The Neural Underpinnings of Expertise in Games

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THE NEURAL UNDERPINNINGS OF EXPERTISE IN GAMES

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Introduction

Most of the games that we will examine here, especially the board games, are deceptively simple. The space is clearly defined and the rules are fixed and so simple that even children can learn them. Yet, as anybody who has tried their hand at the games of chess or Go (also called Baduk) knows, it takes years to become merely competent, let alone to master these games. This simplicity of environment, which still leads to complex games, has been appealing to scientists investigating the human mind. The constrained environment allows experimental manipulations, while the complexity mimics the real world, making it possible to investigate phenomena of interest without reducing their complexity (Bilalić, 2016). Here we will first examine how board games have been used in scientific investigations. We will then move on to illuminate how cognitive processes, such as memory, attention and perception, enable expertise at board games. Finally, we will look at how the brain implements skilled performance at board games.

The Expertise Approach

The complexity of board games enables two different research approaches. Both of these investigate experts' performance, but one focuses on performance in its full complexity, while the other looks at simple components of complex performance. The main idea behind the first approach, called the *expert performance approach* (Ericsson & Smith, 1991), is to capture the essence of the expertise under investigation within a laboratory setting. This is achieved by identifying representative tasks, activities that represent the core of skill, but are simple enough to be executed in the laboratory. For example, the fundamental skill of expert chess players is that they find the right solution among numerous possibilities over and over again in the course of a game. Instead of asking chess experts to play a whole game in the laboratory, researchers choose to present them with an unfamiliar position from a normal game between two masters and ask them to find the best move. Once the laboratory task has been established, researchers can manipulate factors such as *skill* (Bilalić, McLeod, & Gobet, 2008a) and *familiarity* (Bilalić, McLeod, & Gobet, 2009) and see what processes mediate experts' outstanding performance.

The other research approach, called the *expertise approach* (Bilalić, Turella, Campitelli, Erb, & Grodd, 2012; Rennig, Bilalić, Huberle, Karnath, & Himmelbach, 2013), exploits the presence of experts,[1] people who possess large amounts of domain-specific knowledge, and novices, who lack that knowledge, for investigating single components of performance. Finding a good solution in the sea of possibilities may be the pinnacle of board expertise, but that skill encompasses numerous other simpler skills. They may be trivial from the board game aspect, but they feature important cognitive processes, which can be investigated. For example, at the most basic level, one needs to recognize the individual objects, then to retrieve their function, and eventually connect that function with other objects on the board. None of these components would be mistaken for the essence of expertise, but they all involve cognitive processes of general interest. The expertise approach investigates these cognitive processes by comparing the performance of experts and novices on simple domain-related tasks. It seeks to understand how domain-specific knowledge influences human cognition. In that sense, the contrasting expertise approach is not unlike the approach in neuropsychology where patients are compared to healthy controls. In the expertise approach, novices are controls, and they enable us to check whether the results obtained on experts are indeed the consequence of domain-specific knowledge. In other words, the expertise approach enables us to get a better picture of the nature of cognitive processes, even though the tasks employed may represent trivial aspects of expertise.

The expertise performance approach may be more idiosyncratic because its goal is to explain how experts manage to achieve their incredible feats. In contrast, the expertise approach may seem more general as it aims to provide additional insight into the workings of the human mind by manipulating the presence of domain-specific knowledge. The two approaches, however, are complementary in nature. In the following sections, we will see how they are frequently employed together.

Cognitive Mechanisms of (Board) Game Expertise

Before we move to the main topic of the chapter, the neural underpinnings of game expertise, it is necessary to consider the cognitive processes behind experts' outstanding performance in board games. As mentioned above, there are many aspects of skilled performance, some of them absolutely elementary, such as recognizing individual objects (see Chapter 12, The Neural Underpinnings of Perceptual Expertise). Chess experts are better at recognizing individual chess objects, called pieces, than novices and especially than beginners, people who have just started to play the game (Saariluoma, 1995). The differences are rather small, but they increase as the tasks begin to include additional cognitive processes. For example, the usual task where players need to recognize an object, retrieve the function, and put it in relation with other objects, is to examine whether there is a "check" in a chess position. In the case of this task, the experts' advantage becomes greater (Kiesel, Kunde, Pohl, Berner, & Hoffmann, 2009). The reason for this advantage is that experts retrieve the function of an object automatically and in parallel with its identity (Reingold, Charness, Schultetus, & Stampe, 2001). This is particularly on display when there is more than one piece that may give check to the king. Typically, novices need to check each of the objects and see if they connect to the king. Experts grasp the situation with three objects in a single glance (Bilalić, Kiesel, Pohl, Erb, & Grodd, 2011).

Experts' extraordinary familiarity with the objects from their domain and the relations between those objects is evident in the *subliminal priming and stroop paradigms*. It is possible, for example, to prime chess experts subliminally in order to detect more quickly the check relation between a king and a piece on a 3 × 3 board (Kiesel *et al.*, 2009). Similarly, when there are two pieces that may give check to the king, experts cannot ignore their presence even if they are told to, which results in a *stroop-like* interference (Reingold *et al.*, 2001). The recognition of domain-specific objects, retrieval of their function, and relations to other objects are overlearned to such an extent that those automatic and parallel processes may be used to investigate subliminal and stroop phenomena.

These basic level skills are inevitably the building blocks of board game expertise. Quickly identifying objects and relations on a board full of objects is the main ingredient of board game expertise. Indeed, even when they are presented with a board full of objects, experts almost instantly direct their focus to the relevant aspects (Sheridan & Reingold, 2014). When the players need to examine the situation in detail, the main differences between greater and lesser experts consist in where they look for answers (Bilalić, McLeod, & Gobet, 2008b; De Groot, 1978). The very best experts may not search more thoroughly than their less skilled colleagues, but they certainly examine the more promising solution. Plenty of evidence indicates that experts' almost instant focus on the important aspects of the situation is a consequence of their vast domain-specific knowledge. For example, when asked to look for certain pieces in a normal mid-game position, experts immediately focus on the relevant pieces, whereas novices need to examine the whole board to identify the objects of interest (see Figure 11.1, upper panel).

Given the stable nature of board games, with rules that hardly ever change, certain constellations of objects often recur. Players pick up on things that appear

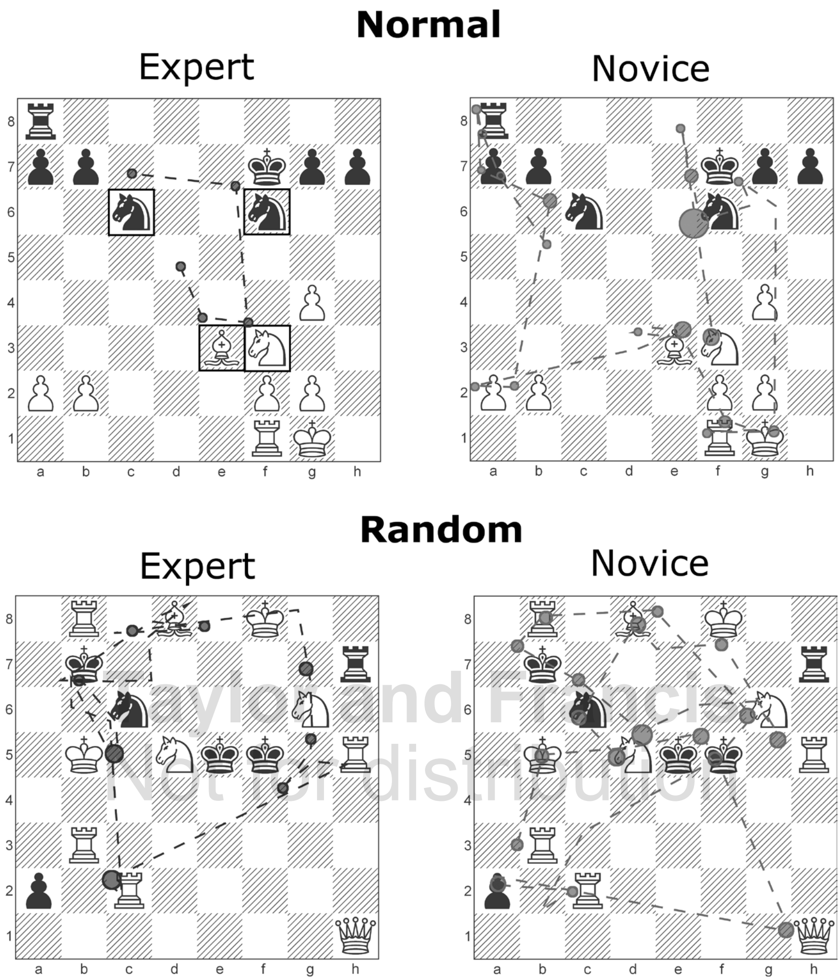

FIGURE 11.1 Perception in Experts. Experts quickly identify knights and bishops (objects highlighted by black squares) in normal positions, whereas novices need to examine the whole board (upper panel). When the position is randomized (lower panel), experts suddenly struggle at the same task (again, the objects of interest are in black squares). They still retain a small edge over novices because they do not need to focus on the objects directly to grasp their identity. Adapted from Bilalić *et al.* (2010).

together frequently, as well as ways of dealing with such constellations, and store them in their long-term memory (LTM). Once similar constellations reappear on the board, they can draw on their LTM to recognize the situation and quickly orient themselves by retrieving typical ways of dealing with the situation at hand (Chase & Simon, 1973; Gobet & Simon, 1996). If the same domain-specific material is used, but the relations between them have been distorted by placing the objects randomly on the board, experts' advantage disappears almost completely (Gobet & Simon, 1996). The randomization manipulation renders the acquired knowledge structures in experts' LTM incompatible with the new patterns on the board. Experts still exhibit better memory and orientation (see Figure 11.1, lower panel) in these random positions, but that is because they still can fall back on their superior knowledge about individual objects (Bilalić, Langner, Erb, & Grodd, 2010).

There are a few theories of expertise, some in the *system production tradition* (Chase & Simon, 1973; Ericsson & Kintsch, 1995; Gobet & Simon, 1996), and others in the *connectionist tradition* (Harré, Bossomaier, & Snyder, 2012). We will not go into the details about their differences here (see also Chapter 3, Cognitive Processes in Chess), but they all propose that experts match the situation on the board with the stored knowledge in LTM. This inevitably leads to the activation of all the knowledge connected to the matched structure, including plans for dealing with the situation. Novices may not necessarily have inferior general cognitive abilities, but they lack domain-specific knowledge that would enable them to grasp the essence of the situation quickly.

Here it is important to understand that experts' strategies, although highly efficient and mostly automated, are in no way simpler than those of novices. They require the retrieval of a large amount of knowledge, which then influences how the situation will be perceived and dealt with. They are not just a quicker version of the steps involved in the strategies of novices. Experts' strategies are qualitatively different because they rely on domain-specific knowledge that enables complex interaction between a number of cognitive processes, such as memory, perception, and attention. As we will see in the next section, the differences between the complexity of experts' and novices' strategies have a profound effect on the way the brain accommodates the performance of experts and novices.

Neural Underpinnings of Expertise in (Board) Games

As with the cognitive mechanisms in the previous section, we will consider the neural underpinning of simpler aspects such as object recognition and then slowly move towards more complex processes such as decision making and problem solving. In all cases presented here, we will see that the brain implementation closely follows the processes involved in the strategies of experts and novices.

Skilled Object Recognition

The first study we will examine comes from one of us (Bilalić, Kiesel, Pohl, Erb, & Grodd, 2011) and investigates how the brain accommodates skilled object recognition. A miniature 3 x 3 board with the fixed position of the king in the upper left corner was used (see Figure 11.2). The first task was to indicate the type of the second object on the miniature board, when both location and type were varied. Unsurprisingly, experts were better at this simple task, confirming the previous findings (Saariluoma, 1995). The recorded eye movements showed that this was due to familiarity with the domain-specific objects – experts did not have to move their eyes and directly fixate on the object (remember that the location was varied and players could not know where the object would appear), instead remaining in the center of the board. Novices, on the other hand, had to fixate the object directly to identify it correctly. The differences were even more pronounced in the check task where the players needed to indicate if the object was giving check to the king in the corner. Here novices not only had to fixate the object to identify it and retrieve its function, but also to see whether the object was spatially connected with the king. Experts again only needed a single fixation in the center, which was sufficient to grasp the identity of the object and its relation to the other object. The advantage of experts disappeared when they had to identify squares and circles on the same miniature board instead of chess pieces. This is more evidence that experts parse the relations between objects in a highly parallel and automatic manner (Reingold *et al.*, 2001; Sheridan & Reingold, 2014).

Skilled object perception has a specific neuronal signature too (Bilalić, Kiesel, *et al.*, 2011). Both experts and novices engaged a large network of brain areas, starting from frontal and spreading over parietal to temporal areas (see Figure 11.2). Most of the brain areas, however, were task-related and were activated in the control task with squares and circles. Only the posterior middle temporal gyrus (pMTG) seemed to be important for object recognition. Its left part was engaged to a similar extent in both experts and novices. However, its equivalent on the opposite side was only engaged in experts. As a matter of fact, novices showed almost no activation above the baseline in the right pMTG. The same pattern of bilateral engagement of the pMTG in experts and unilateral engagement in novices was found in the check task. Here, in addition to the pMTG activation, another bilateral activity in the supramarginal gyrus (SMG) was evident in experts while it was absent in novices.

We can therefore assume that the pMTG is important for recognition of objects, especially its right part, while the SMG additionally codes its function and relates them to other objects in space. These lateral brain areas are well known to be responsible for the perception of manmade objects such as tools (Johnson-Frey, 2004). Now, chess pieces are not common tools, but, not unlike tools, they have a clearly defined function that is based on movement. The pMTG may then be responsible for identification of objects and their function whereas the SMG may deal with explicit retrieval of the physical action of the objects (Johnson-Frey, 2004). It remains unclear why the SMG was not greatly activated in experts even in the identity task, given experts' automatic

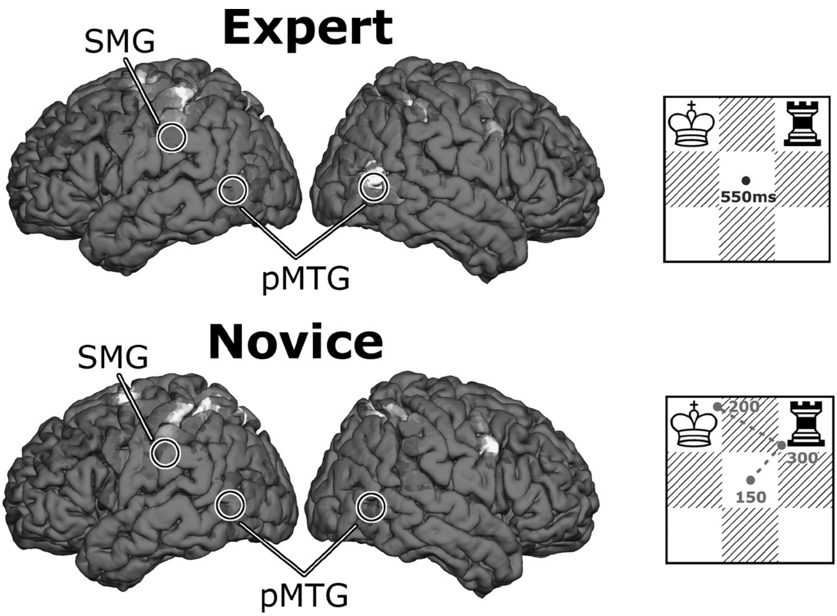

FIGURE 11.2 Object Recognition in Experts. Experts could grasp the relations between the two objects in the chess tasks with a single glance (right upper panel). Novices had to fixate on each object individually (right lower panel). The dots represent fixations and the adjacent numbers indicate the duration of the fixation (rounded). The posterior middle temporal gyrus (pMTG) was more active in experts and novices when they had to identify the object. Experts, however, engaged both pMTG areas whereas novices only engaged the pMTG in the left hemisphere. In the check task, where they had to retrieve a function of the object to examine if the king was in check, the left supramarginal gyrus (SMG) was more active in experts in addition to the pMTG. Novices showed no activation in the SMG. From Bilalić, Kiesel, *et al.* (2011).

response of parsing the relations between domain-specific objects. One possibility is that the tested experts, who were certainly very good players, but nowhere near professional level, were not of sufficient proficiency. The other is that the involvement of the additional brain areas, that is the SMG, is necessary to achieve the efficient performance which is characteristic of experts. The performance may seem automated, but its execution may require additional neural resources.

The above study is an example of the expertise approach. Identifying quickly and correctly the objects and their function on the board is hardly going to be mistaken for board game expertise. Skilled object recognition, however, represents a relevant topic in cognitive neuroscience. The expertise aspect provides insight into how the brain accommodates highly efficient object recognition. We know from the literature on the perception of man-made objects that their neural implementation is left lateralized (Noppeney, 2008). Here we have corroborated that finding but added another detail. The pMTG and SMG in the left hemisphere were indeed activated in experts and partly in novices, but the real differences were in the same areas in the right hemisphere, not known to be particularly relevant for the perception of handmade objects. The skilled perception of objects requires additional engagement of the same brain areas in the opposite hemisphere. This neural expansion, termed the *double take of expertise* (Bilalić, Kiesel *et al.*, 2011, Bilalić *et al.*, 2012), is the consequence of the complex cognitive machinery behind skilled perception of objects. Sharing the computational burden along both hemispheres is a standard way in which the human brain accommodates demanding activities (Weissman & Banich, 2000). Expertise, even its simple aspects such as object recognition, certainly involves the retrieval of a large amount of domain-specific knowledge, which then influences other cognitive processes, such as perception.

The double take of expertise reminds us that the cognitive implementation of experts' and novices' strategies are qualitatively different. It also represents a neural signature of expertise because the brain's double engagement is evident in other expertise domains where one needs to retrieve and manipulate domain-specific knowledge, such as mental (Pesenti *et al.*, 2001) and abacus calculations (Hanakawa, Honda, Okada, Fukuyama, & Shibasaki, 2003). In the next section we will see that more complex processes, such as skilled pattern recognition, also leave the typical neural signature in experts' brains.

Skilled Pattern Recognition

As we mentioned in the section on cognitive mechanisms, the differences between experts and novices are particularly pronounced when they deal with a board full of pieces. This was evident in a series of experiments where experts and novices had to identify a number of particular pieces (Bilalić *et al.*, 2010) or threats (Bilalić *et al.*, 2012) in positions that occurred in normal chess games. In order to do so, one needs to examine the whole position. This is what we find in novices when their eye movements are recorded; they need to examine every corner of the board to ascertain whether it contains the target pieces or threats. In contrast, experts quickly identify the objects of interest without wandering around the board. When the same pieces on the board were randomly placed, the manipulation that distorts the common patterns in the game, experts' performance dropped significantly (see Figure 11.1). They were still better at finding objects and threats in random positions, but mostly because they were drawing on their familiarity with individual pieces for quicker identification. The random positions did not have much effect on novices: Their performance remained the same as on normal positions. The pattern of results indicates that novices were not able to exploit the common game patterns in normal positions, whereas most of the advantage of experts was in skilled pattern recognition.

The fMRI data showed that the same lateral brain areas that are important for skilled object recognition were also relevant for pattern recognition. Experts engaged both pMTG to a greater extent than novices when they had to find particular pieces in both normal and random positions. When they needed to identify threats, experts engaged the left SMG in addition to the bilateral pMTG more than novices. Again, the differences were present in both normal and random positions. The randomization may not have had an effect on the lateral brain areas, but some medial brain areas were significantly affected. The brain areas around the middle of both collateral sulci (CoS), which divide the fusiform and parahippocampal gyri (PHG) in the inferotemporal cortex, demonstrated the expertise effect; that is, more activation in experts (see Figure 11.3). However, experts had more activation in the same areas when they were dealing with normal positions than when they were looking for objects and threats in random positions. Novices, on the other hand, had hardly any activation above the visual control (chess board with the pieces in the starting position) in either kind of position. The same pattern of results was found in the bilateral posterior cingulate cortex, the area also often called the retrosplenial cortex (RSC). It is important to emphasize that the parahippocampal place area (PPA) and RSC were related to the parsing of patterns on the board and not the visual feature. When the same positions were used, but the experts' task was to count all the pieces, essentially having to pay attention to every object, the PHG and RSC were not significantly more active in experts than novices, nor were there any differences between normal and random positions.

The results depict how the brain divides labor for different components of the board skills among its areas. The lateral areas (pMTG and SMG) are responsible for the recognition of individual objects and the explicit retrieval of their function. These areas are not affected by the randomization because the recognition of objects is the common component in both normal and random positions. The randomization affects the CoS and RSC in both hemispheres, but only in experts, which indicates that these areas are responsible for pattern recognition. We have seen that pMTG and SMG are implicated in the perception of everyday stimuli such as manmade objects. The CoS and RSC are connected to perception, but their function is connected rather to stimuli encompassing numerous objects, such as scenes, than individual objects. The CoS, which is essentially a part of the PPA, is responsible for the perception of layout (Epstein, 2008) and relations between objects (Aminoff, Kveraga, & Bar, 2013), while RSC is implicated in spatial navigation (Epstein, 2008).

A few other studies using different paradigms confirmed the involvement of the PHG and RSC in board game expertise. When the recall paradigm in chess was employed, the PHG was the area that was differentiated between normal and random positions (Campitelli, Gobet, Head, Buckley, & Parker, 2007; Campitelli, Gobet, & Parker, 2005). Passively observing normal and random chess positions also induced the differences between experts and novices in RSC (Bartlett, Boggan, & Krawczyk, 2013; Krawczyk, Boggan, McClelland, & Bartlett, 2011).

Another study (Wan *et al.*, 2011), which employed shogi, a board game similar to chess, examined the neural response of experts and novices when they passively observed domain-specific (shogi) constellations and other neutral stimuli, such as faces and places. The pMTG in both hemispheres were engaged for the perception of shogi positions in both experts and novices. The PHG and the RSC (Epstein, 2008), were also important for shogi perception but were activated only in experts. These areas were not only engaged when shogi positions were compared to visually distinctive stimuli such as faces and places, but also when more visually similar stimuli such as Western and Chinese chess positions were used. Somewhat surprisingly, another area also distinguished between normal and random shogi positions among experts. The posterior precuneus was more activated when experts watched normal positions than when they watched random positions. The other medial shogi-related areas, the PHG and RSC, also reacted more strongly to normal shogi constellations than random ones, but these differences did not quite reach statistical significance. Shogi and chess therefore share a common neural implementation, with shogi additionally engaging the posterior precuneus.

At the moment, it is unclear how these areas come together to enable efficient orientation in a complex environment like that of board games. One possibility is that the PPA and RSC are necessary for the activation of stored patterns similar to the incoming stimulus, which is important for forming an initial impression of the situation. This initial impression may then guide attention to important aspects of the stimulus where the SMG and pMTG would be engaged for object identification and retrieval of their function. Obviously, the other way of information direction, starting from lateral areas for individual object recognition and leading to the CoS and RSC, is also possible. Future research, possibly using other techniques such as functional connectivity and neurostimulation, may provide more information on the exact information exchange between these areas.

Problem Solving

It is true that expert (board game) players can recognize isolated objects, retrieve their function, and find particular objects among numerous other similar objects on the board faster than novice players. However, this is more an additional effect of their core expertise; that is, finding an adequate way of continuing the game among the sea of possibilities.

A couple of studies have investigated the way the brain accommodates decision making and problem solving in board game practitioners, but these studies were either conducted with novices only (Atherton, Zhuang, Bart, Hu, & He, 2003) or featured complex designs where it was difficult to pinpoint the exact processes at hand (e.g., Amidzic, Riehle, Fehr, Wienbruch, & Elbert, 2001). Other recent studies (Bilalić, 2016; Bilalić, Langner, Ulrich, & Grodd, 2011) employed the expertise approach to tackle the issue of brain modularity (see Chapter 12, The Neural Underpinnings of Perceptual Expertise). However, the study on shogi that we examined in the previous section (Wan *et al.*, 2011), also featured a task where the players were asked to find the best move in a position presented for only a second. Obviously, this would have been an extremely difficult task for even the best players, but the position presented involved only a quarter of the board and featured well-known motifs. Although skilled practitioners could recognize these motifs, they could not investigate the whole sequence and check to see if it led to the desired effect within a single second. In other words, they had to base their quick intuitive decisions on the pattern recognition processes.

Not surprisingly, experts were better than novices at finding the solution within such a short period of exposure. However, the brain areas engaged in the task were rather similar in both groups. Besides the already mentioned posterior precuneus, the dorsolateral prefrontal cortex (DLPFC) as well as premotor and motor areas were all activated, with no differences between experts and novices in the extent of engagement. Only the head of the *nucleus caudatus* (CaudNuc), a part of the basal ganglia situated in the middle of the brain, was significantly more activated in experts than novices during the quick decision. A number of control experiments demonstrated that the activation of the nucleus caudatus is most likely responsible for fast and efficient decision making in experts. First, spotting a particular piece (e.g., the king) in the same positions, a task that requires the same processes as the previous task except for the final move decision, did activate the well-known areas (precuneus, motor and premotor, and DLPFC) but not the nucleus caudatus (see Figure 11.3). Similarly, longer deliberation of 8 seconds for a decision also activated the common areas except the nucleus caudatus. Finally, the better the experts were at quick decisions, the more their nucleus caudatus was activated. Even novices demonstrated the activation of the nucleus caudatus in rare problems that they could solve. However, when the problems became too difficult for one-second decisions, the activation disappeared.

The nucleus caudatus does seem to be responsible for quick problem solving, because it is not implicated when players have more time or when they just look for an object. It is well known that the basal ganglia, the structure where the nucleus caudatus is situated, is important in the formation and execution of the typical responses that constellations of stimuli elicit (Poldrack, Prabhakaran, Seger, & Gabrieli, 1999). It is therefore possible, according to the authors (Wan *et al.*, 2011), that the typical and good solutions were triggered by the recognition of the well-known constellation. It remains unclear how the nucleus caudatus is able to match the incoming input with constellations stored in memory. Most likely, the constellations are retrieved from the precuneus (and possibly the PHG and RSC) and fed to the nucleus caudatus for a quick response. Not only is the precuneus sensitive to normal and random positions, it is in general implicated in imagery of visuo-spatial stimuli as well as episodic memory retrieval (Cabeza, Ciaramelli, Olson, & Moscovitch, 2008). It is also directly connected through brain tracts to the very same head of the nucleus caudatus, the area engaged in finding quick solutions (Leichnetz, 2001). As it happens, the activation levels in the precuneus and nucleus caudatus fluctuate in the same manner. When more activation is found in the precuneus at one point in time, more activation is available in the nucleus caudatus at the same time.

The final piece of evidence for the role of the nucleus caudatus in quick decisions comes from a training study by the same group (Wan *et al.*, 2012). Shogi novices were trained for 15 weeks and after the training somewhat improved their performance, solving four problems out of ten compared to three before the training. Again, a number of the same brain areas were involved in the

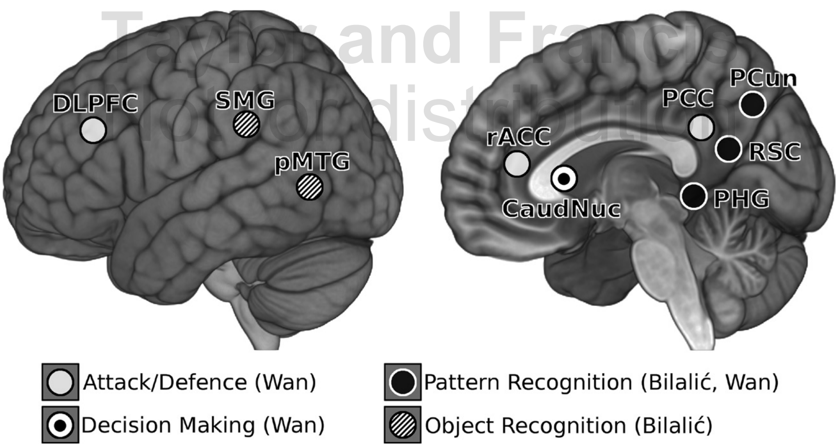

FIGURE 11.3 Overview of Neural Basis of Expertise in Board Games. Experts engage lateral areas for skilled object recognition (SMG and pMTG) whereas they need medial areas for pattern recognition (PHG, RSC, and PCun). The nucleus caudatus (CaudNuc) is important for skilled decision making, while the rostral anterior cingulate cortex (rACC) and posterior cingulate cortex (PCC) parse defense and attack relations between the objects on the board, respectively. The DLPFC is implicated in deciding between attack and defense options. Adapted from Bilalić *et al.* (2010, 2012), Bilalić, Kiesel, *et al.* (2011) and Wan *et al.* (2011, 2012, 2015).

performance (precuneus, premotor and motor areas, and DLPFC) but none of them changed due to training. The only area that had increased the activation after the training was the nucleus caudatus. The nucleus caudatus also predicted the improvement after the training. The more the nucleus caudatus was activated after the training compared to the beginning of the training, the more the player improved the performance.

One plausible explanation of the two studies is that the medial areas process the incoming stimuli for patterns, sending the information to the nucleus caudatus for the generation of suitable solutions. The precuneus–nucleus caudatus connection may act as the equivalent of the cognitive mechanisms where knowledge structures enable pattern recognition, thereby automatically triggering common ways of dealing with the situation at hand. The problem with this explanation is that the nucleus caudatus was not activated when experts had more time at their disposal and mentally played through possibilities. This is at odds with the current cognitive theories of expertise (Gobet & Simon, 1996), which suppose that the same mechanism of triggering the solution is at work in both deliberate search and decision making. In other words, once the first solution to a position has been triggered, it is implemented in the "mind's eye," which then again leads to the triggering of the next move (solution). The recurring process of triggering solutions, which is the essence of deliberate problem solving, does not seem to be reflected in the activation of the nucleus caudatus, the area that is apparently responsible for the generation of quick solutions.

Similarly, a recent study by the same group (Wan, Cheng, & Tanaka, 2015), did not quite lead to the resolution of the inconsistent results. In the study, expert players had to indicate within a second whether the position required a strategy associated with attack or defense, two typical broad approaches to problems in shogi. Experts were better than chance in the task and again a number of areas were activated which we have previously encountered (e.g., Wan *et al.*, 2011). However, other areas were crucial for the quick decisions on strategy. The posterior cingulate cortex (PCC), more anterior to the RSC, was particularly activated if the position required attack but not when defense was the best way to proceed. In contrast, the rostral anterior cingulate cortex (rACC) was engaged in the positions where defense was the best strategy (see Figure 11.3). Therefore, it seems that the PCC and rACC were parsing the relations in presented positions for attack and defense strategies, respectively. It seems that the values were then sent to the dorsolateral prefrontal cortex (DLPFC) for the decision. The activation in the DLPFC was particularly associated with the difference in the values for attack and defense. When the experts chose attack, the DLPFC was more connected to the PCC. When defense was chosen, the activation in the DLPFC was more associated with that in the rACC.

The above-mentioned brain areas are indeed important for decision making in general. The rACC is often implicated in decision making, but its rostral part most likely encodes subjective values of the situation (Nicolle *et al.*, 2012). The PCC is near to the other areas associated with expertise, RSC, and PCun, but is sometimes activated in decision-making settings (McCoy & Platt, 2005). The DLPFC is important for cognitive control (Lee, Shimojo, & O'Doherty, 2014) and decision making based on explicit rules (Hyafil, Summerfield, & Koechlin, 2009). However, the rACC, PCC, and DLPFC did not play an important role in the previous studies on board games expertise. One way to reconcile the results is to look at the paradigm used. Deciding on the strategy in shogi is the first step in solving the problem (i.e., finding the right solution). As a matter of fact, experts in the study were not very good at finding the best moves in the positions; that is, the full board of pieces, rather than the section used in the previous study (Wan *et al.*, 2011), and the short time allowed made the task nearly impossible. The nucleus caudatus, together with other areas (precuneus [PCun], RSC, PHG) may be important for quickly finding the solution, which is in reality only the second step in the problem-solving process in shogi. One needs to decide first on the strategy and then on the actual way to proceed.

The game of shogi seems to be one of the rare board games where the question of whether to attack or defend plays such a crucial role. It is unclear how this paradigm could be implemented with other games. Nevertheless, the inconsistencies between the findings of different studies, as well as between the theoretical cognitive considerations and the current neural evidence, point out the need for further examination of the phenomenon.

Structural Changes

We have seen that the brain adapts to the demands of expertise by additionally engaging brain areas. Here we will look at whether the neural requirements necessary in expert performance result in anatomical changes in experts' brains.

The studies examined above could not establish or did not report morphological differences between the brains of experts and those of novices. However, other studies with more participants found differences even though the findings were somewhat inconsistent over the studies. For example, Baduk (Go) experts had a larger nucleus caudatus, the structure important in experts' decision making (Wan *et al.*, 2011), than novices in one study (Jung *et al.*, 2013), but the opposite pattern was found in another study (Duan *et al.*, 2012). The most recent study (Hänggi, Brütsch, Siegel, & Jäncke, 2014) could find no differences between the experts and novices, although admittedly this related to chess and not Go. That study did find differences in the pMTG, the brain area important for skilled recognition (Bilalić *et al.*, 2010, 2012; Bilalić, Kiesel *et al.*, 2011). However, chess players had a rather smaller pMTG than non-chess players. Non-chess players also displayed increased cortical thickness not only in the pMTG, but also in the SMG and precuneus, all of these areas being implicated in (chess) expertise, compared to chess players. On the other hand, chess players displayed a denser and more compact superior longitudinal fasciculus, a pathway that connects the temporal lobe with the parietal and frontal lobes. Given the importance of temporal and parietal areas in skilled perception in board games, it may not come as a big surprise that the brains of board game experts have reacted by improving the connections between these two areas.

Most likely, the smaller brain areas and thinner cortex are products of the pruning of neurons and neuronal connections that may not be necessary for experts' performance. In any case, the fMRI activation does not have to be smaller in these restricted areas (Lu *et al.*, 2009). In board game expertise it seems to be the case that fMRI activation is instead an indication that the performance is more efficient. For example, recent studies on Chinese chess (Duan *et al.*, 2012, 2014) demonstrated that the activation in the nucleus caudatus in experts was better synchronized with activation in the inferotemporal and parietal areas, the parts of the brain important for skilled object and pattern recognition.

Conclusion

We have seen that board games offer plenty of possibilities for investigating the human mind and brain. The mere presence of differently skilled practitioners enables the expertise approach, where the focus may not be the essence of the board game expertise, but rather the investigation of cognitive processes. Board game expertise also offers a glimpse into the functioning of the human brain at its best, when it needs to perceive a large amount of information present in the environment and connect it with previously acquired knowledge.

One of the recurring themes in this chapter is how domain-specific knowledge modifies the human cognition. The way experts deal with stimuli from their domain of expertise is heavily influenced by the knowledge they have previously stored in the LTM. Their strategies may look effortless compared to those of novices, but they require an immense amount of cognitive resources. This is reflected in the way the brain accommodates the complex interplay between perception, memory, and attention in experts' performance. The double take of expertise is a hallmark of the neural implementation of expertise and further evidence that domain-specific knowledge results in qualitatively different ways of processing information from the environment. Similarly, it demonstrates a close connection between cognitive and neural processing of stimuli.

The neuroscience of expertise (Bilalić, 2017) is a relatively new field of research that offers a unique insight into the functioning of the human brain. We hope that our chapter provides another incentive for researchers to use the expertise approach in investigating cognitive processes and their neural implementation.

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Note

1 Here we define experts as people who consistently and reliably perform clearly above the average in a domain of their specialization (Ericsson & Smith, 1991). In the studies presented in this chapter, experts are at least more than 2 standard deviations above the average player. In contrast, novices perform clearly worse than the average practitioner, but are better than beginners who have just started playing.

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