F. D'ERRICO

Prehistoric accounting? Markings made on a hyena bone by a Neanderthal might have recorded numerical information.

HOW DID ANCIENT HUMANS LEARN TO COUNT?

Recent archaeological studies and other analyses have spurred researchers to construct some of the first detailed hypotheses describing the prehistoric development of number systems. **By Colin Barras**

Some 60,000 years ago, in what is now western France, a Neanderthal picked up a chunk of hyena femur and a stone tool and began to work. When the task was complete, the bone bore nine notches that were strikingly similar and approximately parallel, as if they were meant to signify something.

Francesco d'Errico, an archaeologist at the University of Bordeaux, France, has an idea about the marks. He has examined many ancient carved artefacts during his career, and he thinks that the hyena bone — found in the 1970s at the site of Les Pradelles near Angoulême — stands out as unusual. Although ancient carved artefacts are often interpreted as artworks, the Les Pradelles bone seems to have been more functional, says D'Errico.

He argues that it might encode numerical information. And if that's correct, anatomically modern humans might not have been alone in developing a system of numerical notations: Neanderthals might have begun to do so, too[1].

When D'Errico published his ideas in 2018, he was venturing into territory that few scientists had explored: the ancient roots of numbers. "The origin of numbers is still a relatively vacant niche in scientific research," says Russell Gray, an evolutionary biologist at the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany. Researchers don't even agree, at times, on what numbers are, although a 2017 study[2] defined them as discrete entities with exact values that are represented by symbols in the form of words and signs.

Now the origin of numbers is attracting

increasing attention as researchers from a variety of fields address the problem from different vantage points.

Cognitive scientists, anthropologists and psychologists are looking at contemporary cultures to understand differences among existing number systems — defined as the symbols that a society uses for counting and manipulating numbers. Their hope is that clues buried in modern systems might illuminate details of their origins. Meanwhile, archaeologists have begun looking for evidence of ancient numerical notations, and evolutionary biologists with an interest in language are exploring the deep origins of number words. These studies have spurred researchers to formulate some of the first detailed hypotheses for the prehistoric development of number systems.

And an infusion of funding will stimulate more studies in this area. This year, an international research team with a €10-million (US$11.9-million) grant from the European Research Council will start to test different hypotheses, as part of a broader effort to study when, why and how number systems appeared and spread around the world. The project, called the Evolution of Cognitive Tools for Quantification (QUANTA), might even provide insights into whether number systems are unique to anatomically modern humans, or were conceivably present in nascent form in Neanderthals.

An instinct for numbers

Although researchers once thought that humans were the only species with a sense of quantity, studies since the mid-twentieth century have revealed that many animals share the ability. For instance, fish, bees and newborn chicks[3] can instantly recognize quantities up to four, a skill known as subitizing. Some animals are also capable of 'large-quantity discrimination': they can appreciate the difference between two large quantities if they are distinct enough. Creatures with this skill could, for example, distinguish 10 objects from 20 objects, but not 20 from 21. Six-month-old human infants also show a similar appreciation of quantity, even before they have had significant exposure to human culture or language.

> **"The origin of numbers is still a relatively vacant niche in scientific research."**

What all of this suggests, says Andreas Nieder, a neuroscientist at the University of Tübingen, Germany, is that humans have an innate appreciation of numbers. That arose through evolutionary processes such as natural selection, he says, because it would have carried adaptive benefits.

Others interpret the evidence differently. Rafael Núñez, a cognitive scientist at the University of California, San Diego, and one of the leaders of QUANTA, accepts that many animals might have an innate appreciation of quantity. However, he argues that the human perception of numbers is typically much more sophisticated, and can't have arisen through a process such as natural selection. Instead, many aspects of numbers, such as the spoken words and written signs that are used to represent them, must be produced by cultural evolution — a process in which individuals learn through imitation or formal teaching to adopt a new skill (such as how to use a tool).

MATTHEW HORWOOD/GETTY

Some researchers suggest the mind extends beyond the brain to fingers and other objects.

Although many animals have culture, one that involves numbers is essentially unique to humans. A handful of chimpanzees have been taught in captivity to use abstract symbols to represent quantities, but neither chimps nor any other non-human species use such symbols in the natural world. Núñez suggests that a distinction should therefore be made between what he has dubbed the innate 'quantical' cognition seen in animals and the learnt 'numerical' cognition seen in humans[2].

But not everyone agrees. Nieder argues that neurological studies show clear similarities between the way in which quantities are processed in the brains of non-human animals and how the human brain processes numbers. He says that it is misleading to draw too firm a line between the two behaviours[4], although he agrees that human numerical abilities are much more advanced than those of any other animal. "No [non-human] animal is able to truly represent number symbols," he says.

D'Errico's analysis of the Les Pradelles bone could help to provide some insights into how the earliest stages of number systems took shape. He studied the nine notches under a microscope, and says that their shapes, depths and other details are so alike that all seem to have been made using the same stone tool, held in the same way. This suggests that all were made by one individual in a single session lasting perhaps a few minutes or hours. (At some other time, eight much shallower marks were carved on the bone, too.)

However, D'Errico doesn't think that this individual intended to produce a decorative pattern because the marks are uneven. For comparison, he has analysed the seven notches on a 40,000-year-old raven bone from a site of Neanderthal occupation in Crimea. Statistical analysis shows that the notches on this bone are spaced with the same sort of regularity seen when modern volunteers are given a similar bone and asked to mark it with equally spaced notches[5]. But this type of analysis also shows that the marks on the Les Pradelles bone lack such regularity. That observation — and the fact that the notches were generated in a single session — led D'Errico to consider that they might have been merely functional, providing a record of numerical information.

Marks of sophistication

The Les Pradelles bone is not an isolated find. For instance, during excavations at Border Cave in South Africa, archaeologists discovered an approximately 42,000-year-old baboon fibula that was also marked with notches. D'Errico suspects that anatomically modern humans living there at the time used the bone to record numerical information. In the case of this bone, microscopic analysis of its 29 notches suggests they were carved using four distinct tools and so represent four counting events, which D'Errico thinks took place on four separate occasions[1]. Moreover, he says that discoveries over the past 20 years show that ancient humans began producing abstract engravings, which hint at sophisticated cognition, hundreds of thousands of years earlier than was once thought.

In the light of these discoveries, D'Errico has developed a scenario to explain how number systems might have arisen through the very act of producing such artefacts. His hypothesis is one of only two published so far for the prehistoric origin of numbers.

It all started by accident, he suggests, as early hominins unintentionally left marks on bones while they were butchering animal carcasses. Later, the hominins made a cognitive leap when they realized that they could deliberately mark bones to produce abstract designs — such as those seen on an approximately 430,000-year-old shell found in Trinil, Indonesia[6]. At some point after that, another leap occurred: individual marks began to take on meaning, with some of them perhaps encoding numerical information. The Les Pradelles hyena bone is potentially the earliest known example of this type of mark-making, says D'Errico. He thinks that with further leaps, or what he dubs cultural exaptations, such notches eventually led to the invention of number signs such as 1, 2 and 3 (ref. 7).

D'Errico acknowledges that there are gaps in this scenario. It isn't clear what cultural or social factors might have encouraged ancient hominins to begin marking bones or other artefacts deliberately, or to then harness those marks to record numerical information. QUANTA will use data from anthropology, cognitive science, linguistics and archaeology to better understand those social factors, says D'Errico, who is one of the project's four principal investigators.

Bones of contention

However, QUANTA researcher Núñez, along with some researchers who are not involved in the project, cautions that ancient artefacts such as the Les Pradelles bone are challenging to interpret. Karenleigh Overmann, a cognitive archaeologist at the University of Colorado in Colorado Springs, highlights those difficulties by citing the example of message sticks used by Aboriginal Australians. These sticks, which are typically flattened or cylindrical lengths of wood, are adorned with notches that might look as though they encode numerical information — but many do not.

Piers Kelly, a linguistic anthropologist at the University of New England in Armidale, Australia, who conducted a review of message sticks[8], agrees with Overmann's point. He says that some message sticks are carved with tally-like marks, but these often act as a visual memory aid to help a messenger recall details of the message they are delivering. "They call to mind the act of recounting a narrative rather than accounting a quantity," says Kelly.

Wunyungar, an Aboriginal Australian who is a member of the Gooreng Gooreng and Wakka Wakka communities, says that the sticks might transmit one of any number of distinct messages. "Some are used for trading — for foods, tools or weapons," he says. "Others might carry messages of peace after war."

Overmann has developed her own hypothesis to explain how number systems might have emerged in prehistory — a task made easier by the fact that a wide variety of number systems are still in use around the world. For example, linguists Claire Bowern and Jason Zentz at Yale University in New Haven, Connecticut, reported in a 2012 survey that 139 Aboriginal Australian languages have an upper limit of 'three' or 'four' for specific numerals. Some of those languages use natural quantifiers such as 'several' and 'many' to indicate higher values[9]. There is even one group, the Pirahã people of the Brazilian Amazon, that is sometimes claimed not to use numbers at all[10].

Overmann and other researchers stress that there's nothing intellectually lacking about societies that use relatively simple number systems. But she wondered whether such societies might provide clues about the social pressures that drive the development of more elaborate number systems.

Counting on possessions

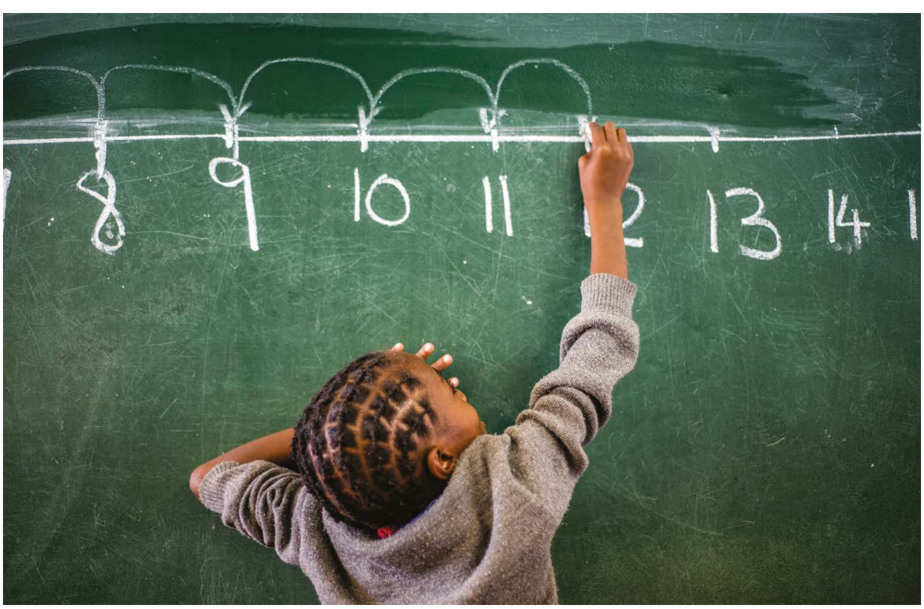
In a 2013 study[11], Overmann analysed anthropological data relating to 33 contemporary hunter-gatherer societies across the world. She discovered that those with simple number systems (an upper limit not much higher than 'four') often had few material possessions, such as weapons, tools or jewellery. Those with elaborate systems (an upper numeral limit much higher than 'four') always had a richer array of possessions. The evidence suggested to Overmann that societies might need a variety of material possessions if they are to develop such number systems.

In societies with complex number systems, there were clues to how those systems developed. Significantly, Overmann noted that it was common for these societies to use quinary (base 5), decimal or vigesimal (base 20) systems. This suggested to her that many number systems began with a finger-counting stage.

This finger-counting stage is important, according to Overmann. She is an advocate of material engagement theory (MET), a framework devised about a decade ago by cognitive archaeologist Lambros Malafouris at the University of Oxford, UK[12]. MET maintains that the mind extends beyond the brain and into objects, such as tools or even a person's fingers. This extension allows ideas to be realized in physical form; so, in the case of counting, MET suggests that the mental conceptualization of numbers can include the fingers. That makes numbers more tangible and easier to add or subtract.

The societies that moved beyond finger-counting did so, argues Overmann, because they developed a clearer social need for numbers. Perhaps most obviously, a society with more material possessions has a greater need to count (and to count much higher than 'four') to keep track of objects.

Overmann thinks MET implies that there is another way in which material possessions are necessary for the elaboration of number systems. An artefact such as a tally stick also



A number line echoes some of the numerical tools that were used by ancient humans.

OLEKSANDR RUPETA/NURPHOTO VIA GETTY

F. D'ERRICO & L. BACKWELL

Researchers think that people cut notches into this baboon bone some 40,000 years ago as an early form of counting.

becomes an extension of the mind, and the act of marking tally notches on the stick helps to anchor and stabilize numbers as someone counts. These aids could have been crucial to the process through which humans first began counting up to large numbers[13].

Eventually, says Overmann, some societies moved beyond tally sticks. This first happened in Mesopotamia around the time when cities emerged there, creating an even greater need for numbers to keep track of resources and people. Archaeological evidence suggests that by 5,500 years ago, some Mesopotamians had begun using small clay tokens as counting aids.

According to Overmann, MET suggests that these tokens were also extensions of the mind, and that they fostered the emergence of new numerical properties. In particular, the shapes of tokens came to represent different values: 10 small cone tokens were equivalent to a sphere token, and 6 spheres were equivalent to a large cone token. The existence of large cones, each equivalent to 60 small cones, allowed the Mesopotamians to count into the thousands using relatively few tokens.

Andrea Bender, a psychologist at the University of Bergen in Norway and another leader of the QUANTA project, says that the team members plan to gather and analyse large amounts of data relating to the world's numeral systems. That should allow them to test Overmann's hypothesis that body parts and artefacts might have helped societies to develop number systems that ultimately count into the thousands and higher. But Bender says she and her colleagues are not presupposing that Overmann's MET-based ideas are correct.

Others are more enthusiastic. Karim Zahidi, a philosopher at the University of Antwerp in Belgium, says that although Overmann's scenario is still incomplete, it has real potential to explain the development of the elaborate number systems in use today.

Linguistic leads

Overmann acknowledges that her hypothesis is silent on one issue: when in prehistory human societies began developing number systems. Linguistics might offer some help here. One line of evidence suggests that number words could have a history stretching back at least tens of thousands of years.

Evolutionary biologist Mark Pagel at the University of Reading, UK, and his colleagues have spent many years exploring the history of words in extant language families, with the aid of computational tools that they initially developed to study biological evolution. Essentially, words are treated as entities that either remain stable or are outcompeted and replaced as languages spread and diversify. For instance, English 'water' and German 'wasser' are clearly related, making them cognates that derive from the same ancient word – an example of stability. But English 'hand' is distinct from Spanish 'mano' – evidence of word replacement at some time in the past. By assessing how frequently such replacement events occur over long periods, it is possible to estimate rates of change and to infer how old words are.

"No non-human animal is able to truly represent number symbols."

Using this approach, Pagel and Andrew Meade at Reading showed that low-value number words ('one' to 'five') are among the most stable features of spoken languages[14]. Indeed, they change so infrequently across language families – such as the Indo-European family, which includes many modern European and southern Asian languages – that they seem to have been stable for anywhere between 10,000 and 100,000 years.

This doesn't prove that the numbers from 'one' to 'five' derive from ancient cognates that were first spoken tens of thousands of years ago, but Pagel says it's at least "conceivable" that a modern and a Palaeolithic Eurasian could have understood one another when it came to such number words.

Pagel's work has its fans, including Gray, another of QUANTA's leaders, but his claims are challenged by some scholars of ancient languages. Don Ringe, a historical linguist at the University of Pennsylvania in Philadelphia, says it isn't clear that the stability of lower-number words can just be projected far back into prehistory, regardless of how stable they seem to be in recent millennia.

That all adds up to a slew of open questions about when and how humans first started using numbers. But despite the debate swirling around these questions, researchers agree it's a topic that deserves a lot more attention. "Numbers are just so fundamental to everything we do," says Gray. "It's hard to conceive of human life without them."

Numbers might even have gained this importance deep in prehistory. The notched baboon bone from Border Cave is worn smooth in a way that indicates that ancient humans used it over many years. "It was clearly an important item for the individual who produced it," says D'Errico.

Not so for the Les Pradelles specimen, which lacks this smooth surface. If it does record numerical information, that might not have been quite as important at the time. In fact, although D'Errico and his colleagues have spent innumerable hours analysing the bone, he says it's possible that the Neanderthal who chipped away at that hyena femur some 60,000 years ago spent very little time using it before tossing the bone aside.

Colin Barras is a science journalist in Ann Arbor, Michigan.

1. D'Errico, F. *et al. Phil. Trans. R. Soc. B* **373**, 20160518 (2018).
2. Núñez, R. E. *Trends Cogn. Sci.* **21**, 409–424 (2017).
3. Rugani, R. *Phil. Trans. R. Soc. B* **373**, 20160509 (2018).
4. Nieder, A. *Trends Cogn. Sci.* **21**, 403–404 (2017).
5. Majkić, A., Evans, S., Stepanchuk, V., Tsvelykh, A. & D'Errico, F. *PLoS ONE* **12**, e0173435 (2017).
6. Joordens, J. C. A. *et al. Nature* **518**, 228–231 (2015).
7. D'Errico, F. & Colagè, I. *Biol. Theory* **13**, 213–227 (2018).
8. Kelly, P. *J. Mater. Cult.* **25**, 133–152 (2020).
9. Bowern, C. & Zentz, J. *Anthropol. Linguist.* **54**, 133–160 (2012).
10. Everett, D. L. *Curr. Anthropol.* **46**, 621–646 (2005).
11. Overmann, K. A. *Camb. Archaeol. J.* **23**, 19–39 (2013).
12. Malafouris, L. *How Things Shape the Mind: A Theory of Material Engagement* (MIT Press, 2013).
13. Overmann, K. A. *J. Cogn. Cult.* **17**, 354–373 (2017).
14. Pagel, M. & Meade, A. *Phil. Trans. R. Soc. B* **373**, 20160517 (2018).