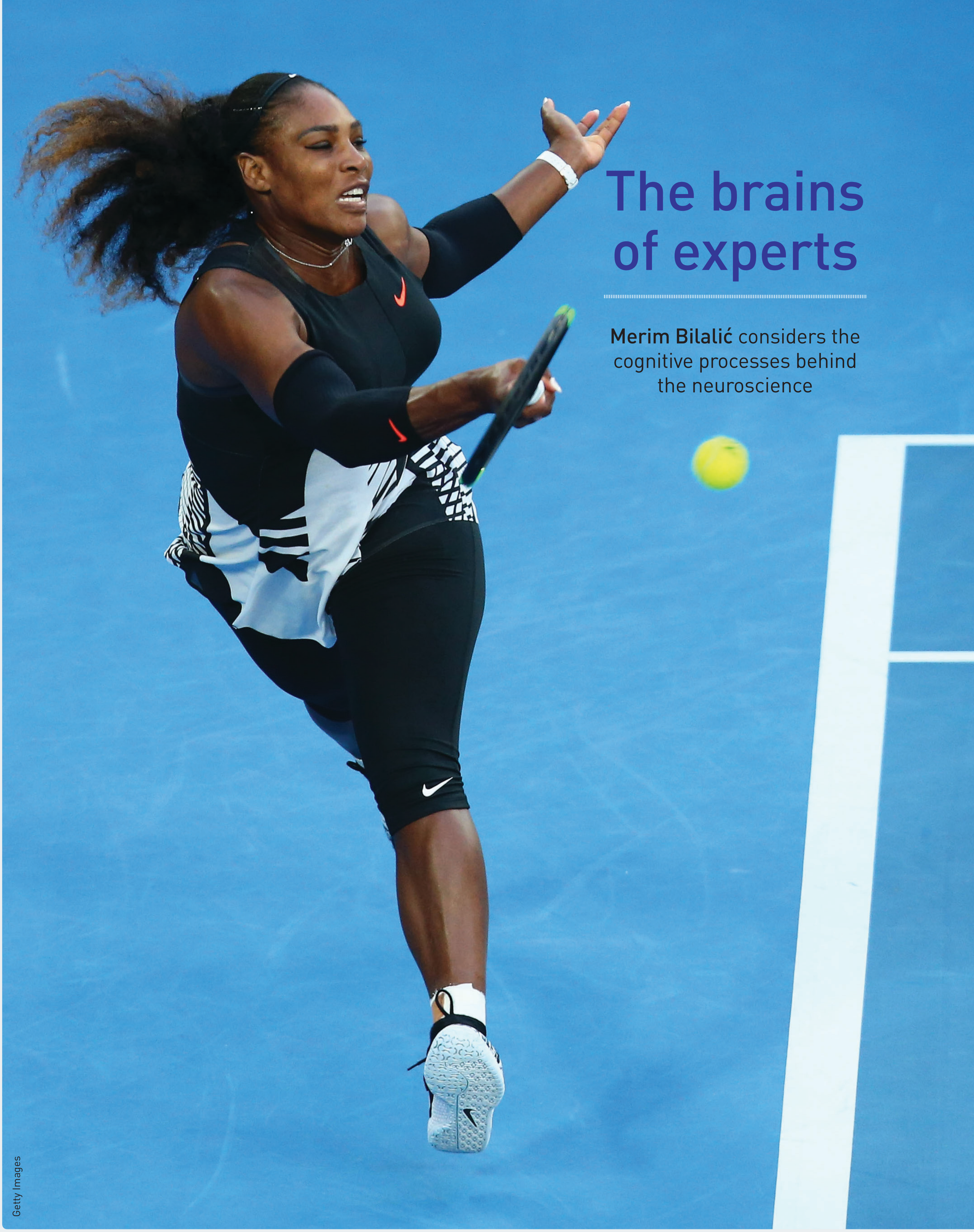

The brains of experts

Merim Bilalić considers the cognitive processes behind the neuroscience

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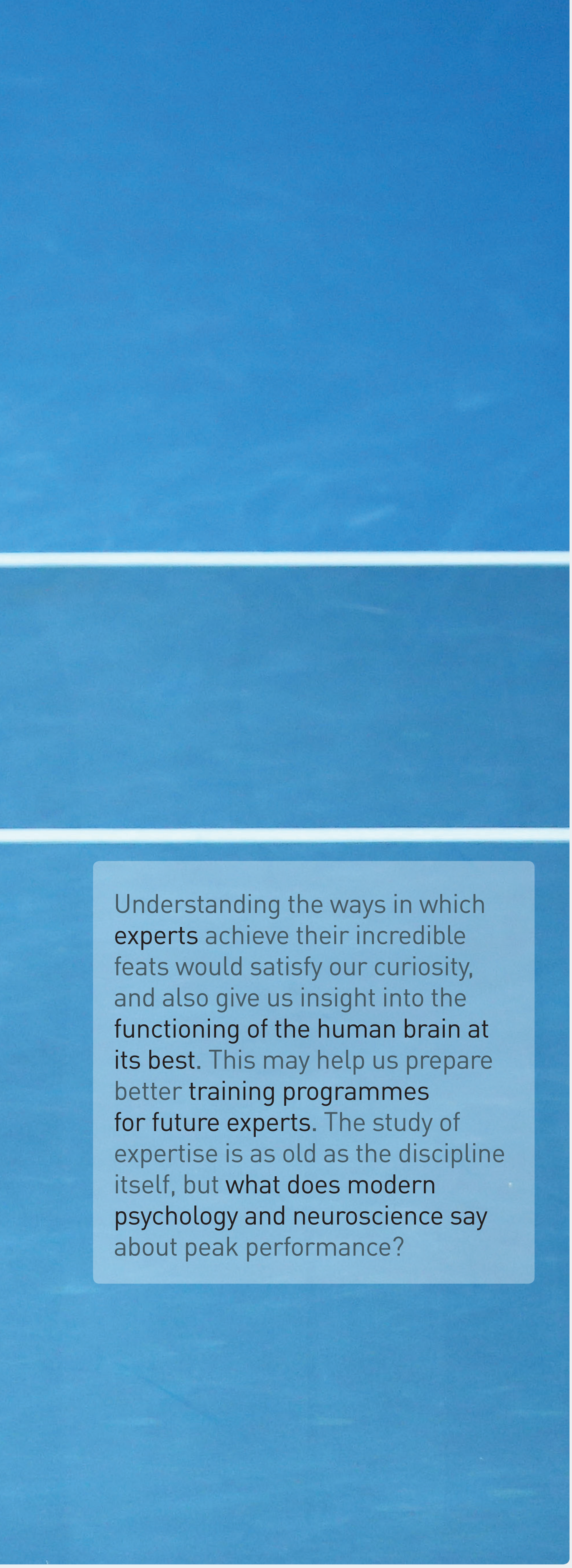

Understanding the ways in which experts achieve their incredible feats would satisfy our curiosity, and also give us insight into the functioning of the human brain at its best. This may help us prepare better training programmes for future experts. The study of expertise is as old as the discipline itself, but what does modern psychology and neuroscience say about peak performance?

Watching the best experts can leave you struggling to come to grips with what you have just seen. Consider the ease with which Serena Williams, who has already won 23 Grand Slam titles, returns the fastest tennis serves. Or how the current world chess champion, Norwegian Magnus Carlsen, takes on and demolishes a dozen opponents simultaneously while blindfolded, in a game where there are more possible combinations of moves than atoms in the universe, and even the most powerful computer would need an eternity to go through all the possibilities. You would be forgiven for thinking that some kind of trick or magic is involved.

You do not even have to look for the very best experts; a trip to your local radiologist, who takes only a split second to realise that all is fine with the X-rays of your lungs, should suffice. After all, radiological images are so complex that it is almost impossible for an untrained eye to spot suspicious tissue, especially with a single glance.

It's human nature to seek to understand such feats, so it should not surprise us that the scientific study of expertise is as old as the science of psychology itself. Beginning with Alfred Binet's work on how chess masters play games without sight of the board, expertise has become an established part of any curriculum or textbook in cognitive psychology. Here I will summarise the main findings from the emerging subfield of expertise research, the neuroscience of expertise, which deals with the way the brain accommodates experts' outstanding performance.

Different kind of experts, same cognitive mechanisms

Given the near impossibility of experts' feats, it seems plausible to expect some outstanding basic abilities, if not supernatural powers. Unfortunately for comic book fans, the reality seems different. Athletes do not necessarily react faster than other people of the same age; chess experts' ability to plan and pick the right strategies disappears when away from the chessboard; and radiologists are no better than you would be when they have to look for Wally instead of pathological tissues. Yet they remain vastly superior in their chosen domains.

To understand the working of experts' brains, it might help to look at situations where most people are everyday experts. Most of us can immediately realise upon entering a room what kind of room it is. We will also have no problem in finding a light switch, should the lights suddenly turn off. Since we have encountered numerous versions of various rooms, we know what kinds of objects to expect in certain rooms, as well as how those objects relate to each other. We will certainly not look for the light switch on the floor or the ceiling, nor would we expect to find a bed in an office. People who lack such 'room-knowledge', such as small children, will have a much harder time orienting themselves in rooms. Only through years of exposure to rooms with all their contents and different variations – through remembering, explicitly or implicitly, things that occur together in the environment – will they be able to reach a high level of proficiency even in such a routine everyday task.

We find a similar situation with experts. Through years of exposure, experts have acquired knowledge about consistencies in their domain. Complex domains, such as radiology, chess or sport, obviously take more time to master than our everyday example of rooms. However, all these domains feature 'rules' that are stable as well as situations that arise again and again in one form or another.

This knowledge, the information about the main features of the domain and the relations between them, is stored in memory. Once experts encounter a seemingly new situation in their domain, they will automatically activate the previously stored domain-specific knowledge. The consequence of this automatic matching of patterns in the outside world and in the memory is that experts quickly grasp the essence of the new situation. Their memory has accumulated not only similar combinations of details to the one at hand, but also ways of dealing with such situations. These methods are automatically retrieved and help to focus on the important aspects and ignore the irrelevant ones.

Experts, then, do not need extraordinary abilities to comprehend the complex situations they face. Their knowledge enables them to look for the 'light switch' in the right place.

Stored patterns of abnormalities, which recur in radiological images, often allow experienced radiologists to spot that something is amiss even when they are allowed just a single glance at the image. This initial impression also leads to highly efficient searching – radiologists often zoom in on the suspicious tissue immediately, unlike residents at the beginning of their training who have to check the whole image to identify the elements of interest. Chess experts do not necessarily look further ahead than their less skilled colleagues; rather, their vast knowledge enables them to quickly identify promising paths. It might be too late to react even for the fastest among us when the tennis ball is in the air, but those who have enough experience would be able to tell the trajectory of the ball well before it is in the air. The positioning and movements of feet, knees, shoulders and the serving hand in tennis give away clues about the direction and power of a tennis serve.

Experts, then, may not possess extraordinary abilities, but their knowledge is akin to a flashlight that is used to find the right path in a complex and seemingly badly lit environment. Novices, lacking such a tool, have no other strategy but to slowly and carefully feel their way forward in hope they will eventually stumble on the right solution (see Figure 1).

The universal expertise mechanism

The influence of knowledge is also evident in the way the brain accommodates the described cognitive machinery. Radiologists' knowledge is visual in nature and it engages the brain areas responsible for dealing with visual information. There are no differences between experienced radiologists and medical students in the early visual areas in the occipital cortex, which process stimuli for basic visual characteristics such as shape and size. The later visual areas in the inferotemporal cortex deal with complex visual patterns, such as words and faces. In particular, the fusiform gyrus (FG), a spindle-shaped area at the bottom of the brain, is more activated in radiologists when they look at radiological images. The activated part of the FG is responsible for holistic processing, a process whereby a complex stimulus, usually formed of several parts, is perceived as a single unit. Faces would be a prime example of such holistic perception, as we do not really notice the individual parts of the face, but rather process the face as a whole. The same seems to be the case with radiological images, which, like faces, are made up of variable elements situated in fixed locations.

Chess positions are also visual stimuli, but unlike radiological images, chess objects in chess positions need to be mentally manipulated. Players need to simulate how the situation will look at some time in the future. This means that besides the aforementioned FG, chess experts activate the neighbouring area important for scene perception, the parahippocampal gyrus, as well as the brain parts specialised for navigation, the retrosplenial cortex. These two brain areas are responsible for quick orientation within a chess position, as they are highly active in expert players while being only sporadically engaged in

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novices, who lack knowledge about chess constellations.

The fact that the human brain possesses neural mechanisms for dealing with stimuli, which are both new (on an evolutionary timescale) and artificial (not occurring in the 'natural' environment), such as radiological images and chess positions, is a testament to its adaptability and plasticity. We find a similar situation in sports, where sequences of movements similar to those of everyday life are of crucial importance. The central areas responsible for the initiation of movements are also engaged when experts observe the movements of other athletes. With the help of prefrontal and parietal regions, which are believed to simulate the outcome of the movements observed in the central areas, tennis experts, and other sporting experts, foresee what is going to happen. This anticipation skill, powered by the brain areas aptly named the action observation network, is the reason why the very best athletes regularly give the impression of having all the time in the world in an environment where split-second responses decide between success and failure.

Double-take of expertise

As we have seen, different domains require vastly different brain areas, whether it is inferotemporal areas in radiology and chess, or parietal and central regions in sports. The underlying principle, however, is the same, because the brain has differently specialised neural mechanisms for dealing with different kinds of information. All experts nevertheless use domain-relevant knowledge to achieve their outstanding performance.

Another neural signature of expertise is that the network of brain areas that experts engage is larger than that of novices. This is in contrast to a widespread belief, among not only laypeople but also other researchers, that the reduction of neuronal activity, often taken as an index of neural efficiency, is a hallmark of expertise. The reduction in neuronal activity makes sense given that experts' performance is mostly effortless, based on automated and parallel processes. This may indeed be the case with fronto-parietal areas that are important for executive functions. What is often forgotten is that these processes require domain-specific knowledge in order to function efficiently. Experts' performances may look effortless, but there is complex cognitive machinery behind them that requires the support of a number of brain areas. The activation and manipulation of all the necessary knowledge unavoidably leads to neural expansion in the areas that are associated with that knowledge. Novices, on the other hand, lack the necessary knowledge and cannot rely on those complex but efficient knowledge-based strategies. Their performance may look cumbersome and effortful, but it is only because it relies on crude strategies that do not require that much in the way of neural reserves.

One way in which the brain deals with increased demand from experts' strategies is greater activation within a single brain area, usually one that is important for the neural mechanism necessary for the task at hand. Often the same areas in the opposite hemisphere

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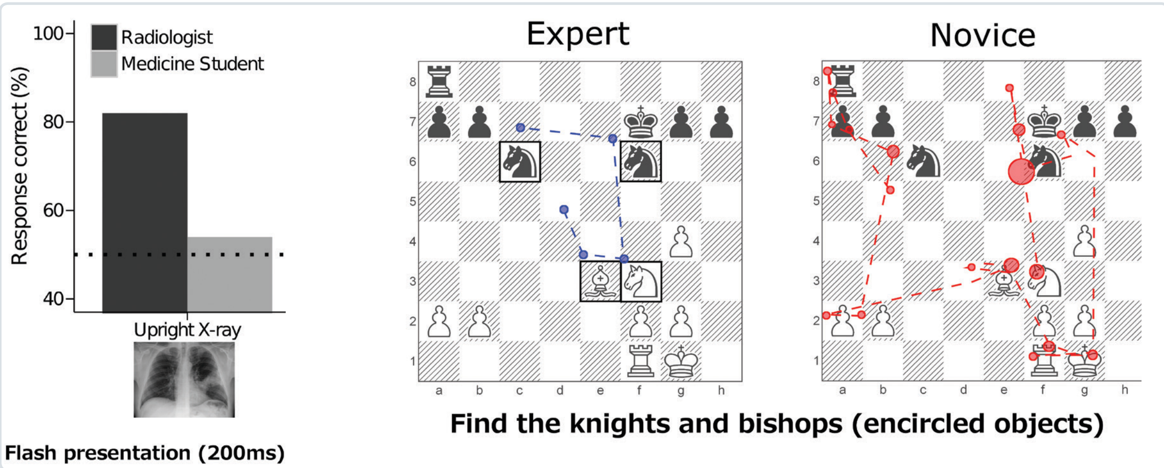

Figure 1. The global impression in radiology and experts' efficient search in chess based on the first impression. When presented with chest X-rays for a very short time that precludes deliberate search, radiologists are still able to identify a large number of pathologies (dotted line, 50 per cent, is chance level). Expert chess players do not need to search the whole board to identify certain objects like novices, but instead focus immediately on the important aspects in the environment.

of the brain also become engaged in experts. This is not only the case in the expertise domains we have discussed so far, but also in other fields, such as mental calculations, abacus calculation and mathematics. Most likely, the engagement of the additional areas in the opposite hemisphere, dubbed the 'double-take of expertise', is related to the complexity of strategies employed by experts. We know that most tasks recruit brain areas in one hemisphere. Only when the task becomes difficult and the brain needs additional resources does it recruit additional areas. These supplementary areas regularly happen to be the same areas as previously employed, but in the opposite hemisphere. The sharing of the computational burden between both hemispheres may support the parallel processes so common and essential in experts' performance.

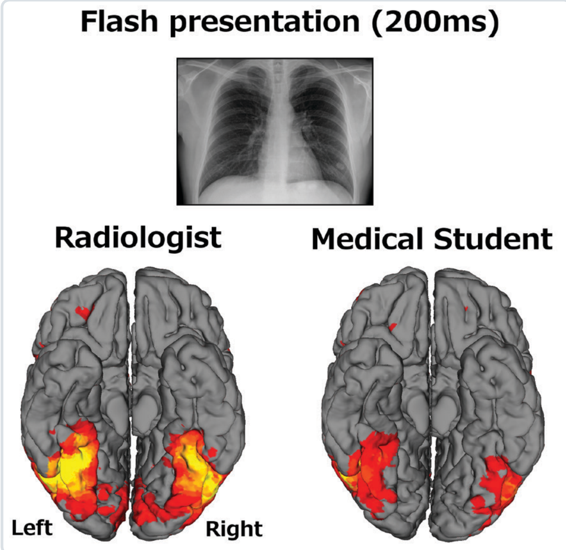

Figure 2. The double-take of expertise. Radiologists activate both fusiform gyri when they deal with briefly presented chest X-rays, unlike medical students who engage only single hemisphere.

Transfer of skill

The performance of Serena Williams is in many respects exactly the opposite of the performance of Magnus Carlsen. Being physically fit is certainly not a bad idea in chess where games can last up to six hours, but it is not going to propel you to the elite (unless you are taking part in the newly established sport of chess-boxing). Similarly, looking ahead and calculating your opponent's moves, even if they are physical movements, won't win you many points in tennis. At first sight, the performances of experienced radiologists, chess grandmasters and professional athletes have little in common, save only their exceptionality. Even the brain areas that they engage to support their outstanding performance are different. Yet, all experts, without exception, employ the numerous patterns from their domain to circumvent inherent cognitive and neural limitations.

This is also the reason why there is limited transfer between domains. Most people would agree that Magnus Carlsen would probably not be a good tennis player just because he is an amazing chess player. Similarly, it is difficult to imagine that Serena Williams could transfer her considerable tennis skills to the chessboard. However, even if we take more similar domains, transfer is questionable. It is a fair guess that neither Serena nor Magnus would be outstanding at another racket sport, badminton, and another board game, Go, respectively. Tennis and badminton are similar, but the seemingly small differences, such as the weight of the racket and the size of the court, add up to vastly different game situations. All the patterns and sequences of movements and moves stored in Serena's and Magnus' memories are of little use in badminton and Go.

The fact that natural talent is no substitute for experience was clearly on display back in August, when a mixed martial arts (MMA) fighter, Connor McGregor, took on one of the best boxers of recent years, Floyd Mayweather Jr, in a boxing match. Even though boxing constitutes only a small skill set in MMA, where striking and grappling with both hands and legs, both while standing and on the ground, is allowed, at least some people believed that McGregor's speed, athleticism and youth could erase the advantage of accumulated knowledge acquired through years of experience. McGregor was not completely embarrassed, but proved to be without a prayer in a one-sided beat down.

Conclusion

I hope it is clear that we cannot understand the neural basis of expertise if we do not take into account the cognitive processes behind the phenomenon. Traditional research on expertise demonstrates how basic cognitive processes, such as memory, attention and perception, come together to enable experts' outstanding performance. It tells us why some athletes appear to have all the time in the world in domains where everything changes and moves quickly, why chess grandmasters can foresee the future without really looking more than a couple of moves ahead, and why radiologists need just a split second to realise that something is amiss in a radiological image. Somewhat disappointingly, there are no superpowers, but the beauty of expertise lies exactly in the way that experts nevertheless circumvent their limited cognition to pull off their amazing feats. The end product of expertise may look mesmerisingly simple, even effortless, but the process requires a complex interplay between basic cognitive processes to make it work. That our brain is able to accommodate such complex machinery is a testament to its incredible adaptability.

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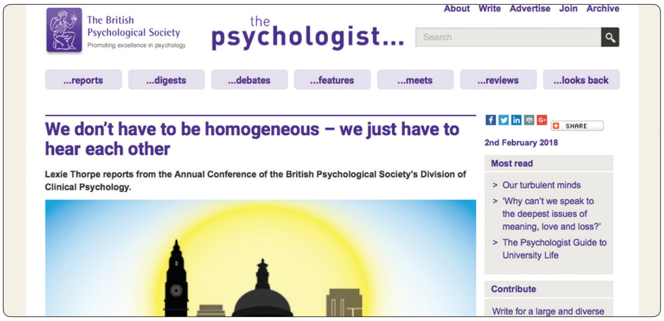

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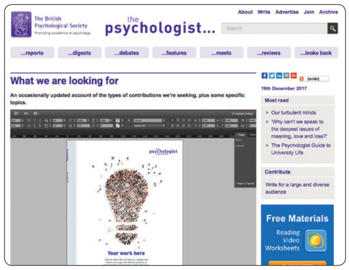

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