, says D'Esposito, who concludes that "working memory" involves many different parts of the brain working together. "It doesn't appear that information is transferred to some other location, like RAM in a computer," he says.

The field is split, with many Europeans and psychologists tending to favor the Baddeley model, whereas many Americans and neuroscientists tend to favor activation models. "There are pretty much two traditions," says Andrade.

Baddeley finds the brain-imaging studies inconclusive. They "result in a veritable plum pudding of different areas activated by apparently similar tasks, whereas the [psychological and clinical] evidence has been broadly coherent and very fruitful over a 35-year span," he says. Psychologist David Linden of Bangor University in Gwynedd, U.K., also sees no reason to jettison the Baddeley model. He says working memory "is preserved in many patients who have severe amnesia and cannot encode new material into long-term memory. And it can deal with information that has no relevant representation in long-term memory, such as characters of an unknown language or novel sounds."

Although Wynn and Coolidge favor Baddeley's model, they say they are not wedded to it. "I don't think our approach stands or falls with the Baddeley model," says Wynn. Coolidge agrees: "Our puzzle for the future lies more in explaining what enhanced working memory did for humans rather than in strict lab tests of Baddeley's components." **–M.B.**

paper, was like "modern human thinking" but with "a single piece missing": enhanced working memory.

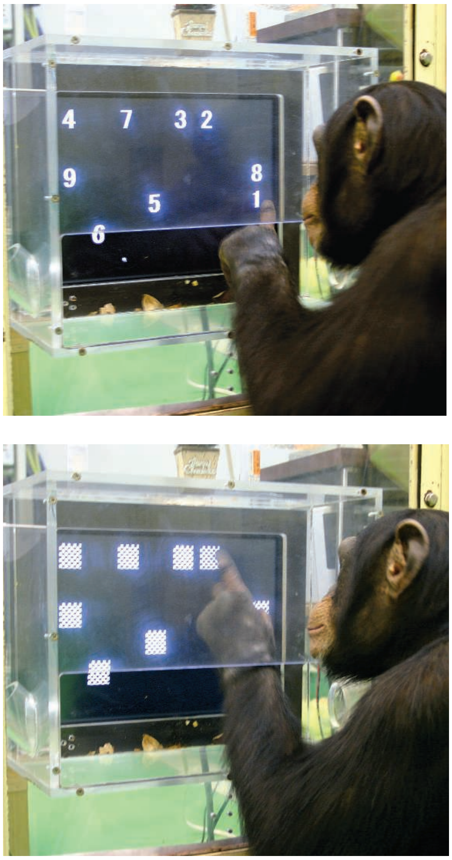
Not everyone agrees with this evaluation of Neandertals, but Wynn and Coolidge see other examples of uniquely modern human behaviors that they think required enhanced working memory. Chief among them is the iconic Hohlenstein-Stadel figurine. "That is a beautiful archaeological example of their model," says archaeologist Lyn Wadley of the University of the Witwatersrand, Johannesburg, in South Africa. Wynn and Coolidge also cite research at Niah Cave in Borneo suggesting that about 40,000 years ago, modern humans deliberately set forest fires to nurture tubers and other edible plants and perhaps also trapped pigs. This "managed foraging" is evidence for advanced planning, they say.

The pair also sees enhanced working memory at work in the bone "tally sticks" found at sites in France and the Democratic Republic of the Congo. These notched objects date to 28,000 years ago or later and may have been "external memory devices" used to record something, according to work by archaeologist Francesco D'Errico of the University of Bordeaux in France. Wynn and Coolidge think that the sticks were used to perform calculations and perhaps to enhance working memory by transferring it to a physical object.

In choosing these examples, however—none of which date to earlier than 40,000 years ago—Wynn and Coolidge have bucked an increasing trend in archaeology. Many researchers now interpret artifacts such as 75,000-year-old beads and etched ochre at Blombos Cave in South Africa and 90,000-year-old beads at Qafzeh Cave in Israel as evidence that symbolic expression has much deeper evolutionary roots.

"They may have painted themselves into a corner by setting down a date of 40,000 years for modern cognition," Wadley says. Miriam Haidle, an archaeologist at the University of Tübingen in Germany, agrees. "Everything must start much earlier than they think," Haidle says. "Working memory was a neurological complex that slowly developed over at least 2 million years."

Wynn and Coolidge acknowledge that their model swims against the current tide of early claims for modern human behavior. But they argue that the Blombos artifacts may have represented only a simple sort of symbolism, such as that used to mark social identities, rather than the fully realized symbolic behavior typical of later modern humans. "We just think the late, jerky expla-



What was that number? Chimpanzees are better than humans at some memory tasks.

nation requires fewer assumptions and caveats and takes the archaeological record seriously, instead of trying to explain it away," says Wynn.

Still, Wynn told *Science* that he is now "mostly convinced" by evidence, reported by Wadley last year, for the use of ochre adhesives to haft stone tools at the 70,000-year-old South African site of Sibudu, which suggests enhanced working memory. He and Coolidge say that the genetic mutation or mutations they propose may not have been as late as 40,000 years ago. They're open to other scenarios, such as that the cognitive advance was gradually manifested in the archaeological record, or that the genetic variants coding for enhanced working memory did not rise to high frequencies in human populations until more recently.

From past to future

While Wynn and Coolidge have focused their attention on relatively recent enhancements in working memory capacity, other researchers trace its evolution much further back in time—back to the split between humans and chimpanzees, about 5 million to 7 million years ago. In a 2008 paper in *Evolutionary Psychology*, UCLA's Read marshaled several lines of evidence suggesting that chimpanzees have much more limited working memory capacity than modern humans. He argued that the common ancestor of humans and chimps also had limited working memory capacity and limited ability to engage in what linguists call recursion, the embedding of phrases within each other, as in this sentence. Many researchers consider recursion the hallmark of modern human language.

However, primatologist Tetsuro Matsuzawa of Kyoto University in Japan claimed in 2007 that some young chimps are better than adult humans at a memory task using numbers flashed on a computer screen. "Seeing is believing," Matsuzawa told *Science*. "They are better than us in this memory test."

Read argues that this test measures a simpler form of passive photographic memory rather than full-fledged working memory. Wynn agrees that the chimp studies are not comparable with the dual-task experiments done with humans. "The tests included no distractions" to engage the central executive and explore the ability to focus attention on the task at hand, Wynn says.

Meanwhile, the working-memory concept continues to inspire others. Psychologists Thomas Suddendorf of the University of Queensland in Brisbane, Australia, and Michael Corballis of the University of Auckland in New Zealand think working memory is crucial to "mental time travel," the ability to harness memories of the past to imagine the future. They argue that this capacity was crucial to the evolution of language. Harvard University psychologist Daniel Schacter agrees. On the basis of brain-imaging studies and other research, Schacter and Donna Rose Addis of the University of Auckland have concluded that the same neural networks are implicated in both remembering the past and imagining the future and that both processes probably involve something like Baddeley's proposed episodic buffer. "Working memory is critically important for constructing simulations of future events," Schacter says.

Wynn and Coolidge, who routinely cite Schacter and Addis in their own papers, say that a jump in working memory capacity was also key to the construction of modern human symbolism and artistic expression, including the ability to imagine things that have never existed and never will, like the Lion Man. "We may have the exact timing wrong and the exact nature of the genetic events" wrong as well, Coolidge says. "But something happened that was less than gradual in the evolution of the human mind."

–MICHAEL BALTER

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