

Two brain circuits explain the unique human capacity for invention – an insight that may also shed light on the evolution of autism, says researcher **Simon Baron-Cohen**

Our restless minds

DESCENDING the ladder into Hohle Fels cave, I felt like I was going back through layers of time. At the bottom, Nicholas Conard, archaeologist and director of the nearby museum in Blaubeuren, Germany, pointed to a layer of rock. “Right here is 20,000 years ago,” he said. Then he pointed about a metre lower. “Here, we are at 40,000 years ago.”

I was in awe, suddenly aware that I was standing where our early human ancestors lived and breathed so long ago. But it was what they invented that inspired my trip. Hohle Fels is where, in 2008, Conard and his colleagues discovered the earliest known musical instrument, a flute carved from a vulture bone that is thought to be about 40,000 years old.

It is the product of what I argue are parallel revolutions in human cognition. In my career studying the human brain through the lens of understanding autism, I have devoted a lot of time to understanding empathy, its role in our evolution and how it still underpins human interaction today. But around the same time that the brain changes arose that enabled us to use empathy, another equally critical set of changes took place: the evolution of a pattern-seeking brain network, what I refer to as the systemising mechanism, that provides the foundation for human invention – including that of musical instruments.

The consequences of this dual revolution for humanity were profound. What’s more,

my recent research suggests that the pattern-seeking network is more highly tuned in autistic people and may help explain why autistic traits often overlap with an extraordinary capacity for invention.

If we take the long view of human evolution, simple tool use dates back more than 2 million years. There is evidence of some advancements in early technology – the emergence of more sophisticated hand axes around 1.7 million years ago, for instance. But among early hominins, for about 2 million years, stone tools mostly had just a few basic functions: to smash, cut and scrape. There was little change, no sign of “generative” invention. Our ancestors had largely made just one change and stuck with it for millions of years, and didn’t show how they could invent continuously, with each change building on the last, and they didn’t show a range of inventions.

When our species, *Homo sapiens*, first emerged around 300,000 years ago, we begin to see signs of more invention with tools and specific kinds of blades. However, we start to see an explosion of invention in the archaeological record about 100,000 years ago, with evidence of the first engraving and the first examples of jewellery. Around 70,000 years ago, we see the first signs that modern humans were using “stealth weapons” such as the spear and bow and arrow.

Sewing needles appeared 60,000 years ago. By 44,000 years ago, we see the



earliest known evidence of counting, engravings on a bone that look like a tally. And in this fast-moving area of research, new artefacts are being discovered all the time. What most impressed me, though, is the earliest musical instrument: the bone flute excavated in Hohle Fels cave.

Empathy and systemising

After my visit to the cave, Conard played me a recording of a replica flute. It was profoundly moving. I was hearing the same notes our ancestors would have heard 40,000 years ago. The bone flute has five holes, an indication that it was used to play melodies using the pentatonic scale still prevalent in many musical traditions today. Our ancestors weren’t just inventing complex tools, but complex systems – music itself.

This explosion of artefacts in the archaeological record is a sign that modern humans had developed the capacity for generative invention. Between 40,000 and 10,000 years ago, we see the emergence of sculpture, cave painting, agriculture and night-sky gazing. By 5000 years ago, there are signs of writing, mathematics, religion and the wheel. We are still inventing unstoppably – most recently vaccines against covid-19.

So what changed? In my new book, *The Pattern Seekers*, I argue that two circuits in the brain that drove this cognitive revolution began to evolve, surprisingly about the same time, between 100,000 and 70,000 years ago.

One of these circuits, the empathy circuit, enabled a raft of new behaviours, including the ability to deceive others, teaching, self-reflection, social “chess” and flexible communication that relied on shared reference, including storytelling. These explain why modern humans could make stealth weapons and jewellery: we were keeping track of what others might think, know, intend, feel, want and believe.

With my colleagues, I have been studying the empathy circuit for the past 35 years, and we now know that it recruits a complex network of at least 10 brain regions. Empathy

“Our capacity for empathy explains what we invent, but not how we came to invent”



DANIEL MAURER/AP/SHUTTERSTOCK

This 40,000-year-old bone flute is the earliest known musical instrument

has at least two components: cognitive empathy, also known as theory of mind, which is the ability to imagine another’s thoughts; and affective empathy, the drive to respond to another person’s mental state with an appropriate emotion. Although we see some evidence of empathy in some non-human animals, there is no convincing evidence that other animals can attribute false beliefs to another animal or that they engage in flexible deception and teaching, for example – unlike a 4-year-old child.

The other discovery we have made is that genetics influences this ability. Differences in empathy fall on a bell curve, with most people in the middle of the distribution and a tiny percentage at the extremes. In recent studies with up to 80,000 people, our international group of collaborators looked at the associations between common genetic variants and particular traits, finding that certain genes are associated with where each of us falls on the curve.

While upbringing and our early experiences undoubtedly influence how much empathy an individual has, the finding that empathy is even partly genetic is a clue that it was the result of natural selection. It is easy to see why it might have been highly adaptive. It would have helped people build traps into which prey would fall, for example, or to read the mind of preverbal infants to attend to their emotional and physical needs so that they survived to the age of reproduction, to pass on genes.

However, the empathy circuit isn’t enough. It can explain why we see jewellery, musical instruments, sculpture and cave paintings in the archaeological record – we were thinking about an audience and what they might be interested in. But it isn’t enough to explain how modern humans became capable of these sorts of inventions in the first place. To fully explain the cognitive revolution in our capacity for invention, humans must have developed a second new brain circuit.

This is where the systemising mechanism comes in. This allowed us to seek patterns in the world in a new way. Our hominin ancestors could see simple patterns using

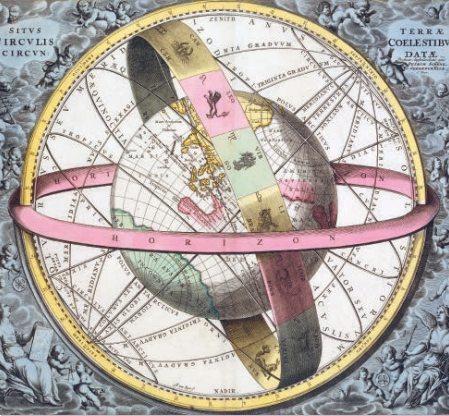


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associative learning: A is associated with B, or using a hammer to crush a nut is associated with getting the tasty reward, for example. This enabled them to make simple tools. But modern humans were looking for more complex if-and-then patterns. This allowed them to invent advanced tools, and still enables us to do so today.

I borrow the if-and-then idea from the 19th-century logician George Boole, whose analysis of how we think logically is credited with the invention of the modern computer. In engineering terms, if-and-then patterns are the equivalent of input-operation-output patterns: if I take an input and I perform (or observe) an operation on the input, then I see a change in the output. An operation could be a wide range of actions, but the most interesting of these are causal operations, ones that change the input to a new output for a reason. The “and” in the if-and-then algorithm is the magic word.

The systemising mechanism enabled us not only to find such if-and-then patterns,



Clockwise from far left: the 30,000-year-old Venus of Willendorf sculpture, a roughly 2000-year-old Mesopotamian cuneiform tablet and the 17th-century star atlas *Harmonica Macrocosmica* are products of the uniquely human capacity for invention

but to confirm their truth through repetition. This is where generative invention arises. Humans became experimentalists.

It was the beginnings of music: if I blow down this hollow bone, and I cover one hole, then I make sound A. Changing the “and” variable leads to invention: if I blow down this hollow bone, and I uncover one hole, then I make sound B. Beautiful musical sequences of notes, riffs and rhythmic patterns emanate from an engine in the brain that enables invention. You can see the same exquisite logic underlying the invention of any complex tool.

Pattern seekers

The invention of stealth weapons like the bow and arrow that could kill from a distance was based on the following logic: if I attach an arrow to a stretchy fibre and release the tension in the fibre, then the arrow will fly. The invention of agriculture: if I take a tomato seed, and plant it in moist soil, then I get a tomato plant. Medicine: if I have a headache and I eat the bark of a willow tree, then my headache goes away. And so on.

The critical role of this pattern seeking in the story of human progress led me to wonder: with the empathy circuit, we know that there are individual differences in how dominant this ability is, and that they correspond to genetic differences. Is this true for systemising as well, indicating that it, too, was actively selected for in our evolution?

It might well be. When my colleagues and I looked at more than 630,000 people as part of our Brain Types study, we found individual differences in systemising that are distributed across a bell curve. To determine whether these differences corresponded to genetic differences, last year we did an analysis of 50,000 people. As with empathy, we found that common genetic variants were associated with where each of us falls on the systemising curve: whether we are barely interested in if-and-then patterns, are average at systemising or systemise non-stop – so called hyper-systemisers.

The fact that how much we tend to ➤

What's your brain type?

To study the balance between empathy and systemising in individuals, my colleagues and I ask participants to complete short versions of two surveys: the Systemising Quotient (SQ) and the Empathy Quotient (EQ). In both, people are asked to choose whether they strongly agree, slightly agree, slightly disagree or strongly disagree with a list of 10 statements. For the SQ, these include “I am interested in knowing the path a river takes from its course to the sea” and “When I listen to a piece of music, I always notice the way it's structured”. For the EQ, they include “I can't always see why someone should have felt offended by a remark” and “I can tune into how someone feels rapidly and intuitively”.

We score these to see where a person falls along these two dimensions. This research has shown that the human spectrum of neurodiversity can be divided into just five types of brain, and that there are typically trade-offs between empathy and systemising: that is, the higher you score on one, the lower you score on the other.

Type E: people whose empathy is at a higher level than their systemising. This group makes up roughly 30 per cent of the population.

Type S: people whose systemising is at a higher level than their empathy. Again, roughly 30 per cent of people. **Type B:** those who show no difference in their drive to empathise or to systemise. Also roughly 30 per cent of the population.

Extreme Type E: people whose empathy circuit is tuned super high and who empathise non-stop, but their systemising mechanism is tuned to average levels or below. These comprise about 3 per cent of people. **Extreme Type S:** people whose systemising mechanism is tuned super high and who systemise non-stop, but their empathy circuit is tuned to average levels or below. They also comprise about 3 per cent of the population.

We recently built an online tool to enable people to take these surveys at home, so that they can contribute to our research. We will be able to use this data to explore a range of significant questions: do the five brain types vary by culture, age, gender, neurology, occupation, biology and experience? And what advantages does each brain type confer? To join in our research, please go to yourbraintype.com

systemise is even partly genetic means that, again, this ability was the product of natural selection. It isn't difficult to imagine how hyper-systemisers might have had adaptive advantages that enabled them to survive and pass on their genes. They could have been the person people would go to when their child was sick, for example, or to fix a gadget; or those who could invent new and better ways of doing things, amassing significant resources.

The data revealed another intriguing facet: we also found that most people are biased either towards systemising or empathy, instead of striking an equal balance of the two. That suggests that being more dominant in one or the other might have been adaptive in different ecological niches (see “What's your brain type?”, left).

All of this starts to add up to a new idea about how our inventing minds evolved. But it may also tell us something about autism, which I have spent most of my career studying.

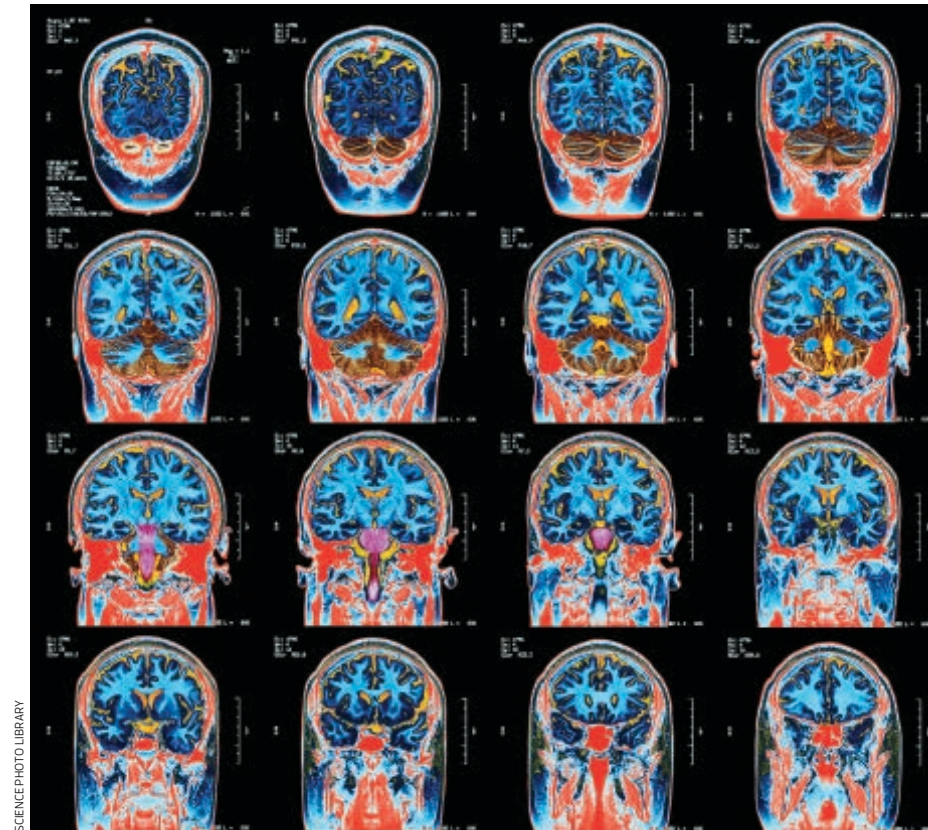
Among the people I call hyper-systemisers, I would place some of the most famous inventors in history such as Thomas Edison, Isaac Newton and Nicholas Tesla.

According to their biographers, Edison became so immersed in his experiments that his wife moved a mattress into his study for him to sleep, while Newton continued to give his lectures at Trinity College, University of Cambridge, even if no students attended, because it was in his job contract. Both could use their talent at systemising in a niche where it was valued. Unfortunately, that is too often the exception – a point I shall return to.

Autistic talent

These examples are at best suggestive that these historical figures may have had elevated autistic traits. But I wanted to better understand this link. When we looked more closely at our Brain Types study, we found that the 36,000 participants who had been diagnosed as autistic were more likely to be systemisers or hyper-systemisers and this was true of both men and women.

We also found that among the 600,000 people in the study who didn't have an



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autism diagnosis, those working in science, technology, engineering or mathematics (STEM) roles had a higher number of autistic traits than those who weren't. In studies of mathematicians at the University of Cambridge, we have found an elevated rate of diagnosed autism compared with people in the humanities or the general population.

On average, autistic people outperform non-autistic people on tests of pattern recognition and mechanical reasoning. This link between autistic traits, autism diagnosis and systemising appears to be genetic. Parents of autistic children are over-represented in STEM, and show superior pattern-recognition skills.

All of these associations are compelling, but to truly pin down the link between autism and systemising we conducted another large-scale, genetic association study. Sure enough, there was an overlap between the common genetic variants associated with autism and those associated with hyper-systemising. It was 26 per cent. That means that some of the genes for autism aren't just coding for autism, but also for talent at systemising.

“Hyper-systemisers have driven human invention for 70,000 years”

MRI scans can reveal details of how different brains work

This insight matters. It suggests that autism isn't genetic happenstance, but that it is entwined with our capacity for invention and has been actively selected for in our evolution. Too often, autistic people have been marginalised, stigmatised and excluded. This was the focus of my 2017 speech at the United Nations, on the subject of autism and human rights. Worrying studies from our lab have shown that two-thirds of adults with autism have felt suicidal, one-third have attempted suicide and the majority have poor mental health such as high levels of anxiety and depression.

Let's be clear: mental health struggles aren't inherently part of autism. They are a sign of a lack of support and inclusion into society. Unemployment levels of autistic adults are unacceptably high, and it is well established that unemployment can undermine our sense of inclusion, autonomy and value to society.

I am hopeful that discovering the connection between autism and invention will contribute to the growing movement to respect and celebrate the diversity of our human brains. Hyper-systemisers are part of the neurodiversity we find in any population, and this brain type and the genes associated with it have driven human progress through the evolution of invention for more than 70,000 years.

We have a civic duty to support autistic people into work, both for the sake of their well-being and to maximise the likelihood of future human innovation. ■



Simon Baron-Cohen is director of the Autism Research Centre at the University of Cambridge. His book *The Pattern Seekers: A new theory of human invention* is out now

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