

unprofessional, and I make fun of the situation on Twitter all the time. I am convinced that the current publishing model needs to change and that there are major issues with pre-publication peer review. Traditional peer review slows down the dissemination of knowledge, makes us unhappy, and can be biased as well as unfair. This makes the editors' work extremely important and difficult. I think that anonymity brings out the beast in people and facilitates unethical behavior (e.g., blocking of competitors). Revealing the reviewers' identities is not a good option either because it could lead to retaliation. We need another solution altogether.

**What's the role of journals and what do you think about post-publication peer review of papers?** I think that the solution is for peer review to happen post-publication. After this evolution, the journals' role would be to curate, choose the papers that they want, and compete over the best studies (I'm not even calling these papers 'pre-prints': they are manuscripts to me). The journals would choose what papers they want based on different methods of assessment. For example, one journal might employ expert reviewers (scientists specializing in that field), while another journal might employ professional reviewers or summarize comments posted online. Another journal might publish critical commentaries on the papers that they choose to publish (this happened during the early days of peer review). There would be many solutions. Maybe futuristic AI would advance to a point where it could help. Who knows? Some journals might ask you to revise your paper based on the post-publication peer review that they conducted, while others might publish the papers that they choose as is. I believe that, if journals acted as curators, there would still be 'prestigious' and 'less-prestigious' publishers, as a difference in standard is something that we unfortunately still need for assessment (there are too many papers and not enough experts or time — of course, it would be better if committees read all the candidates' papers). A journal's prestige would be determined by its circulation, how it curates, and how it improves the work (the quality of the editors and how they edit the paper). It would be a revolution with dramatic effects on our quality of life.

**What do you think is the role of social media in shaping science?** Mostly I use Twitter to tell stupid jokes about life in academia, but I also enjoy it because I learn a lot from the people I follow. My sci-Twitter community is very progressive and makes me optimistic about the future of science. Diversity, fairness, replicability, openness, collaborations, work-life balance, and the publishing world get center stage, and I discover something new every day about how scientists think, at every career stage (with the limitation that it's an echo chamber). Twitter revolutionized the dissemination of scientific knowledge, for example, I don't know whether bioRxiv would have been so successful otherwise. Recently, I organized a conference for scientists who know each other only through Twitter. I called it 'The Physiologically Irrelevant Conference', but it was also dubbed (by others) as 'The Woodstock of Biology' because it had a counterculture and freedom-from-social-conventions vibe (perhaps similarly to the original Woodstock). It was a big party/show: every speaker had a walk-up song and the schedule was randomized (so you couldn't go to get coffee — it might be your turn to speak). Each participant had just one slide and 5–10 minutes, and there was a giant screen that showed in real time the reactions of people on Twitter to what was being discussed. People on Twitter had hilarious comments; you can read them at #physiologicalirrelevantconference. It was unbelievably interdisciplinary, and only unpublished materials were discussed. I think it embodied the spirit of sci-Twitter and attracted scientists who don't take themselves very seriously (even though many participants were extremely established). It was tremendous fun and people really got into it. Many attendees wrote that it gave them hope and transformed the way that they see scientific meetings.

**So, what's the physiological relevance?** I don't know, I'm still working on the mechanism.

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## My Word

# Searching for the neural correlates of human intelligence

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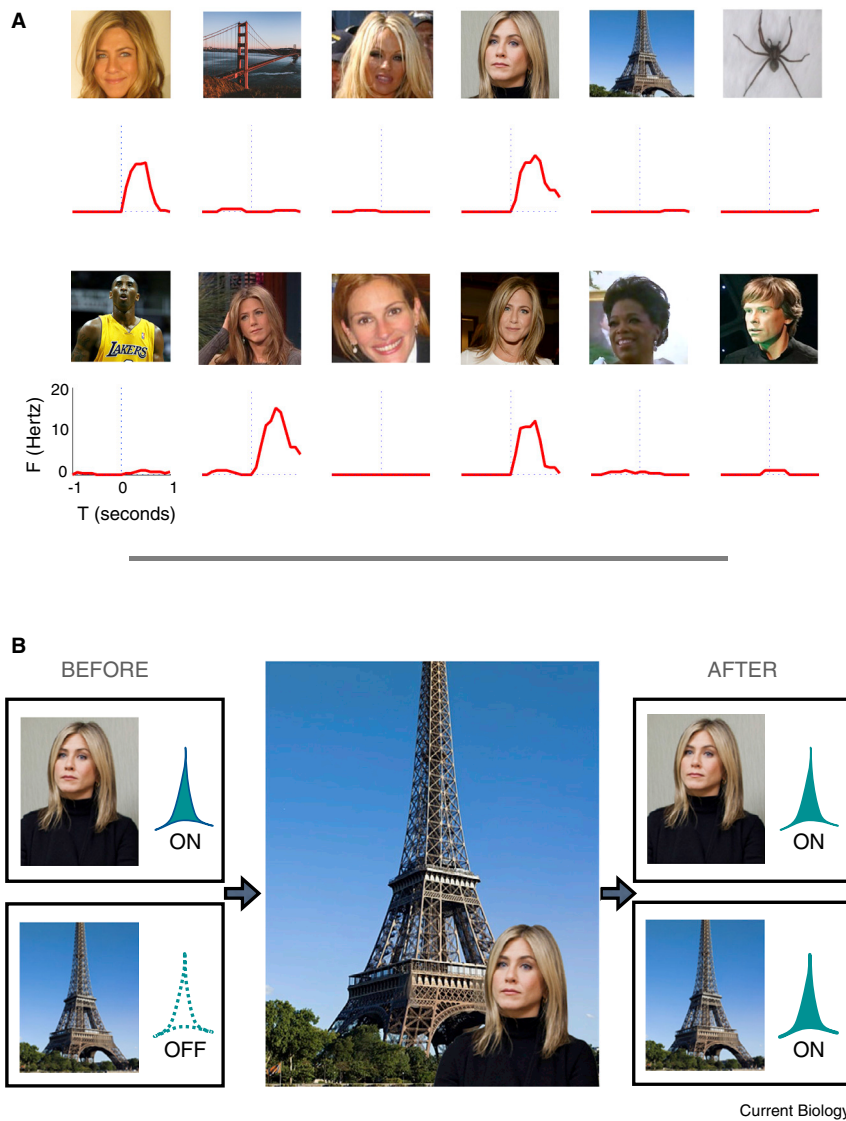
On a clear night in the savannah, a chimpanzee may look up and wonder about the bright spots in the sky. Chimps are very clever. They have different calls with which they can somehow communicate with each other; they can use and even shape simple tools to fish for termites or crack nuts. But only we, humans, polish glasses to form lenses that we arrange in very precise configurations to stare at the stars. Only we use an exquisitely refined language to share knowledge about the Universe, theorize about its physical laws and origins in a Big Bang, and even wonder about our place within it. Chimps are very clever, no doubt, but there is a huge gap between their cognitive abilities and ours. Why?

## More than numbers

There is a vast literature describing cognitive differences with other species. Humans have language, imagination, an unmatched creativity, nested thoughts, culture, and so on (for an excellent overview see [1]). But let us go beyond behavioural comparisons and seek for more mechanistic insights, asking what in our brain gives rise to these unique abilities.

Insects are capable of very complex behaviours [2], but nothing close to the vast repertoire of human cognitive functions. If you compare the number of neurons in a human and a fly, for example, the reason seems obvious — with a quarter of a million neurons, the fly is no match to the 86 billion neurons in our brain [3]. But if you now consider a chimp, it is a different story because the chimp's brain is about one third the size of ours. This is comparable (just a bit smaller) to the difference between the chimp's brain and that of a macaque monkey — the primate species that is





**Figure 1. Coding of concepts and associations in the human hippocampal formation.**

(A) A neuron in the hippocampus of a patient that responded selectively to different pictures of Jennifer Aniston. The lines show the average of six presentations of each picture, shown for 1 second, starting at time zero. The neuron also responded to another three pictures of Aniston and did not respond to about 80 pictures of other persons (not shown due to space limitations). (B) Neurons in the hippocampus initially responding to a person, for example Jennifer Aniston, began to respond to an associated place, for example the Eiffel Tower, once the patients learnt the association between the two concepts, after seeing the person in the place. Due to copyright issues, the pictures were replaced by similar copyright-free pictures of the same persons. Luke Skywalker image from Mirko Toller (CC BY 2.0); Golden Gate Bridge image from soomness (CC BY 2.0); Eiffel Tower image from Julie Anne Workman (CC BY-SA 3.0); spider image from David Short (CC BY 2.0); Jennifer Aniston images from Dave Matthews (CC BY-SA 2.0), Walt Disney Television (CC BY-ND 2.0) and Andres Useche (CC BY-SA 2.0).

typically used in lab experiments — and although chimps are clearly more intelligent than macaques, there is nothing like the huge gap between chimps and ourselves. So, number of neurons (or number of neurons in a specific area) cannot be the only

difference. There has to be something more.

To further illustrate this point, take a neural network performing some task. Now consider another one that is three times larger. You would not expect to see such a massive

difference in performance as the one you see between humans and chimps — with the larger network proving theorems and solving integrals, and the smaller one hardly able to count. You could still argue that a large difference might be enforced by how the networks are trained or other implementation details. But that is exactly the point. The networks are not different just because of their size, but rather by how they work.

Back to our problem. There is a comparable number (and type) of neurons in the chimp and the human brain, and both species have more or less the same anatomical structures. Therefore, our neurons, or at least some of them, must be doing something different, and one such difference is given by how they store our memories.

### Our coding of memories — with a Hollywood twist

Some patients suffering from epilepsy cannot be treated with medication and are candidates for a surgical procedure in which the epileptic focus is removed. Before this surgery, intracranial electrodes may be implanted to accurately localize the epileptogenic area, which allow us to record the activity of dozens of individual neurons while the patients perform different tasks [4]. In one of these cases, we showed the patient images of different people, places, animals and objects, and found a neuron firing selectively to completely different pictures of Jennifer Aniston (Figure 1A) [5]. So, the neuron did not fire to one or another picture, but to her: to the concept ‘Jennifer Aniston’. Similarly, another neuron fired to pictures of Halle Berry, another to Oprah Winfrey, and yet another to Luke Skywalker — the cells even responding to the written and spoken names of their target subjects and not to other names [6].

These neurons, which we named ‘Concept Cells’, are located in the hippocampus and surrounding cortex, an area that it is typically involved in epilepsy — and is therefore targeted with the intracranial electrodes — and that is also critical for episodic memory, the memory of our lifetime

experiences [7]. This has been clearly established from the study of Henry Molaison (the famous patient H.M.), who had his hippocampus surgically removed and subsequently couldn't form or retrieve episodic memories [8]. But why do we have neurons firing to specific concepts in a memory area? Because that's the way we store our memories. We tend to remember concepts and associations between them and to forget irrelevant details — so, we'll recall seeing pictures of Jennifer Aniston at the hospital ward, for instance, but won't remember details of the specific images.

To show that Concept Cells are indeed involved in memory, we designed a simple experiment. First, in a 'screening session' we showed about 100 pictures and determined which pictures (typically of famous persons) triggered a response in any of the recorded neurons. Then, we created an association between the persons to which the neurons initially fired and arbitrary places. Say we had a neuron firing to Jennifer Aniston; we then showed a picture of her in the Eiffel Tower (created using Photoshop) and found that the neuron started firing to the Eiffel Tower as well, without Aniston needing to be in the picture (Figure 1B), at the exact moment the patient learned the association [9] — a proxy of the episodic memory of remembering seeing her in the Eiffel Tower. Furthermore, we found that in a passive viewing task (during the screening sessions) Concept Cells tend to respond to items that are related for the patients, thus providing a long-term coding of meaningful associations that supports episodic memory [10]. For example, the neuron initially firing to Jennifer Aniston also responded to Lisa Kudrow, a co-star of the TV series 'Friends' (but not to other actors of the same TV series), when tested again the next day, including more persons related to Aniston.

### Are concept cells uniquely human?

Neurons like Concept Cells, firing in such a selective and abstract manner to specific persons/concepts, have so far not been found in other species. The closest to Concept Cells

seem to be neurons in the anterior medial face patch in the monkey temporal lobe, which respond selectively to relatively few faces [11]. A recent study [12], however, showed that these neurons do not actually code for specific individuals, but rather respond to complex visual features. In another study [13], now in the monkey hippocampus, researchers analysed responses to familiar faces — for example, faces of other monkeys in the colony, and so on — replicating the protocol used to find Concept Cells in humans, but did not find neurons with such a degree of selectivity and abstraction. Yet another study [14] focused on hippocampal responses in rats while the animals interacted with conspecifics — as a proxy of the response a human has when seeing a familiar person — and found that no cell responded selectively to individual rats.

It could still be argued that more experiments are needed to establish whether, and to what extent, a neural representation like the one by Concept Cells exists in other species. More such experiments would certainly be very useful to have good quantitative comparisons across species. But the argument that Concept Cells may be exclusively human is not just based on absence of evidence, because, in rats and monkeys, very strong neuronal responses are found in the same area but with a different type of coding: responses tend to change when altering the context or the task performed by the animals, whereas with Concept Cells they do not. For example, neurons in the rat hippocampus fire at specific locations of the environment [15]. The locations to which these 'Place Cells' fire can be also seen as concepts, which are very salient for rats, to know their precise location and routes to reach safety. The key difference, however, is that Place Cells change their responses after even slight modifications of the environment or the task [16,17]. Similarly, other studies have shown context and task modulation of hippocampal responses in monkeys [18,19]. In contrast, Concept Cells fire to a particular concept

in completely different situations: irrespective of whether the subject is passively looking at a picture of a person, seeing morphed versions of it in a recognition task, recalling its presentation from memory, or learning associations, as in the experiment described above, where the person to which the neuron fired was shown on their own or in a specific location.

### Beyond memory

Memories shape our thoughts and the way we store them should no doubt have an impact on our cognitive abilities. What, then, are the implications of a coding scheme like the one by Concept Cells in humans?

An obvious advantage is that with such context-independent representation it is trivial to generalize, to make analogies and transfer knowledge, as the same neuronal representation of concepts applies to different situations. This contrasts with the difficulty that rats have in performing the same tasks when the environment or overall context is altered, given the change in the neuronal representation. An explicit and abstract representation, devoid of meaningless details and context, also facilitates rapidly establishing associations between disparate concepts, which is the basis of our imagination and creativity — for example, to realize that two disparate things, like an apple falling from the tree and the moon orbiting around the Earth, respond to the same phenomenon: the law of gravity. But to make these associations we need to leave aside meaningless details; it doesn't matter if the apple is big or small, red or green, or if the moon is crescent, in its zenith, and so on.

Abstract representations, such as the ones provided by Concept Cells, are ideal for generalisations and for building nested and elaborated thoughts — to go beyond the particular things present in our immediate surroundings and think about thoughts, about concepts and their relationships. This is the basis of the unique workings of our brain, perhaps a key component of our intelligence and what distinguishes us from other species.



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## Quick guide

## The island syndrome

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**What is the island syndrome?**

Organisms on islands predictably differ from their continental counterparts in a host of ecological, behavioural, and morphological traits. Together, the differences are referred to as the ‘island syndrome’. The phenomenon has been described in a wide variety of animal and plant species (Figure 1).

**Can you give examples of such traits?**

The life-span of animals from island populations tend to be longer than those of mainland relatives. This is one of several recurrent life-history changes observed in island organisms. Reduced fecundity is a second — island animals typically produce smaller clutches or litters, funneling their reproductive effort into fewer, but larger, and more competitive offspring.

**What about body size?** Some island animals are larger than their mainland relatives, others are not. Rodents, iguanas, geckos, monitor lizards, tortoises and most species of bird tend to grow larger on islands. Spectacular examples of this tendency towards ‘island gigantism’ include the giant tortoises of the Galápagos and the Seychelles archipelago (*Chelonoidis*, *Aldabrachelys*; Figure 1), Saint Martin’s giant hutias (*Amblyrhiza inuncta*), and the giant earwig of Saint Helena (*Labidura herculeana*). In contrast, hippopotamuses, elephants, rabbits, deer, pigs, foxes, raccoons, snakes show the opposite tendency: the miniature hippopotamuses (*Hippopotamus creutzburgi*) and elephants (*Mammuthus creticus*) of Pleistocene Crete represent extreme cases of dwarfism. In addition to being larger, or smaller, than their mainland counterparts, island animals often also differ in body shape and colouration. A common theme in island evolution is the reduction of body parts implicated in locomotion (Figure 1). The wings of several species of weevils (Curculionidae), rails (Rallidae), and

pigeons (Columbidae, such as the dodo, *Raphus cucullatus*), for instance, have shrunk to the extent that the animals have lost their ability to fly. In several species of lizard and snake, island populations exhibit an increased incidence of melanism (Figure 1). The colours of island birds tend to be less bright and less intense.

**Do island animals behave differently?**

Island mammals, birds and lizards tend to be less territorial and more tame. For instance, in comparison to their mainland conspecifics, deer mice (*Peromyscus maniculatus*), song sparrows (*Melospiza melodia*) and bronze anoles (*Anolis aeneus*) all have smaller, more overlapping territories and are more tolerant towards intruders. Falkland Island foxes (*Dusicyon australis*) and tammar wallabies (*Macropus eugenii*) from Kangaroo Island have lost their natural fear of large predators, including humans, a phenomenon called ‘island tameness’.

**What is driving the island syndrome?**

Compared to their mainland counterparts, island biota are exposed to a predictably different set of environmental conditions. Due to small size and remoteness, islands tend to house fewer species. Especially, the paucity of larger predators turn islands into safe havens, where prey species can afford to be slower or less wary. The scarcity of competitor species allows island species to expand their ecological niche. Islands often also enjoy relatively mild, predictable climates. Combined, these favourable environmental conditions allow island populations to reach higher, more stable densities, a phenomenon called ‘density compensation’. This may shift the balance of interspecific versus intraspecific competition towards the latter, prompting changes in morphology, behaviour and life-history characteristics. Along these lines, many of the features typical for island populations are thought to be adaptive, resulting from natural selection or plasticity responses goaded by the insular environment. However, some of the more unique and eccentric characteristics of creatures found on islands may be coincidental, products of genetic drift.

