The Origins of Invention and Its Link with Autism

9

Simon Baron-Cohen

9.1 Introduction

What are the origins of invention? And is there a link between our uniquely human capacity for invention, and autism? And what are the implications for understanding the nature and significance of autism and its relation to human evolution and society? In this chapter, I present a personal review summarising my decades long research and some by others and present an overarching perspective.

9.2 Evolution and Autism

If we take the long view of human evolution, we can see evidence of simple tool use going back as far as *Homo habilis*, who lived 2.5 to 1.5 million years ago, and *Homo erectus*, who lived 2.1 million years ago until as recently as 250,000 years ago (Fig. 9.1). Both of these ancestors used simple tools with few functions: to smash, cut and scrape. And even *Homo neanderthalis*, who lived 300,000 years ago until as recently as 40,000 years ago, still only used simple stone axes, with the same limited functions. Although these three early humans showed some differences in their technology, I argue these *simple* tools showed no signs of *generative invention*—that there was little change over this long period of over two million years.

Homo sapiens appears 300,000 years ago and I and others argue a ‘cognitive revolution’ took place, a change in the modern human brain, between 100,000 and 70,000 years ago. Modern humans appear to have developed the capacity to invent generatively. What is the evidence for this? If we look in the archaeological record, we see the earliest examples of engraving from 77,000 years ago, the first jewellery (in the form of a necklace of beads) from 75,000 years ago (Fig. 9.2), and the first

S. Baron-Cohen (✉)
Autism Research Centre, Cambridge University, Cambridge, UK
e-mail: sb205@cam.ac.uk

G. Ikkos, T. Becker (eds.), *Psychiatry after Kraepelin*,
https://doi.org/10.1007/978-3-032-09475-9_9

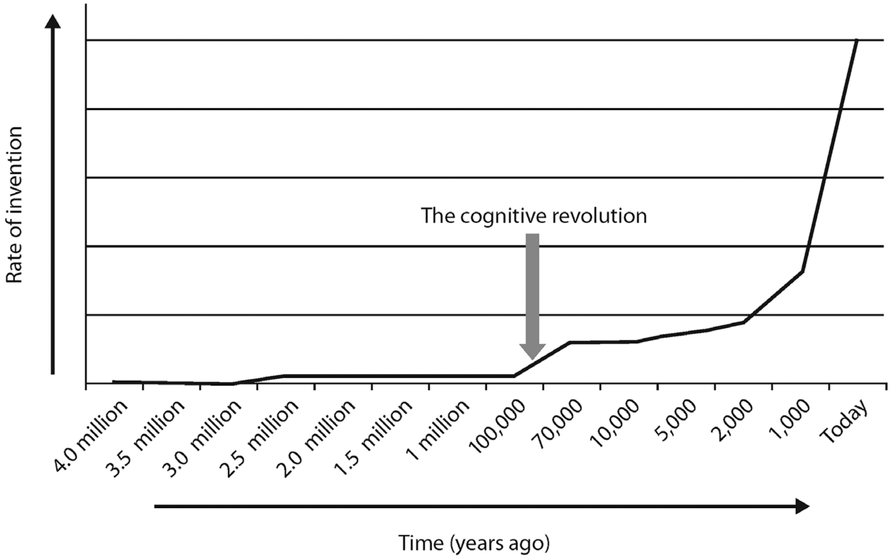

Fig. 9.1 70–100,000 years ago the rate of invention took off. (From Baron-Cohen (2020) The Pattern Seekers)

signs that modern humans were using a bow-and-arrow 71,000 years ago, so-called ‘stealth’ weapons.

And that is not all. By 43,000 years ago we see the first evidence of counting, in the form of systematic engravings on a bone of what looks like keeping a tally, and the first cave paintings from 40,000 years ago (Fig. 9.3). To me, most striking of all, 40,000 years ago we see the earliest musical instrument—the bone flute (Fig. 9.4). I had the privilege of going to the cave (Hohle Fels) in Schelklingen, Swabia in Germany where this was found, with archaeologist Professor Nicholas Conard, and to his delightful museum in Tübingen (Museum der Universität Tübingen, MUT, www.unimuseum.de), to listen to a recording of the flute being played. Modern humans were not just inventing *complex* tools but were inventing music.

To me, this explosion of artefacts in the archaeological record is a sign that modern humans alone had the capacity for generative invention—not just making one change and sticking with that for millions of years but inventing unstoppably and in a myriad of different ways. By 32,000 years ago we see the first sculpture, by 23,000 years ago the first sewing needles, by 13,000 years ago the first signs of agriculture, by 10,000 years ago the first signs of star gazing as we analysed the movement and changing shape and colour of the moon in relation to the sun, 5000 years ago the first signs of writing, mathematics and the wheel.

As historian Yuval Harari points out in his excellent book *Sapiens*, [1] humans over the last 13,000 years went through the agricultural, industrial and now the digital revolutions. And we are still inventing unstoppably. Fast forward to the twenty-first century, we have invented the first vaccine targeting coronavirus disease 2019

Fig. 9.2 The earliest jewellery, dated 75,000 years ago, made from shells, thought to be a necklace, each drilled with a small hole. (From Baron-Cohen (2020) The Pattern Seekers)

Fig. 9.3 A cave painting, dated 40,000 years old. (From Baron-Cohen (2020) The Pattern Seekers)

(COVID-19), and NASA are collaborating with Nokia to install 4G on the moon's surface so we can do live streaming when we take our holidays there.

So what was this cognitive revolution in the modern human brain that occurred 100,000 to 70,000 years ago? In my new book *The Pattern Seekers* [2], I argue for

Fig. 9.4 The earliest musical instrument ever found, a flute made from the hollow bone of a bird, dated 40,000 years old. (From Baron-Cohen (2020) The Pattern Seekers)

the evolution of two new circuits in the brain, and surprisingly both seem to have evolved around the same time. One was the *Empathy Circuit*, that enabled a raft of new behaviours, including deception, teaching, self-reflection, advanced social cooperation, social 'chess' and flexible referential communication, including story telling. These explain *why* modern humans could make stealth weapons and jewellery, as we were keeping track of what others might think—using a so-called 'theory of mind', and of what others might know, need to know and believe (including their false beliefs).

The Empathy Circuit recruits a complex network of at least ten brain regions, including the amygdala and the ventromedial prefrontal cortex. It was the subject of my earlier book *Zero Degrees of* Empathy [3] Empathy is also not a single module but has at least two 'fractions': cognitive empathy (also, called Mindreading or theory of mind, and which is defined as the ability to imagine another person's thoughts and feelings) 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 other non-human animals, there is no convincing evidence that other animals can attribute false beliefs to another animal and engage in flexible deception and teaching, for example, unlike even a four-year old modern human child.

And our recent studies using molecular genetics show that empathy and theory of mind show associations with common genetic variants in our genome, combinations of 'single nucleotide polymorphisms' or SNPs that are associated with where each of us falls on what I call the Empathy Bell Curve of individual differences in this ability. Finding that empathy is partly genetic is a clue that it was the result of natural selection and it is easy to see why it might have been highly adaptive—for example, to build traps into which your prey would fall, or to read the mind of your pre-verbal infant to attend to its emotional and physical needs so that it survived to the age of reproduction to pass on your genes.

This was impressive enough, and the Empathy Circuit could 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 by itself the Empathy Circuit cannot explain *how* modern humans were capable of invention. I argue that to fully explain the cognitive revolution in our capacity for generative invention, we also needed a second new brain circuit, the *Systemizing Mechanism.*

The Systemizing Mechanism allowed us to seek new patterns in the world—we became pattern seekers of a new kind. Whereas *Homo habilis, erectus* and *neanderthalis* could see patterns using a learning mechanism that is widespread in the

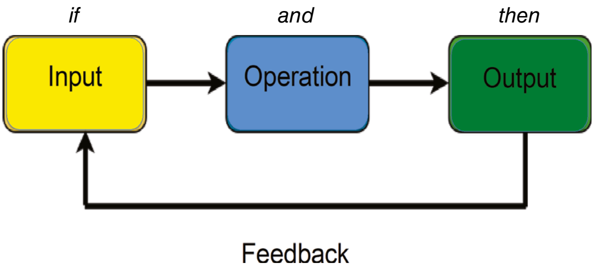

Fig. 9.5 The key steps in systemizing, using the terminology of engineers (input-operation-output) and logicians (if-and-then). (From Baron-Cohen (2020) The Pattern Seekers)

animal kingdom—associative learning—where we can engage in statistical learning of regularities such as A is associated with B (using a hammer to crush a nut is associated with getting the juicy reward, for example), modern humans for the first time from 100,000 to 70,000 years ago were looking for special *if-and-then* patterns (Fig. 9.5). This was a powerful new algorithm in the modern human brain that enabled a new raft of behaviours, all emanating from the capacity for generative invention. So, we could invent music, cooking, medicine, weapons, agriculture, astronomy, sports, business, science, technology, engineering and mathematics (STEM), arts and crafts and even syntax, to name just a few of the benefits of the Systemizing Mechanism.

Humans were looking for *if-and-then* patterns which in engineering terms are 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, and the most interesting of these would be a *causal* operation. And the job of the Systemizing Mechanism was not only to find such *if-and-then* patterns, but to confirm them through repetition, to confirm their truth, where truth is a regularity that is seen over and over again. Critically, generative invention arises from playing with these *if-and-then* patterns, by changing the input (the *if*) or the operation (the *and*) to observe a change in the output (the *then*). Humans had become *experimentalists*, a skill that is still absent in any other living species today and was absent in our Homo ancestors.

I call this the Systemizing Mechanism because the basis of any system is the *if-and-then* pattern, a powerful regularity or law, whether we are talking about a natural system like the weather, a mechanical system like a bow-and-arrow, an abstract system like music or mathematics, a social system like a business or an army unit, a motoric system like throwing a frisbee or skate-boarding or a collectible system like classifying plants and animals into a taxonomy. None of these behaviours are seen in non-human animals today.

I borrow the *if-and-then* algorithm from the nineteenth century logician George Boole whose analysis of how we think logically is credited with the invention of the modern computer, and his analysis overlaps with other logicians such as Venn (of Venn diagram fame). But when you read Boole's important textbook of logic [4], it seems dry, abstract and hard to relate to the uniquely human capacity for invention. For me, seeing the first musical instrument is a much more concrete example of systemising:

If I blow down this hollow bone,
and I cover one hole,
then I make sound A.

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 emanating from an *engine* in the brain that enables invention, explaining why humans alone are attracted to listen to and produce music. And you can see the same exquisite logic underlies the invention of any complex tool, defined as a system that does work for us. For brevity, I'll give you just eight more examples:

1. The invention of **stealth weapons** like the bow-and-arrow that could kill from a distance was based on *if* I attach an arrow to a stretchy fibre, *and* release the tension in the fibre, *then* the arrow will fly.
2. The invention of **mechanical systems** such as how to move a heavy rock (explaining how Stone Henge was built for example) involved *if* I have a heavy stone, *and* I harness it to my ox, *then* the heavy stone will move.
3. The invention of **agriculture** involved logic such as *if* I take a tomato seed, *and* plant it in moist soil, *then* I get a tomato plant.
4. The invention of **mathematics** involved logic such as *if* I take the number 3, *and* I cube it, *then* I get the number 27.
5. The invention of **cooking** involved for example that *if* I take an egg, *and* put it in boiling water for 4 min, *then* the yolk will turn from soft yellow to hard yellow.
6. The invention of **medicine** involved observing that *if* I have a headache, *and* I eat the willow tree bark, *then* my headache goes away.
7. The discovery of **astronomy** involved logic such as *if* the moon looks white, *and* the sun, moon and Earth lie in a straight line, *then* the moon looks red.
8. Even the invention of **public health** involved the same beautiful logic: *if* the infection rate is doubling every week, *and* we don't do lockdown, *then* 50,000 people will die this winter.

Like the Empathy Circuit, there are individual differences in the drive to systemise, giving rise to the Systemizing Bell Curve in the population, and there are common genetic variants that are associated with where each of us falls on this bell curve, whether we are barely interested in if-and-then patterns (though all humans are to some extent), or if we are average in systemising or if we systemise non-stop—so called hyper-systemisers. We know less about the brain basis of systemising but at least one brain region that is involved is the intraparietal sulcus. Whilst the Empathy Circuit has been mapped in exquisite detail using functional magnetic resonance imaging over the last 25 years in the field of social neuroscience, the neuroscience underpinning the Systemizing Mechanism awaits more research.

But the fact that where we fall on the Systemizing Bell Curve is even partly genetic again means that this uniquely human ability was the product of natural selection. It is not difficult to see how hyper-systemisers might have had some adaptive advantages, being the persons you would go to in your tribe when your child was sick, or to fix your gadget, and who could invent new and better ways of doing things, amassing significant resources. And we know from anthropology that fertility is associated with reproductive success—surviving long enough to pass on one's genes.

It is time to turn to autism, but there's one more piece of the argument to lay out, which is the relationship between these two new circuits that I argue explain the cognitive revolution 100,000–70,000 years ago. If we plot the Empathy Bell Curve along the Y axis and the Systemizing Bell Curve along on the X axis, so that we can map every individual according to their difference (D) score, we see some interesting patterns (Fig. 9.6).

In our big data study of 600,000 typical people and 36,000 autistic people, we find all humans fall into just five types of brain (a beautiful demonstration of 'neurodiversity'). There are those whose empathy is at a higher level than the systemising, those I call Type E. They are about 30% of the population, and more females (40%) than males (20%) fall into this group. There are those whose systemising is at a higher level than their empathy, those I call Type S. Again, these comprise about 30% of the population, but this time the on average sex difference is flipped over, more males (40%) than females (20%) falling into this group. There are those who

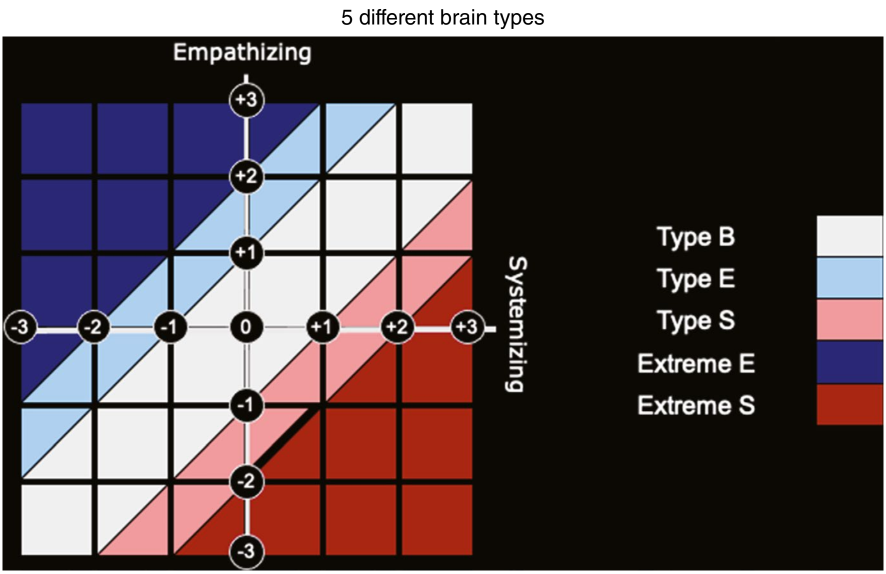

Fig. 9.6 The Empathizing-Systemizing Theory, showing 5 brain types in the population. (From Baron-Cohen (2020) The Pattern Seekers)

show no difference in their drive to empathise or to systemise, being equally good in both, who I call Type B. Again, these comprise about 30% of the population.

And then there are those of us who fall at the extremes [5]: Extreme Type E, whose Empathy Circuit is tuned super high and who empathise non-stop, but their Systemizing Mechanism is tuned to just average levels or below. These comprise about 3% of the population, with more females (4%) than males (1%) falling into this group. And then there are the mirror image, those who are Extreme Type S, whose Systemizing Mechanism is tuned super high and who systemise non-stop, but their Empathy Circuit is tuned to just average levels or below. They also comprise about 3% of the population and the sex ratio is flipped over: more males (4%) than females (2%) fall into this group. I call these the hyper-systemisers, and among these are inventors in history like Thomas Edison, Isaac Newton and Nicholas Tesla, or modern-day inventors like Bill Gates and the musician Glenn Gould. Each of these inventors showed behaviours that suggest they had a higher than average number of autistic traits, even though they did not have or need an autism diagnosis. We will come back to that intriguing connection to autistic traits.

Why are these sex differences seen among the five brain types? A moderate proposal is that this reflects the interplay of prenatal biology (genetics and the prenatal sex steroid hormones such as testosterone and oestrogen, both of which shape brain development in utero during a critical period, and shape behaviour postnatally) interacting with social and cultural influences, such as how we unconsciously may treat our sons and daughters differently through our parenting styles, how teachers may unconsciously interact differently with male and female pupils, how role models influence our interests and aspirations and how the media insidiously influences our behaviour. Our studies of the correlations between prenatal sex steroid hormones such as testosterone levels in the womb and a child's later language development, empathy, systemising and pattern-recognition skills were all laid out in what was the subject of another of my earlier books, *The Essential Difference* [6].

9.3 Autism and Neurodevelopmental Disability

So what is the link—if any—between the human capacity for invention and the neurodevelopmental disability of autism? I have been researching autism for almost 40 years. We found that the 36,000 autistic people in our Brain Types study were also more likely to have a brain of Type S or Extreme Type S—to be systemisers or hyper-systemisers—and that this was true of both autistic men and women. We found that among the 600,000 people in the population we studied who did not have an autism diagnosis, those working in STEM (science, technology, engineering and mathematics) had a higher number of autistic traits than those not working in STEM. In our studies of mathematicians in Cambridge University, we found an elevated rate of diagnosed autism among them in comparison with those in the Humanities or in the general population.

If we look at the question from the other perspective, we find autistic people anecdotally may be 'savants' in systemising. Derek Paravacini has a mental age of a three-year old, is congenitally blind and autistic, but can play any jazz piece on the piano after hearing it just once. Daniel Tammet is autistic and has synaesthesia (a mixing of the senses, and which we found is more common in autistic people than in the general population). He has learnt ten languages because he loves syntactic patterns and memorised the number Pi to 22,514 decimal places. He can also multiply three-digit numbers together faster than a hand calculator.

But anecdotes do not add up to data even if they are important clues that warrant systematic empirical testing. On average, autistic people outperform non-autistic people on tests of pattern recognition and on tests of mechanical reasoning and are over-represented in STEM subjects if they go to university. And this link between autistic traits, autism and systemising appears to be genetic. Among their fathers and grandfathers, we found a disproportionate number end up in the occupation of engineering. Mothers of autistic children are also over-represented in STEM, and both mothers and fathers of autistic children show superior pattern-recognition skills, reflecting 'assortative mating' may be occurring. This led us to predict that autism should be more common in places like Silicon Valley, which we tested in the Dutch city of Eindhoven, the Silicon Valley of the Netherlands. We found that autism was more than twice as high in Eindhoven compared to two other Dutch cities (Utrecht and Haarlem), which have a similar population size and are matched on relevant demographic variables, but which are not information-technology hubs [7].

But to really prove that autism and systemising are linked we conducted a molecular genetic analysis, to test if there was an overlap between the common genetic variants associated with autism and those associated with hyper-systemising. Sure enough, there was [8] The overlap was 26%. Some of the genes for autism are not just coding for autism but for talent at systemising. We had nailed the link.

9.4 Discussion

Autistic people have been marginalised, stigmatised and excluded by modern society because of their social disability. We found 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 [9]. Poor mental health is not part of autism but I argue it is a sign of lack of support and inclusion into society. Unemployment levels of autistic adults are unacceptably high, and we know that in anyone, unemployment is bad for your mental health. It robs you of feeling you have a purpose in life, it makes you feel excluded from society, that you are not valued, and it robs you of your economic autonomy and independence.

9.5 Conclusion

It is time to respect and celebrate autistic people's difference that their brain types are just one of the five forms of neurodiversity we find in any population and that their brains and genes have driven the evolution of human invention, for

70,000–100,000 years. It's time to support them into work, both for their own well-being, for societal productivity and a civic duty towards anyone with a disability, and to maximise the likelihood of future human innovation.

Key Points

- Biologically evolved autistic traits have contributed significantly to the unique capacity for inventiveness of *Homo sapiens* and, therefore, the shaping of science, technology and societies, including contemporary ones.
- Autistic traits can be divided into low empathising and high systematising dimensions and these two are genetically dissociable. Some of the genes for autism are not just coding for autism but for talent at systemising.
- Autistic people outperform non-autistic people on tests of pattern recognition and on tests of mechanical reasoning and are over-represented in STEM (Science, Technology, Engineering and Medicine) subjects if they go to university. And this link between autistic traits, autism and systemising appears to be genetic.
- The disability arising from autistic traits is determined through social exclusion, to which low empathising traits may contribute, rather than exclusively from the inherently biological traits as such and there is a need to address this and ensure equitable inclusion.
- Though there are genetic determinants of autistic traits which contribute to contemporary diagnostic practice in relation to autism, such practice presents fundamental challenges to Emil Kraepelin's concept of mental health conditions understood as disease entities of the natural kind.

References

1. Harari Y. Sapiens. Random House Harper; 2014.
2. Baron-Cohen S. The pattern seekers: a new theory of human invention. Penguin; 2022. ISBN-13 978-0141982397
3. Baron-Cohen S. Zero degrees of empathy: a new understanding of cruelty and kindness; 2012.
4. George Boole, The mathematical analysis of logic, being an essay towards a calculus of deductive reasoning archived 11 May 2016 at the Wayback Machine (London, UK: Macmillan, Barclay, & Macmillan, 1847).
5. Greenberg DM, et al. Testing the Empathizing-Systemizing theory of sex differences and the Extreme Male Brain theory of autism in half a million people. Proc Natl Acad Sci U S A. 2018;115:12152–7.
6. Baron-Cohen S. The essential difference. Men, women and the extreme male brain. Penguin; 2012. ISBN 978-0-241-96135-3
7. Roelfsema MT, Hoekstra RA, Allison C, et al. Are autism spectrum conditions more prevalent in an information-technology region? A school-based study of three regions in The Netherlands. J Autism Dev Disord. 2012;42:734–9. https://doi.org/10.1007/s10803-011-1302-1.
8. Warrier V, Toro R, Won H, Leblond CS, Cliquet F, Delorme R, De Witte W, Bralten J, Chakrabarti B, Børglum AD, Grove J, Poelmans G, Hinds DA, Bourgeron T, Baron-Cohen S. Social and non-social autism symptoms and trait domains are genetically dissociable. Commun Biol. 2019;2:328. https://doi.org/10.1038/s42003-019-0558-4. eCollection 2019

9. Hossain MM, Khan N, Sultana A, Ma P, McKyer ELJ, Ahmed HU, Purohit N. Prevalence of comorbid psychiatric disorders among people with autism spectrum disorder: an umbrella review of systematic reviews and meta-analyses. Psychiatry Res. 2020;287:112922. https://doi.org/10.1016/j.psychres.2020.112922. Epub 2020 Mar 18