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# The Double Take of Expertise: Neural Expansion Is Associated With Outstanding Performance

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**Abstract**
The performance of experts seems almost effortless. The neural-efficiency hypothesis takes this into account, suggesting that because of practice and automatization of procedures, experts require fewer brain resources. Here, I argue that the way the brain accommodates complex skills does indeed have to do with the nature of experts' performance. However, instead of exhibiting less brain activation, experts' performance actually engages more brain areas. Behind the seemingly effortless performance of experts lies a complex cognitive system that relies on knowledge about the domain of expertise. Unlike novices, who need to execute one process at a time, experts are able to recognize an object, retrieve its function, and connect it to another object simultaneously. The expert brain deals with this computational burden by engaging not only specific brain areas in one hemisphere but also the same (homologous) area in the opposite hemisphere. This phenomenon, which I call *the double take of expertise*, has been observed in a number of expertise domains. I describe it here in object- and pattern-recognition tasks in the domain of chess. I also discuss the importance of the study of expertise for our understanding of the human brain in general.

**Keywords**
expertise, neural efficiency, object recognition, pattern recognition

Experts are people who consistently produce outstanding performance in a particular domain (Ericsson & Smith, 1991). For example, expert chess players can quickly find the right path in an environment in which there are arguably more possibilities than there are atoms in the universe (Shannon, 1950). Understanding how the brain implements expertise would not only provide us with the neural mechanism behind experts' outstanding performance but also explain one of the defining characteristics of humans. After all, even seemingly routine activities, such as dealing with everyday life, require immense skill in perceiving and navigating through numerous interconnected elements. Here, I demonstrate a particular way that the brain deals with cognitive demands when producing outstanding performance in one of the most researched domains of expertise, the game of chess.

## Neural Efficiency of Expertise

Compared with the cumbersome performance of novices, experts' efficiency seems effortless. Classical theories of skill acquisition (Fitts & Posner, 1967) assume that the initial effortful performance is replaced by automated procedures in the final stages. It would seem only natural that the final product requires fewer neural resources, a hypothesis known as *neural efficiency of expertise* (Haier et al., 1992). There are indeed numerous studies showing that brain activity decreases in related brain areas after practice. For example, when participants are required to indicate whether a presented word (e.g., "rose") is a member of a specific category (e.g., "flower"), they engage a network of areas mostly located in the frontal and parietal parts of the brain (Chein & Schneider, 2012). The activated brain areas, which are important for the manipulation and integration of information from memory, reflect the difficulty of the task. As people become more and more proficient in executing the task with

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practice, these brain areas become progressively less activated. After some time, only the visual brain areas will remain activated, reflecting the visual presentation of the task.

However, language expertise requires much more than the categorization of retrieved words. Simple skills, the main interest of the research on skill acquisition, may require only a few laboratory sessions to be mastered. In contrast, expertise requires decades of immersion in the field (Ericsson, Krampe, & Tesch-Roemer, 1993). Even seemingly simple subcomponents of expertise, as we will see in this article, may require a considerable amount of domain-specific knowledge. Greater neural efficiency (i.e., the reduction of the fronto-parietal activity) may explain the neural response to the diminishing reliance on attentional resources in expertise. However, it is unclear how the brain accommodates a different kind of resource, domain-specific knowledge, which is the actual engine behind any kind of expertise.

## Cognitive Processes in Expertise: Object and Pattern Recognition

Brain implementation of expertise is not independent of its cognitive mechanisms. It is essential to understand how perception, memory, and attention come together to enable outstanding performance if we are to have a proper insight into the neuronal implementation of expertise. Fortunately, we can build on several decades of behavioral research on expertise (Gobet, 2015). We know that acquisition of domain-specific knowledge, stored in the long-term memory, is essential (Chase & Simon, 1973; Gobet & Simon, 1996). Consider, for example, the simple identity chess task depicted in Figure 1 (left side), in which the participant needs to recognize a chess object (Bilalić, Kiesel, Pohl, Erb, & Grodd, 2011). Even in this simple task, experts' performance is superior to that of novices. The experts' advantage increases as new objects are added to the task, as in the check task (the right side of Fig. 1). Here, chess players need not only to recognize two objects but also to retrieve the objects' functions to determine whether one of the objects puts the king (the other object) in check.

Eye-movement recordings allow us to gain insight into the strategies that experts and novices employ when they are faced with such tasks. Experts do not need to fixate the objects directly to recognize them because their knowledge of the object's properties enables them to use their peripheral vision (Reingold, Charness, Pomplun, & Stampe, 2001). Similarly, experts' knowledge allows them to automatically recognize both objects and simultaneously retrieve their function to

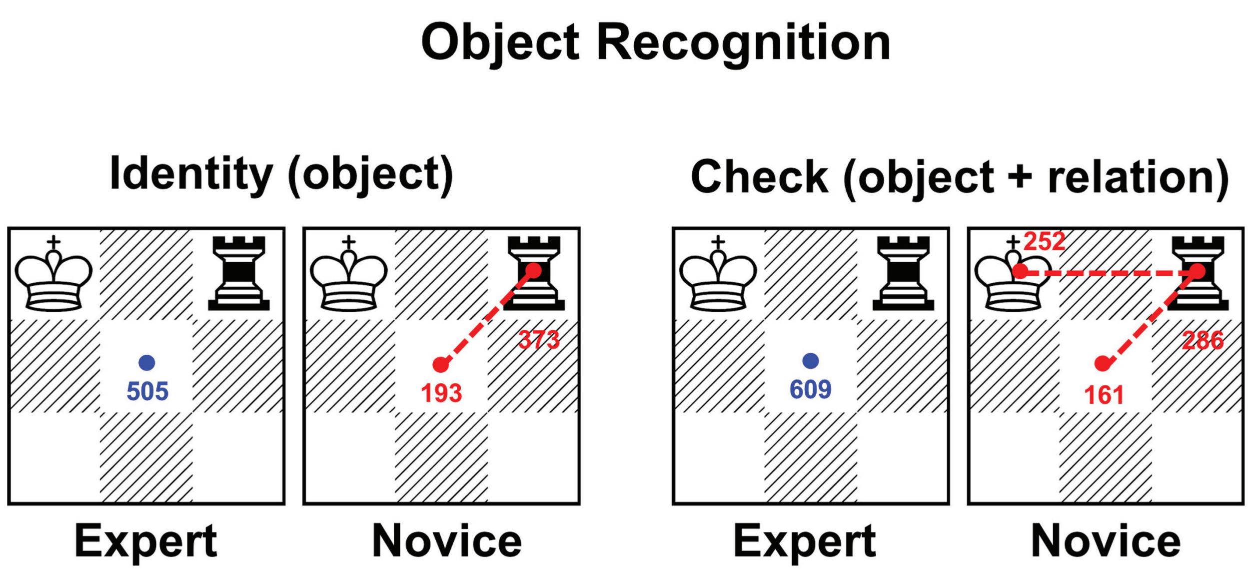


**Fig. 1.** Cognitive mechanisms of expertise: object recognition. Experts, unlike novices, do not need to fixate the object directly to recognize whether the chess piece is a rook or a knight (chess objects were presented in different squares) because of their high familiarity with visual features of the domain-specific stimuli (identity task). Dots represent fixations, numbers indicate the duration of fixation in milliseconds, and dashed lines are saccades for a typical trial. The advantage of experts becomes greater when they need not only to recognize the object but also to determine its relation to the other object in order to establish whether the first object puts the king in check (the position of the king was fixed in the upper left corner; the other objects could appear in different squares). Even with two objects, the experts do not need to fixate the objects directly to recognize them, retrieve their function, and establish the relations between the objects (check task). Novices need to fixate both objects to execute the task.

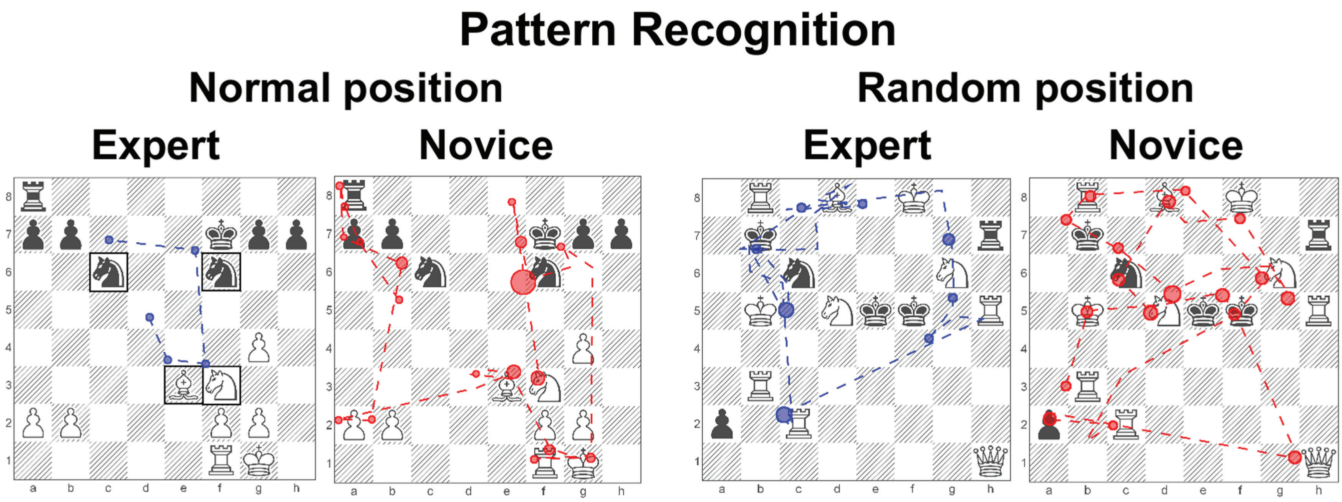


**Fig. 2.** Cognitive mechanisms of expertise: pattern recognition. Experts use their knowledge about typical constellations to quickly focus on the objects of interest in normal positions (the task was to find bishops and knights). Novices, on the other hand, do not possess the necessary knowledge and are forced to execute the task using a qualitatively different strategy—unselectively checking the whole stimulus. Filled circles represent fixations, with the size of the circles indicating the duration of fixation. Dashed lines indicate saccades (eye movements). When the chess objects on the board are scattered around in random positions, experts' advantage is significantly reduced. They are still better at finding the objects because they can rely on their superior recognition of individual chess objects. Similar results were found when the task was to explicitly identify threats in the positions (Bilalić, Turella, Campitelli, Erb, & Grodd, 2012).

establish the relation between the objects (Reingold, Charness, Schultetus, & Stampe, 2001). Experts need only a single glance to determine whether there is a relation between the two objects. The process in novices, who lack the relevant knowledge about these objects, is instead serial in nature. They need to fixate the object, retrieve its function, and then fixate the other object to establish the connection. The means by which experts can use this parallel and automatic processing is domain-specific knowledge. Once chess objects are replaced with neutral geometric shapes, experts' advantage in object recognition disappears (see Bilalić et al., 2011).

Chess objects are basic parts of chess, but chess positions involve a great number of objects. These objects inevitably form a vast maze of relations, making chess a difficult game to master. Unsurprisingly, experts are much better at parsing complex chess positions. Figure 2 illustrates the extent of their advantage. Faced with the task of identifying particular objects among numerous other objects, experts can spot them almost immediately (Bilalić, Langner, Erb, & Grodd, 2010). In contrast, the eye movements of novices show that they need to examine every corner of the position to identify the target objects. Novices lack domain-specific knowledge about chess objects and the relations between them. Consequently, they have to rely on a crude strategy of examining the whole stimulus. Similar results were found when participants had to identify explicit threat relations between objects (Bilalić, Turella, Campitelli, Erb, & Grodd, 2012).

The superior performance of experts is related to their domain-specific knowledge of typical constellations of objects and the relations between them. If the same chess objects are placed randomly on the board, thereby breaking the constellations of patterns typically found in chess games (and in experts' long-term memory), experts' performance suffers. The randomization of material does not affect novices because they continue to employ the same strategy of exhaustive search that they used with normal constellations.

## Neural Implementation of Expertise

The main message from this series of experiments is that experts' strategies are qualitatively different. Experts do not use faster and more efficient versions of the strategies used by novices. Instead, the domain-specific knowledge stored in their long-term memory allows them to execute a number of cognitive processes simultaneously. The end product may look effortless, but experts' superior performance has been achieved in a markedly different manner from the performance of novices.

We find further evidence for the parallel nature of experts' knowledge-based strategies when we examine the way the brain accommodates their efficient performance. Figure 3 demonstrates that there is a difference between the brain activation of experts and that of novices when they need to check the relation between the two objects (the check task from Fig. 1). Although experts and novices engage similar areas on the lateral

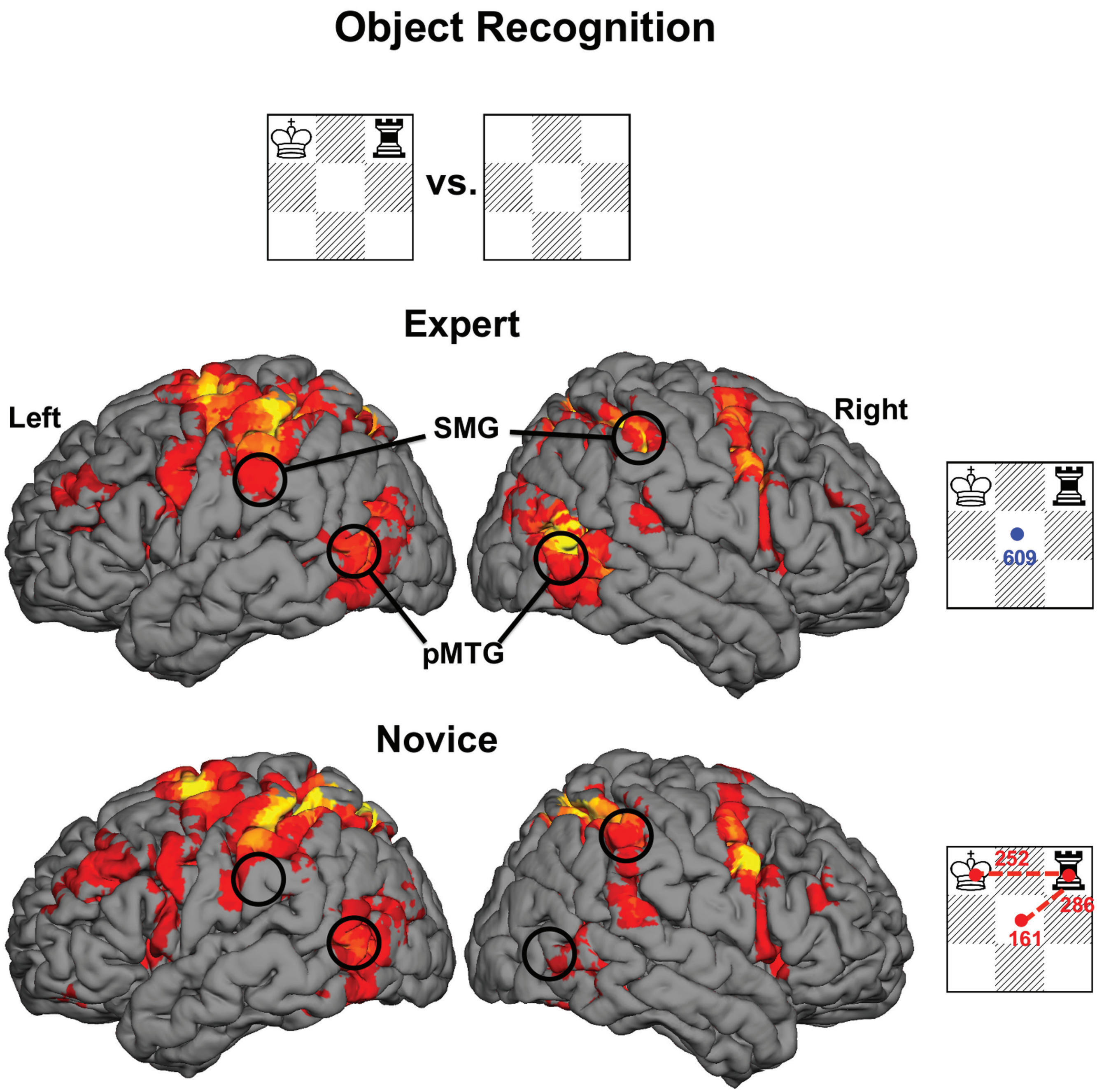


**Fig. 3.** Neural implementation of expertise: object recognition. The brain activation of experts and novices when they execute the check task (see Fig. 1) is compared with baseline (a checkerboard with the same dimensions but with a cross in the middle instead of chess objects). Both experts and novices engage similar brain areas, with the difference being the posterior middle temporal gyrus (pMTG) in the temporal lobe and the supramarginal gyrus (SMG) in the parietal lobe. These areas remain activated when a control task involving geometrical shapes is compared with the check task. The pMTG in the left hemisphere is activated in both experts and novices, but the right pMTG is activated only in experts. The SMG in both hemispheres is hardly engaged by novices, indicating that they most likely execute the task using the left pMTG. We found the same pattern of activation in the identity task (with the exception of the SMG, which is only active in the check task).

(outer) side of the brain, the activation in two areas is more pronounced in experts. The posterior middle temporal gyrus (pMTG) in the temporal lobe and the supramarginal gyrus (SMG) in the parietal lobe are the main hubs of skilled object recognition. We can compare the two object-recognition tasks and, in this way, disentangle the function of the two areas. The pMTG is responsible for experts' superior performance in object recognition, whereas the pMTG and SMG are both necessary for the recognition of relations between objects.

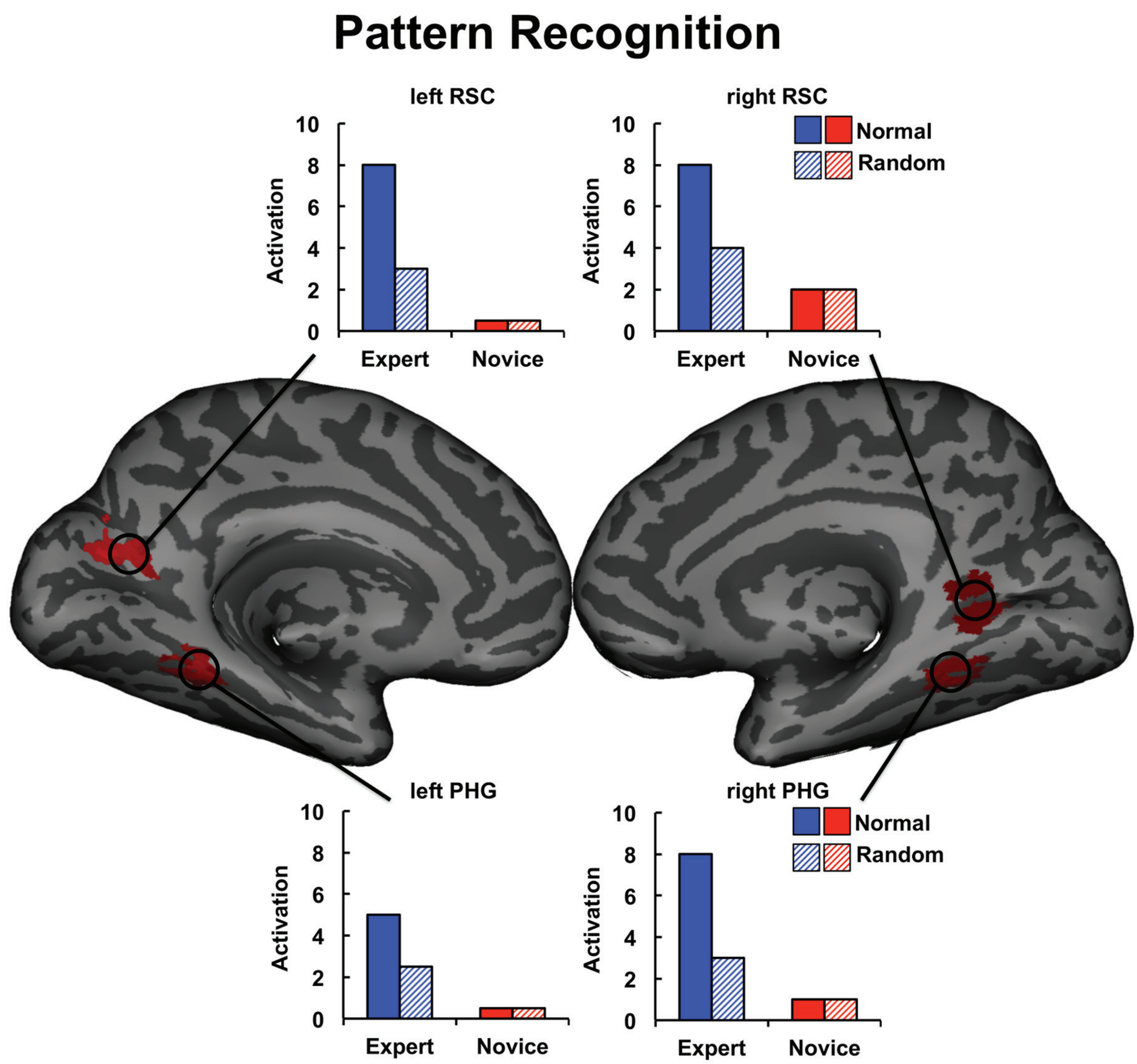


**Fig. 4.** Neural implementation of expertise: pattern recognition. The search task (see Fig. 2) elicits the activation in the same areas responsible for object recognition—posterior middle temporal gyrus (pMTG) and supramarginal gyrus (SMG; not shown here). The focus of the activation was in the inferior and medial part of the brain. The parahippocampal gyrus (PHG) and retrosplenial cortex (RSC) were not activated much more in experts than in novices. Again, we found that experts' brains recruited both left and right PHG and RSC for their performance, whereas there was hardly any activation in these areas among novices. Both pairs of areas also differentiated between the normal and random chess positions among experts—normal positions elicited more activation than random ones—indicating their importance for pattern recognition. The brain models used here are "inflated" versions where sulci, hidden from normal view (as in Fig. 3), are visible. The depicted brain areas significantly differentiate between experts and novices and normal and random positions (interaction: Expertise x Randomization). The depicted activation in the bar graphs represents the brain activity in individual conditions compared with the activity during the baseline (chessboard with chess objects in their initial positions).

The common factor linking experts' object recognition and their recognition of the relations between objects is the simultaneous engagement of pMTG and SMG in both hemispheres. Novices, on the other hand, engage the left pMTG (to a similar extent as experts) but do not activate its counterpart in the opposite hemisphere.

We found the same pattern of results when the same tasks were executed on the whole board with numerous other chess objects (tasks from Fig. 2; Bilalić et al., 2010, 2012). Both experts and novices engaged the left pMTG, but only experts required the right pMTG for their performance. These areas were activated in both normal and random positions, indicating that they do not discriminate between the common and uncommon patterns of relations that these two position types produce. However, the other two pairs of brain areas differentiated between normal and random positions (see Fig. 4). The parahippocampal gyrus (PHG) at the inferior (bottom) of the temporal lobe and the neighboring medial (middle) structure of the brain, the retrosplenial cortex (RSC), were significantly more activated in experts when they dealt with normal positions than when they dealt with random ones. The same areas in novices, on the other hand, did not differentiate between the two position types. In fact, only the right PHG and RSC in novices were activated significantly above the baseline level, whereas both PHG and RSC in experts were engaged. Most importantly, as was the case for the pMTG and SMG in experts' object recognition, we found that experts engaged the PHG and RSC in both hemispheres, unlike novices, who engaged only the area in one hemisphere.

## Double Take of Expertise

Chess is a relatively new game in human history, but the human brain is well equipped to deal with its complexity. One reason for this is that chess mimics the complexity of real life remarkably well (Simon & Chase, 1973). For example, individual chess objects are essentially manmade objects such as we find in everyday life. Just like a hammer or saw in everyday life, a knight or bishop in chess has a typical shape and a well-defined function connected with its appearance. It should not surprise us, then, that the pMTG is involved in perception of tools, whereas the SMG is associated with the retrieval, observation, and execution of an action associated with a particular tool (Johnson-Frey, 2004; Lewis, 2006). Novices can recognize objects fairly well, which would explain their single-hemispheric engagement of the pMTG. However, they struggle with the retrieval of a chess object's function and its relations to other objects, which explains their lack of activation in SMG.

On the other hand, a chess position with its objects and relations resembles a typical (visual) scene, which normally contains a number of elements. The same area of the PHG that is responsible for chess expertise is also involved in parsing scenes. Similarly, the RSC is activated when viewing, imaging, and navigating through complex scenes (Epstein, 2008). Both the PHG and RSC were hardly activated in novices, reflecting the difficulty that novices experienced with parsing complex multilayered stimuli and the relations between them.

Given the similarities between chess and everyday life, it may come as no surprise that the human brain already has tools in place to deal with chess stimuli. What might surprise us is the way in which it deals with such stimuli. In all instances, superior performance of experts was accompanied by more, rather than less, brain activation. More specifically, the additional brain areas that support experts' performance are the very same areas that are already engaged in the performance of novices. The difference is the engagement of additional brain areas in the opposite hemisphere. This specific neural expansion pattern has been called *the double take of expertise* (Bilalić, 2017). The name refers to territorial properties of the phenomenon as well as to the deceptive nature of the seemingly effortless performance of experts. The double take of expertise is believed to reflect the qualitatively different cognitive strategies that take place in experts compared with novices. Experts' automatic and parallel processing may produce seemingly effortless performance, but it requires the retrieval of large amounts of relevant knowledge. The way in which the brain deals with additional demands is to engage the equivalent brain areas in the opposite hemisphere to those that are already recruited (i.e., homologous areas; Banich, 1998).

The double take of expertise may reflect independent parallel processing of task subcomponents. For example, recognizing an object and retrieving its function may be processed in one hemisphere, whereas the spatial integration with the neighboring object (e.g., in the check task described previously) is processed by the homologous area in the other hemisphere. Similarly, it can also be a consequence of highly dependent processing through interhemispheric interaction. Although the exact mechanism behind the double take of expertise phenomenon is unclear, it is certain the large quantity of domain-specific knowledge powering experts' outstanding performance necessitates the use of additional (bilateral) neuronal resources. Whether we are dealing with perceptual domains, such as radiology (Bilalić, Grottenthaler, Nägele, & Lindig, 2016); cognitive domains that involve mental manipulations, such as mental calculation (Pesenti et al., 2001), abacus calculation (Tanaka, Michimata, Kaminaga, Honda, & Sadato, 2002), mathematics (Amalric & Dehaene, 2016), or board games (Wan et al., 2011); or domains with predominantly motor components, such as sports (Abreu et al., 2012), the same phenomenon of the dual activation of the same bilateral brain areas is present (for a review, see Bilalić, 2017). The general nature of the neural (and cognitive) signature of expertise underlines the feasibility of using a single domain, such as chess, in examining the common underlying mechanism behind expertise in general.

## Conclusion

The study of expertise provides us with insight into the function of the human brain at its peak performance. We know that the neural-efficiency phenomenon is a consequence of experts' lack of reliance on attentional resources. We now also know that the engagement of the additional areas in the opposite hemisphere reflects the way the brain deals with the large amounts of domain-specific knowledge that enables experts' outstanding performance. The main reason for the double take of expertise is that knowledge allows people to perceive and deal with stimuli in a fundamentally different way from those who lack this knowledge. This knowledge phenomenon may have far-reaching consequences for research paradigms in general. Success in everyday life depends on prior knowledge, but the experimental approach tries to minimize the influence of knowledge on cognitive and neural processes. The study of expertise, even in a form as simple as that presented here (for more examples, see Bilalić, 2017; Gobet, 2015), may represent a fruitful compromise between the experimental approach, which does not rely on knowledge, and the processing of complex stimuli from real life that inevitably invoke previous experience.

## Recommended Reading

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## Action Editor

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