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Mechanisms and Neural Basis of Object and Pattern Recognition: A Study With Chess Experts

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Comparing experts with novices offers unique insights into the functioning of cognition, based on the maximization of individual differences. Here we used this expertise approach to disentangle the mechanisms and neural basis behind two processes that contribute to everyday expertise: object and pattern recognition. We compared chess experts and novices performing chess-related and -unrelated (visual) search tasks. As expected, the superiority of experts was limited to the chess-specific task, as there were no differences in a control task that used the same chess stimuli but did not require chess-specific recognition. The analysis of eye movements showed that experts immediately and exclusively focused on the relevant aspects in the chess task, whereas novices also examined irrelevant aspects. With random chess positions, when pattern knowledge could not be used to guide perception, experts nevertheless maintained an advantage. Experts' superior domain-specific parafoveal vision, a consequence of their knowledge about individual domain-specific symbols, enabled improved object recognition. Functional magnetic resonance imaging corroborated this differentiation between object and pattern recognition and showed that chess-specific object recognition was accompanied by bilateral activation of the occipitotemporal junction, whereas chess-specific pattern recognition was related to bilateral activations in the middle part of the collateral sulci. Using the expertise approach together with carefully chosen controls and multiple dependent measures, we identified object and pattern recognition as two essential cognitive processes in expert visual cognition, which may also help to explain the mechanisms of everyday perception.

Keywords: expertise, object and pattern recognition, eye movements, fMRI, chess

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Chess players face a daunting task: They need to orient themselves in an environment filled with different objects that form numerous functional relations. Yet the very best chess players use their specialized chess knowledge to find ingenious ways through the jungle of possibilities created by chess objects and their functional relations (De Groot, 1978; Shannon, 1950). This remarkable skill is only one example of many comparably complex situations people master every day. For instance, people routinely find their way in everyday life despite being surrounded by numerous objects and the complex relations between them. People probably would not even consider the feat of everyday orientation as a kind of expertise, but it is. People are experts in mastering the daily routine because of previous exposure to and knowledge about everyday objects and their relations. The similar complexities in everyday life and the game of chess is one of the reasons why the game of chess has been a major paradigm used to investigate cognition (Charness, 1992; Chase & Simon, 1973; Gobet, de Voogt, & Retschitzki, 2004; Simon & Chase, 1973). Despite extensive behavioral research on the mechanisms behind expertise (for a review, see Gobet et al., 2004), we are still left wondering which brain structures mediate experts' outstanding performance. This is unfortunate because examining highly proficient experts enables insights into the functioning of cognition at the highest level and represents an avenue to further our understanding of how mind and brain work in general. Here we examined the mechanisms and

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neural basis behind skilled object and pattern recognition that form the basis not only of chess expertise but also of people's everyday expertise.

Experts possess domain-specific knowledge structures acquired through extensive and focused exposure to the domain-specific stimuli (Ericsson, Krampe, & Tesch-Roemer, 1993; Ericsson, Nandagopal, & Roring, 2009). These knowledge structures, called *chunks* (Chase & Simon, 1973) and *templates* (Gobet & Simon, 1996b), are composed from several individual objects connected through their common relations.[1] Knowledge structures include information about individual objects, such as the objects' form and function. This low-level knowledge enables experts' superior recognition of domain-specific objects and, in particular, their function, even when they are isolated, that is, devoid of their typical context (Kiesel, Kunde, Pohl, Berner, & Hoffmann, 2009; Saariluoma, 1990). Additionally, knowledge structures represent the statistical nature of a domain-specific environment by encompassing information about typical locations of objects and their relations, that is, the temporospatial pattern of their occurrence (Chase & Simon, 1973; Gobet & Simon, 1996b; McGregor & Howes, 2002). Knowledge structures enable predictions about stimulus input and modulate input processing in a top-down manner. For instance, they direct experts' attention automatically toward the most important stimulus features, enabling fast and efficient pattern recognition. This way, experts reduce the complexity of the environment and deal with it successfully despite limited cognitive resources. Novices do not have inherently weaker cognitive abilities than experts do, but they lack specific knowledge structures that guide perception and feel overwhelmed by the complexity of the situation (Chase & Simon, 1973; De Groot, 1978). The acquisition of these knowledge structures involving objects and relations between them is considered not only the core aspect of any expertise but also a general learning mechanism (Biederman, Mezzanotte, & Rabinowitz, 1982; Gobet et al., 2001; Shank & Abelson, 1977). The perceptual mechanisms that lead to recognition and the creation of chess experts' knowledge structures have been specified in detail (Gobet & Simon, 1996b, 2000) and have also been implemented in a computational model (De Groot, Gobet, & Jongman, 1996; Gobet et al., 2001; Gobet & Simon, 1996b, 2000).

The crucial finding is that knowledge structures are domain specific and related to the objects and their typical relations. Chess experts can remember a previously unseen game position of 20 or more objects on the board after only a brief exposure, typically 5 s, but their performance drops considerably when the objects are randomly distributed and the typical relations between them are disturbed (Chase & Simon, 1973; Gobet & Simon, 1996a). Manipulating the typical relations through object randomization has become one of the main research paradigms for uncovering mechanisms behind expertise and cognition in general (Ericsson & Lehmann, 1996; Vicente & Wang, 1998).

Here we compared chess experts and novices on a chess task where they needed to identify and enumerate certain chess objects (called *pieces*) and a nonchess control task where they needed to enumerate all objects on the board (see Figures 1A and 1B). The chess enumeration task (Saariluoma, 1985, 1990) requires discrimination between chess objects, whereas the control task only requires discrimination between foreground and background without regard to the kind of objects (Saariluoma, 1995). We manipulated the relation between chess objects by presenting normal positions

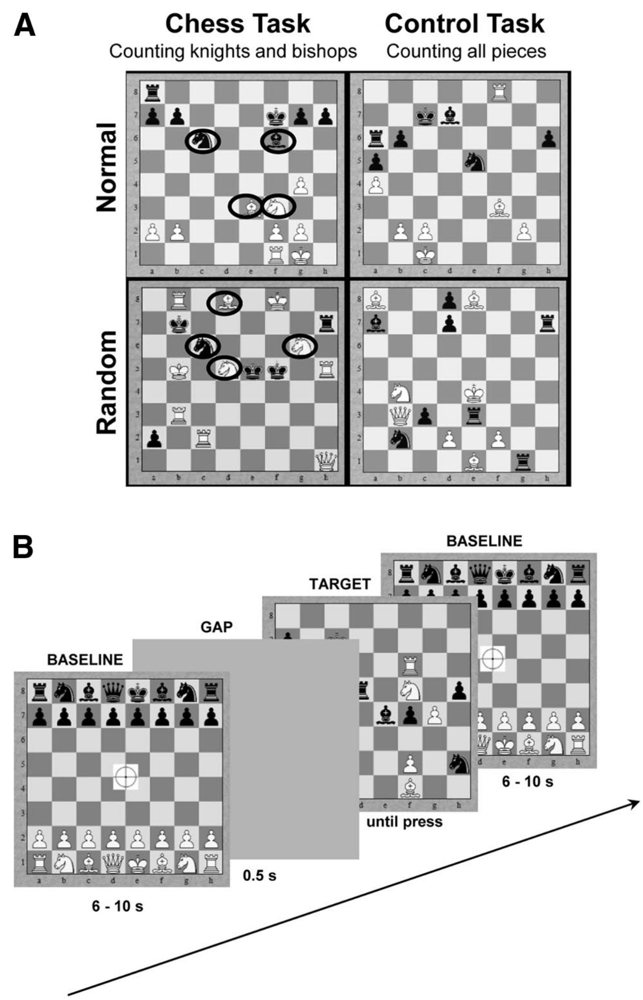

Figure 1. A: The stimuli used in the study. In the chess task (left column), participants had to indicate whether the number of knights and bishops (indicated by circles, which were not seen by participants) was four. In the control task (right column), they had to indicate whether the number of all pieces on the board was 15. The upper row presents normal positions taken from masters games unknown to participants; the lower row depicts random positions obtained by distributing pieces randomly on the board. B: Trial structure. Baseline stimulus was an initial chess board configuration with a fixation cross; its duration was jittered. A gap in stimulus presentation was used as a warning about the upcoming stimulus. The actual chess stimulus (normal and random positions) was then presented. After the players indicated their answers by pressing one of the response buttons, the baseline stimulus of the next trial was presented.

with typical relations between objects and random positions where the objects were randomly scattered on the board, disturbing typical relations. The chess objects and their relations present the

[1] Chunks are meaningful units of a few individual objects that are related to each other: A chair, desk, and a computer together with keyboard would be a single chunk (see also Miller, 1956). However, templates are large constellations composed of a core (a large chunk) and slots that can be filled with other less stable environmental features or with other smaller chunks. Typical ideas of what different types of rooms look like (e.g., office, bedroom) are based on templates.

core of chess-specific knowledge structures (Chase & Simon, 1973; Gobet & Simon, 1996b, 1998; McGregor & Howes, 2002), and, just like how people know by experience where the light switch is typically located in a room, expert chess players should be able to use their knowledge structures to quickly locate certain pieces. Scattering chess objects randomly on the board breaks their typical relations and makes predictions useless. In this situation, pattern recognition has to rely much more on bottom-up input, becoming less efficient (Gobet & Simon, 1996a; Gobet & Waters, 2003). Just like the typical schema about rooms will not be helpful in finding the light switch on, say, the ceiling, expert chess players will not be able to fully use their complex chess knowledge to find randomly scattered chess objects. They can, however, still rely on their superior knowledge about individual chess objects, such as the chess objects' form and function (Kiesel et al., 2009; Saariluoma, 1990, 1995).

Our design thus captures chess-specific pattern and object recognition processes. Besides measuring behavioral responses (reaction time and errors), we also concurrently recorded players' eye movements and neural responses (as measured by functional magnetic resonance imaging [fMRI]). The eye-movement recordings are analyzed to assess perceptual strategies used by experts during domain-related object and pattern recognition, providing important clues about the cognitive mechanisms behind these recognition processes (Rayner, 1998; Underwood, 2005). The neuroimaging data are taken to substantiate the claim of the top-down modulation of two separate processes—object and pattern recognition—by expertise. These data will enable the localization of this modulation in the human brain and thus reveal the neural basis behind two highly important processes in everyday perception. Behaviorally well specified and well understood cognitive processes can provide us with unique information on the function of brain structures associated with these processes (Henson, 2005; Shallice, 2003; Wilkinson & Halligan, 2004). Although a few studies have used chess as a domain of investigations, they featured only novices (Atherton, Zhuang, Bart, Hu, & He, 2003; Nichelli et al., 1994; Onofrj et al., 1995) or were interested in different phenomena (Amidzic, Riehle, Fehr, Wienbruch, & Elbert, 2001; Campitelli, Gobet, & Parker, 2005; Campitelli, Parker, Head, & Gobet, 2008; Saariluoma, Karlsson, Lyytinen, Teras, & Geisler, 2004). The only study designed to investigate questions similar to ours (Campitelli, Gobet, Head, Buckley, & Parker, 2007) unfortunately lacked a control group of novices.

This is regrettable, because neuroimaging studies comparing experts with novices provide valuable insight into the nature and development of cognitive processes behind expertise (Bukach, Gauthier, & Tarr, 2006). The expertise approach (e.g., Bukach et al., 2006) offers a crucial advantage in comparison with classical approaches that hold previous experience constant. The expertise approach explicitly uses a falsifications strategy (Mill, 1843; Popper, 1968; Wason, 1960) by contrasting experts, who possess domain-specific knowledge relevant for the task at hand, with novices, who do not possess this knowledge. This falsifications strategy is difficult to apply to other approaches where participants possess equal knowledge.

Specifically, in the context of the present experimental design, we know that recognition of single isolated objects is related to inferotemporal (IT) brain areas because the neurons in these areas are responsible for shape, size, and orientation discrimination (Logothetis & Sheinberg, 1996; Malach et al., 1995; Tanaka, 1996). We also know that objects are associated with their functions, recognition of which is related to the left posterior middle temporal gyrus (pMTG) around the occipitotemporal junction (Johnson-Frey, 2004; Lewis, 2006; Mahon & Caramazza, 2009). The chess pieces in our experiment are manmade objects that have characteristic visual features but also clearly specified functions through chess rules (e.g., bishop moves diagonally). The fMRI data collected in our experiment will thus show how these brain areas are connected to chess-specific object recognition. Similarly, we also know that recognition of complex stimuli made of different components is accommodated further anterior in the IT areas (e.g., Gauthier, Anderson, Tarr, Skudlarski, & Gore, 1997; Palmeri & Gauthier, 2004; Peissig & Tarr, 2007). In addition, retrieval of semantic knowledge is closely connected to the medial temporal lobe (Baxter, 2009; Eichenbaum, Yonelinas, & Ranganath, 2007; Squire & Zola-Morgan, 1991). Our experimental design will enable us to see if any of these brain areas are also connected to chess-specific pattern recognition. By using a clearly specified domain-specific task, which taps domain-specific object and pattern recognition, together with a control task, we can ascertain that the identified neural correlates are related to these processes and not to familiarity with the stimuli per se.

Finally, the expertise approach will also provide insights on the development of object and pattern recognition processes. If these processes required a quantitatively different transformation of the same knowledge in experts, we would then expect a higher or lesser engagement of the same brain areas in comparison with the brain activity of novices. The engagement of additional or even different brain areas, however, would indicate a qualitative shift with expertise (Palmeri & Gauthier, 2004).

Method

Participants

Eight experts (mean age = 30 years, $SD = 5$) and 15 novices (M age = 29 years, $SD = 4$), all male and right-handed, participated in the study. Although our expert sample is not big, it corresponds to the size of samples used in behavioral research on expertise (e.g., Bilalić, McLeod, & Gobet, 2008b, 2008c, 2009; Brockmole, Hambrick, Windisch, & Henderson, 2008; Kiesel et al., 2009). Most important, our experts were exceptionally skilled players. In competitive chess, players get rated on the basis of their performance against other rated players. The international chess Elo scale is an interval scale with a theoretical mean of 1,500 and standard deviation of 200 (Elo, 1978). Beginners have a rating of around 500, whereas the best players, grand masters, have ratings over 2,500. Experts are players with a rating of 2,000 or more Elo points. Our experts were 3 standard deviations above the average player: on average, 2,108 ± 148 Elo points. Novice players were hobby players who played chess occasionally for recreation. Written informed consent was obtained from all participants, and the study was approved by the ethics committee of Tübingen University.

Stimuli and Design

In the chess task, players had to decide whether there were exactly four knights and bishops (of either color). In the control task, players had to decide whether there were exactly 15 pieces. In both tasks, 20 normal and 20 random positions with between 15 and 18 pieces (and four to six knight and bishops) were presented. The number of correct "yes" and "no" responses was equal in all conditions. The normal positions were taken from a large database of over four million games (ChessBase Mega Base 2007; ChessBase GmbH, Hamburg, Germany; http://www.chessbase.com). These were normal middle-game positions by masters and it is highly unlikely that the games were known to the participants. The random positions were generated by distributing the pieces on the board randomly using the rule that any piece of either color can appear on any square (Gobet & Waters, 2003; Vicente & Wang, 1998).

The dimension of the whole stimulus was 305 × 305 pixels, while the board with the pieces had a dimension of 276 × 276 pixels. The dimension of a single square was 34 × 34 pixels. The physical dimensions of the stimulus were 256 mm for the whole stimulus, 230 mm for the board, and 29 mm for the single square. The setup resulted in a visual field of 14.6° for the whole stimulus, 13.2° for the chess board, and 1.65° for a single square in the board.

Procedure

Before the actual sessions, participants were given two practice trials for each task. The structure of the trial is presented diagrammatically in Figure 1B. In a single trial (see Figure 1B), a chess board with the initial position of a game with a fixation cross in the middle was presented for 6–10 s (baseline). After a short gap (0.5 s), the target stimulus was presented. The stimulus disappeared after participants indicated their response, and the baseline of the next trial was presented. There were four runs, two for each task, with only one task in a single run. In one run, 10 normal and 10 random trials were presented in random order. The runs were block randomized and counterbalanced across participants. The reaction time (or the time to complete the task) was the time from stimulus appearance until response.

Apparatus

Participants' eye movements were recorded by an infrared remote long-range eye-tracking device with a sampling rate of 50 Hz (iView X MEyeTrack Long Range; SensoMotoric Instruments; Berlin, Germany; http://www.smi.de). The eye-tracking system had an error of 0.5–1°, corresponding to 8.6–17.1 mm (or less than half a square) on the board. In both tasks, participants indicated their decision by pressing one of two buttons of an MRI-compatible response device held in the right hand (the left button was for *YES* and the right button was for *NO*). All devices were MRI compatible and did not interfere with participants' performance. Brain activity was measured in a 3-T scanner (Siemens Trio; Siemens AG, Erlangen, Germany) with a 12-channel head coil at the fMRI center in Tübingen, Germany (see Figure S1 in the supplemental materials). Participants saw the stimuli through a mirror mounted on the head coil. The stimuli were projected onto a screen above the head of the participants via a video projector in the adjacent room (see the supplemental materials).

Statistical Analysis

Behavioral analysis. We only considered the correct trials and those that were not longer than 2.5 standard deviations from the average reaction time of each participant in each experimental condition. We used a 2 (expertise: experts, novices) × 2 (type of position: normal, random) analysis of variance (ANOVA) for the chess and control tasks, separately. Additionally, we tested for the difference between normal and random positions using a *t* test for dependent samples, separately for both experts and novices.

Eye-movement analysis. We used a 9-point calibration with biquadratic functions before each run. We created a program in MatLab 7.1 (MathWorks Inc., Natic, MA; http://www.mathworks.com) to analyze the eye-movement data of five experts and six novices (technical problems prevented eye-movement measurement in the other participants). First, we defined a fixation as an event where participants kept their eyes within a diameter of 34 pixels for 80 ms or more. The diameter of 34 pixels is roughly the size of a square on the chess board. We then extracted the fixations for each participant on each position in each task. The number of fixations and average duration of fixation among expert and novice chess players in the chess and control tasks are provided in the supplemental materials.

To differentiate between relevant and irrelevant objects in the stimuli, we identified the areas of interest for each position in the chess task. These were the knights and bishops (see Figure 1A). In the control task, participants had to enumerate all pieces, and all pieces were therefore taken as areas of interest. We then calculated the distance in pixels from every fixation to the center of the nearest area of interest. For each trial, the distances were then averaged separately for individual participants. These averaged distances were used in a 2 (expertise: experts, novices) × 2 (type of position: normal, random) ANOVA for the chess and control tasks, separately. We did the same distance analysis for the initial and subsequent fixations. We also analyzed the first second of each trial in both chess and control tasks (see the supplemental materials).

Neuroimaging analysis. The whole brain was covered using a standard echo-planar-imaging sequence with the following parameters: repetition time (TR) = 2.5 s; field of view = 192 × 192; echo time (TE) = 35 ms; matrix size = 64 × 64, 36 slices with a thickness of 3.2 mm + 0.8 mm gap resulting in voxels with the resolution of 3 × 3 × 4 mm^3. Anatomical images covering the whole brain with 176 sagittal slices were obtained after the functional runs using an MP-RAGE sequence with a voxel resolution of 1 × 1 × 1 mm^3 (TR = 2.3 s, TI [inversion time] = 1.1 s, TE = 2.92 ms).

All fMRI data were analyzed using the Statistical Parametric Mapping software package (SPM5; Wellcome Department of Imaging Neuroscience, London, United Kingdom; http://www.fil.ion.ucl.ac.uk/spm). Data preprocessing involved spatial realignment to the mean image including unwarping, coregistration of the anatomical image to the mean EPI (echo planar image), and the unified segmentation procedure. The normalization parameters to the Montreal Neurological Institute (MNI) brain template (MNI space; MNI Template Avg152T1) from segmentation were used for spatial normalization of the functional images at a voxel size of 3 × 3 × 3 mm^3 and of the anatomical images with a voxel size of

$1 \times 1 \times 1$ mm^3. Finally, the data were spatially smoothed, using a Gaussian filter with 8-mm full width at half maximum.

In the chess task, we modeled the first second of each trial separately from the rest of the trial (modeling the last second produced similar results). The use of the first second ensured that the activation results would not be affected by differences in trial durations. Similar approaches have been used previously (e.g., Iacoboni et al., 2004; Koenig et al., 2005); in the supplemental materials, we provide further evidence that this approach effectively controls for the length of trials. It is important to note that eye-movement parameters (number and duration of fixations) were almost identical for experts and novices within the first second of the trial (see the supplemental materials). The button press was also explicitly modeled, whereas the baseline was implicitly modeled in a general linear model. Modeling of the time series of hemodynamic activation relied on a canonical response function. Autocorrelation correction was estimated with an autoregressive—AR(1)—model and considered by prewhitening the data. A high-pass filter was applied (discrete cosine transform with a cutoff of 128 Hz) to eliminate low-frequency noise components. The control task was analyzed using the same procedure as described above.

In the group analysis, we used the parameters (contrast images) of the individual analysis of each participant to perform a 2 (expertise: experts, novices) $\times$ 2 (type of position: normal, random) ANOVA, including nonsphericity correction (see Friston, Ashburner, Kiebel, Nichols, & Penny, 2007), for the chess and control tasks, separately. Both main effects (expertise and type of position) and their interaction were based on *t* statistics, corrected for multiple comparisons across the whole brain. We set the significance level at $p < .05$ (familywise error correction for multiple comparisons) and considered clusters with a size of five or more voxels only.

We defined regions of interest (ROIs) comprising the significantly activated voxels for the main effect of expertise and the interaction between expertise and type of position in the chess task. For illustrative and descriptive purposes, we used the MarsBaR SPM Toolbox (Marseille ROI Toolbox, Version .041) to extract the parameter estimates (beta weights) for the normal and random positions in the chess task for each participant (see Poldrack & Mumford, 2009). Although this only confirms the whole-brain analysis and gives an overview over different conditions, of crucial interest are the activations in these same regions in the control task. Thus, the outcome of the chess-task ANOVA was used as an independent functional localizer for defining ROIs for the examination of expertise and position-type effects in the nonchess control task. Consequently, we used the same regions and the same procedure to extract activations in the control task.

For graphical presentations of results, we used the SurfRend Toolbox in SPM5 extracting statistical maps, which were then overlaid onto a standard template brain surface with FreeSurfer software (Athinoula A. Martinos Center for Biomedical Imaging, Harvard University, Cambridge, MA; http://surfer.nmr.mgh.harvard.edu/).

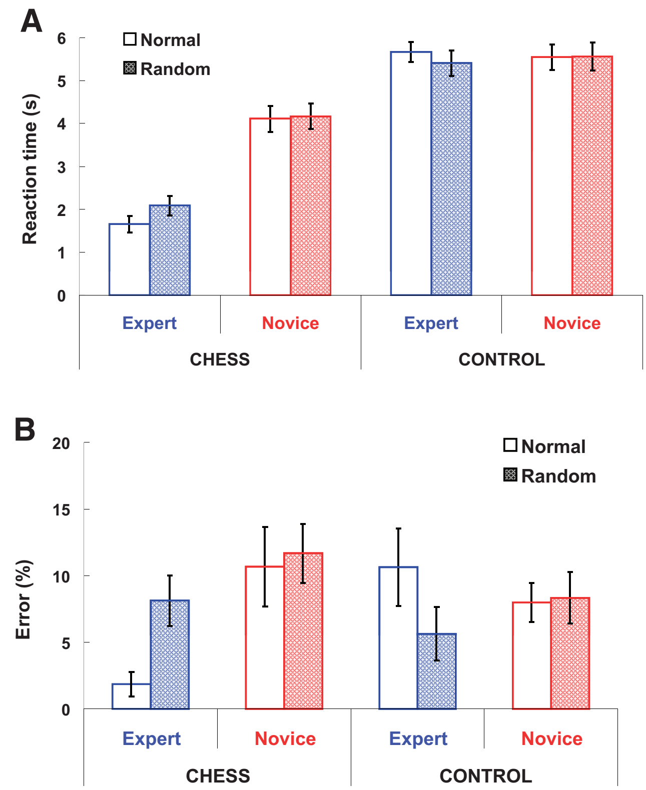

Figure 2. A: Time in seconds experts and novices needed to complete the chess and control tasks depending on the type of position. B: Percentage of errors made by experts and novices in completing the chess and control tasks depending on the type of position. Blue color represents experts; red color represents novices. Error bars indicate the standard error of the mean. * $p < .05$ in a two-tailed *t* test for dependent samples.

Results and Discussion

Behavioral Data

Expert chess players needed only about half the time to enumerate knights and bishops in the chess task compared with novices (see Figure 2A); a two-way Expertise (experts, novices) $\times$ Type of Position (normal, random) ANOVA for the chess task produced a significant expertise effect, $F(1, 21) = 26.7$, $p < .0001$. The type of position also played a role, as the players were faster on normal positions, $F(1, 21) = 6.3$, $p = .021$. This difference was exclusively driven by experts as the difference between normal and random positions was not pronounced among novices: The ANOVA for the Expertise $\times$ Type of Position interaction in the chess task yielded $F(1, 21) = 3.6$, $p = .071$; the *t* test for dependent samples for the differences between normal and random positions was significant only for experts, $t(7) = 6.2$, $p < .001$. In the control task, however, there were no significant differences.

The pattern of errors was similar to the pattern for reaction times. In the chess task, experts tended to make fewer errors than did novices, although this difference did not quite reach significance (see Figure 2B): two-way ANOVA for the expertise effect in the chess task, $F(1, 21) = 3.3$, $p = .082$. Players made fewer errors on normal positions—ANOVA for type of position in the chess task, $F(1, 21) = 4.6$, $p = .044$—but the difference was driven mostly by experts—ANOVA for the Expertise $\times$ Type of Position interaction in the chess task, $F(1, 21) = 2.4$, $p = .131$; normal versus random positions among experts, $t(7) = 3.4$, $p = .011$. In the control task, however, none of the effects or interactions were significant.[2]

Our behavioral data show that the perceptual advantage of experts is closely related to the use of both object and pattern recognition processes. Experts were not faster than novices in the control task, indicating that the general speed of perceptual and response-related processes was comparable between both groups. The differences are thus related to the use of chess knowledge in the chess task. Experts were also affected by randomization, whereas the effect was absent in novices. Experts' performance in the chess task on normal positions was also helped by the processing of relations.

It should be noted that experts still kept a considerable advantage over novices on random positions in the chess task. This is surprising given that previous studies using the recall paradigm (e.g., Chase & Simon, 1973; Gobet & Simon, 1996a) showed that experts are much more affected by randomization than was the case here in the enumeration paradigm. Previous studies also demonstrated that experts can use their pattern knowledge to some extent even in random positions, because some objects form familiar relations by chance (Gobet & Simon, 1996a). It is more likely, however, that experts' advantage on random positions is related to the nature of the enumeration task. In this task, participants need to identify single objects repetitively to count them correctly, whereas the recall task requires the identification of all objects on the board. It is reasonable to assume that the enumeration task draws more heavily on object-recognition processes, whereas the recall task engages more pattern-recognition processes. Random positions disturb the complex relations between objects, thus making it difficult to fully use pattern recognition. The relocated objects in random positions, however, kept the same defining features that make cognitive mechanisms of object identification also applicable to random positions (Kiesel et al., 2009; Saariluoma, 1990).

Eye Movement Data

The reaction times indicate that a highly selective mechanism might be responsible for experts' superior performance, but they do not reveal what kind of mechanism is at work. Recordings of eye movements have often been used to gain insight into problem-solving strategies used by experts and novices (Bilalić et al., 2008c; Charness, Reingold, Pomplun, & Stampe, 2001; De Groot et al., 1996; Gobet et al., 2004; Reingold & Charness, 2005; Reingold, Charness, Pomplun, & Stampe, 2001; Reingold, Charness, Schultetus, & Stampe, 2001). Figure 3A presents individual examples of eye movements of an expert and a novice in the chess task. The top left position in Figure 3A depicts trajectories (lines) and fixations (circles) of the expert (blue color) on a normal position. Video F1 shows the depicted eye movements of the expert in this position in real time and can be seen in the supplemental materials. The top right position in Figure 3A displays the performance of a novice (red color) on the same normal position (corresponding Video F2). The bottom left position in Figure 3A corresponds to the eye trajectories and fixations of an expert on a random position (corresponding Video F3), whereas the bottom right position corresponds to the eye movements of a novice on the same random position (corresponding Video F4). To identify the relevant pieces in the normal position, the expert focused solely on the objects of interest (bishops and knights, highlighted in green in Figure 3A) and disregarded other objects. In contrast, the novice checked almost every single object in the position to be sure how many relevant objects there were. These differences were, however, less pronounced in the random position for the same novice and expert. In contrast, the patterns of eye movements were similar in the control task (see Figure 3B; see also corresponding Videos F5–F8). Similar patterns of results were obtained when we plotted the location of all fixations for all experts and novices in the chess and control tasks on these particular normal and random positions (see Figures 3C and 3D).

The fixations and their durations (see the supplemental materials) confirm the behavioral results, but they still do not reveal the mechanism behind experts' superior performance. We thus calculated the distance of experts' and novices' fixations from the nearest object of interest (chess pieces that needed to be counted) across all normal and random positions in the chess and control tasks (see Figure 4A). In the chess task, experts generally fixated nearer to the objects of interest than did novices: ANOVA for expertise in the chess task, $F(1, 9) = 5.2$, $p = .048$. On the one hand, when experts looked for the objects of interest in normal positions, they fixated closer to the objects of interest than when they dealt with random positions. Novices, on the other hand, could not get much advantage from normal positions: ANOVA for the Expertise $\times$ Type of Position interaction in the chess task, $F(1, 9) = 9.7$, $p = .012$; ANOVA for the type of position, $F(1, 9) = 24.2$, $p = .001$; normal versus random positions among experts, $t(4) = 4.9$, $p = .008$. The absence of the expertise and position-type effects in the control task is not surprising, given that players had to investigate all pieces to count them correctly.

The eye movements suggest that one advantage of experts lies in their pattern knowledge, which can be predictively used to focus exclusively on the objects of interest. The pattern recognition processes were thus a possible reason why experts had their fastest reaction times on normal positions (see Figure 2). To get a better grasp of the pattern recognition mechanism, we analyzed the initial and subsequent (first) fixation among experts and novices in both tasks and both positions.[3] If the pattern recognition mechanism enabled experts to immediately grasp the essence of the position during the initial fixation, then we would expect a major improve-

[2] Experts made more errors than did novices on normal positions, but the difference was not significant. Previous studies (Saariluoma, 1985, 1990) reported similar effects, which probably reflect automatic activation of chess knowledge structures. Although the control task does not require chess knowledge, normal positions feature chess pieces and their typical relations, which may activate chess knowledge structures. This activation interferes with the task, which results in more errors and longer reaction times (see Figures 2A and 2B). Similarly, there was a trend, albeit not a significant one, for experts to have more CoS activation on normal positions than on random ones in the control task too. Some previous neuroimaging studies also reported the phenomenon of automatic activation of expert knowledge regardless of the explicit task (e.g., Gauthier, Skudlarski, Gore, & Anderson, 2000). In this particular case, although the trend was visible, the explicit instruction to use domain-specific knowledge made much bigger differences than did the automatic activation of the same knowledge (see also Harel, Gilaie-Dotan, Malach, & Bentin, in press).

[3] We are grateful to Eyal Reingold for suggesting this analysis.

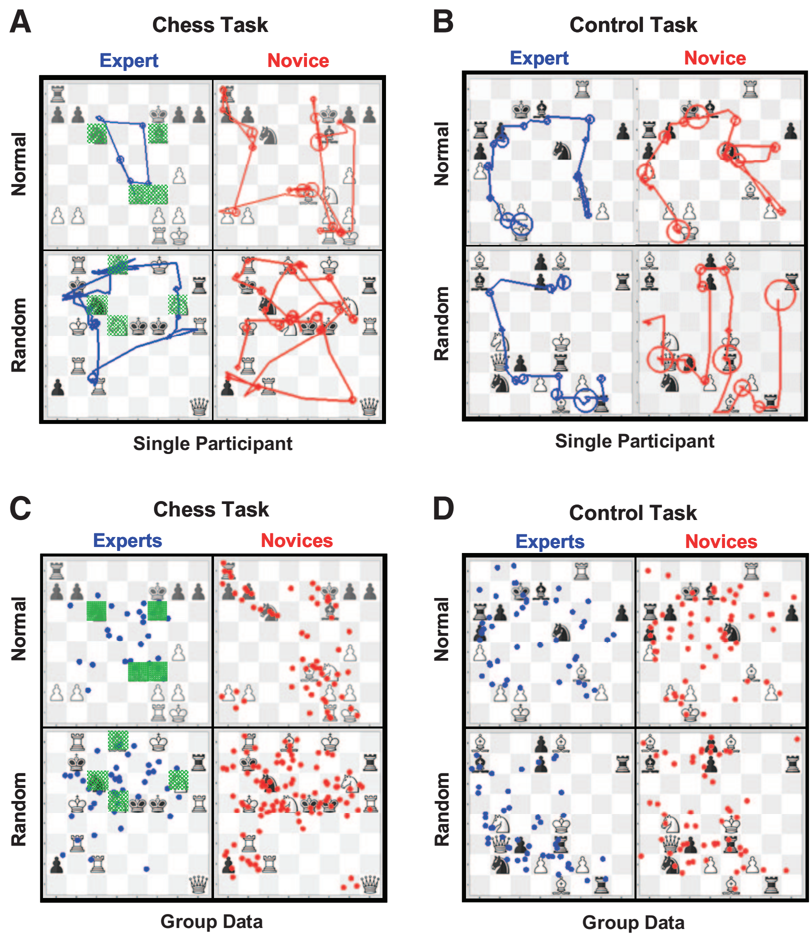

Figure 3. A. An example of the eye-movement trajectories (lines) with fixations (represented by circles; their individual sizes denote the duration of fixation) for an expert (blue color, left column) and a novice (red color, right column) on a normal position (upper row) and a random position (lower row) in the chess task. The objects of interest are highlighted by green squares (for illustrative purposes only). B: Eye-movement trajectories with fixations in the control task. The objects of interest are all pieces on the board. C: All fixations of all experts (blue dots) and novices (red dots) on a normal position (upper row) and a random position (lower row) in the chess task. The objects of interest are highlighted by green squares (for illustrative purposes only). D: All fixations of all experts and novices in the control task. The objects of interest were all pieces on the board. Five experts and six novices were included in the analyses.

ment in the accuracy of the subsequent ("first") fixation.[4] Indeed, Figure 4C shows that only experts could make immediate use of the pattern recognition in the normal position, as the distance to the next object of interest was considerably smaller in the subsequent (first) fixation than in the initial one. On the one hand, experts could not use pattern recognition in random positions, because the patterns of relations were disrupted through randomization. Novices, on the other hand, could not apply pattern recognition in either position type, because they lacked the necessary knowledge structures. A three-way Expertise (experts, novices) × Type of Position (normal, random) × Fixation (initial, first) ANOVA for the chess task produced a three-way interaction that approached significance, $F(1, 9) = 4.5$, $p = .063$; initial versus first fixation on normal positions among experts, $t(4) = 3.2$, $p = .032$. Experts were not generally better than novices at directing their eye movements toward objects in general, because there were no differences in the chess task between groups when the distances from any object, irrespective of its relevance, for the initial and subsequent (first) fixation were measured (see the supplemental materials). Both experts and novices put the first fixation in the chess task on normal positions at approximately the same distance from an object. The only difference is that the objects attended to by experts were mostly objects of interest, unlike the objects attended to by novices. If we apply the same pattern-recognition process

[4] The initial fixation usually falls at the middle of the stimulus because of the previous cross at the same position. Even if some participant tried to immediately focus somewhere else, it is difficult to predict where the objects of interest would be, even on normal positions. Consequently, there should have been (and, indeed, there were) no big differences in the initial fixation.

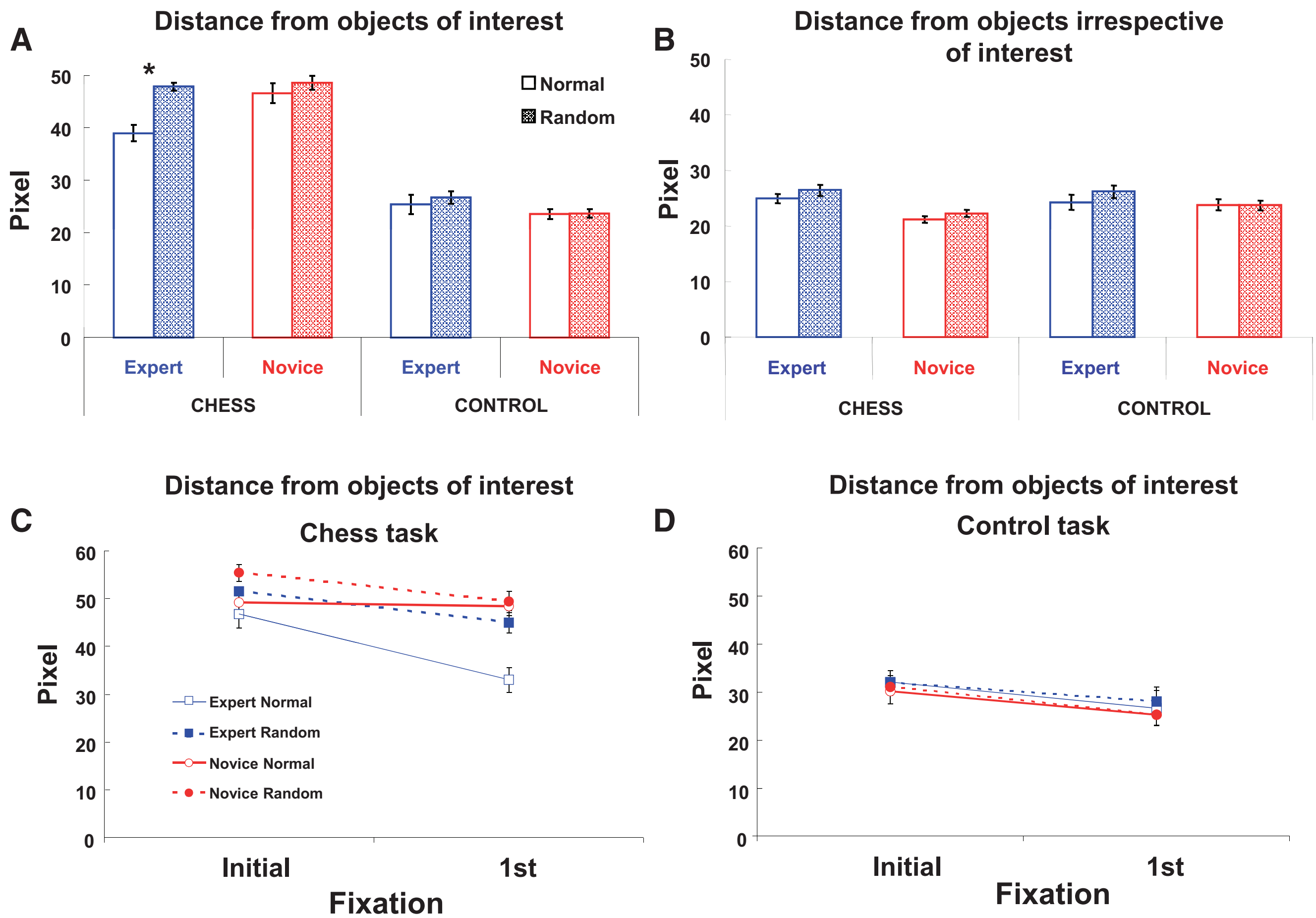

Figure 4. A: Average distance (in pixels) from the nearest objects of interest for experts and novices in the chess and control tasks depending on the type of position (normal or random). B: Average distance (in pixels) from the nearest object irrespective of its importance. C: Average distance (in pixels) from the nearest objects of interest for experts and novices in the chess task, depending on the type of position (normal or random), for the initial and the subsequent (first) fixation in the chess task. D: Average distance from the nearest objects of interest for the initial and the subsequent (first) fixation in the control task. Error bars indicate the standard error of the mean. $^{*}p < .05$ in a two-tailed t test for dependent samples.

several times, as was necessary to enumerate the objects of interest in the chess task, we can understand why experts needed half the time on normal positions, compared with novices. Further evidence for a domain-specific and not general advantage in pattern recognition is given by the control task: Both experts and novices were similarly accurate with both position types in the subsequent fixation (see Figure 4D).

Although the pattern-recognition advantage disappeared on random positions, as indicated by the distance measures in Figures 4A and 4C, experts were nevertheless considerably faster than novices (see the reaction time data in Figure 2A). This seemingly paradoxical result is explained by experts' superior skill in differentiating between individual objects. On the one hand, experts generally do not fixate on the objects exactly, but their vast knowledge about individual chess pieces (Kiesel et al., 2009; Saariluoma, 1990) enables them to identify these symbols even when they focus a few pixels away from the actual object (Charness et al., 2001; Reingold, Charness, Pomplun, & Stampe, 2001). Novices, on the other hand, tend to fixate on the pieces directly, because their lack of knowledge about individual pieces renders the use of parafoveal vision inefficient. This is also evident in the distance measures from the nearest object, irrespective of its relevance, during the whole duration of a trial (see Figure 4B). Experts needed fewer fixations and consequently less time to find the target objects on random positions, because they could make the best even out of the fixations that did not fall exactly at the objects of interests: ANOVA for expertise in the chess task, $F(1, 9) = 14.9$, $p = .004$; the data in the control task are the same as the data in Figure 4A.

Neuroimaging Data

The eye movement analysis shed light on the cognitive mechanism behind experts' superior performance on the chess task. Experts' extensive knowledge facilitates immediate pattern recognition by directing experts toward the relevant objects and allowing them to ignore irrelevant ones. Experts, as compared with novices, spent less time and wandered less on the normal positions, where the common object location and typical relations between them were preserved. In contrasts, in random positions, where the typical relations were disturbed by scattering pieces around, experts could not apply their knowledge-driven predictions to guide their perceptual focus. Nevertheless, experts' greater knowledge about individual objects enabled their superior object recognition, which in turn resulted in superior performance even on random positions. Here we identified the brain structures associated with experts' remarkably efficient use of knowledge. Of particular interest were the main effect of expertise and the interaction in the chess task. The areas that are generally more activated in experts than in novices in both normal and random positions could be seen as the neural basis of experts' ability in differentiating and identifying individual objects, that is, object recognition. The areas that also react to randomization, in particular among experts, would shed light on the neural correlates of pattern-recognition mechanisms that are driven by complex (chess) knowledge structures.

Using fMRI in a whole brain analysis, we found a number of brain areas that were significantly more activated in experts than in novices in the chess task across both positions (for the main effect of expertise, see Figure 5). This network included (a) right collateral sulcus (see Figure 5 for MNI coordinates); (b) left posterior middle temporal gyri (pMTG); (c) right occipitotemporal junction (OTJ); (d) the supplementary motor area (SMA) on the right side, also spreading partly to the left side; (e) left primary motor cortex (M1); and (f) left anterior insula (see Figure 5). In contrast, normal and random positions did not produce different activations in the chess task across groups (main effect of position). Further, the main effects and their interaction were not significant in the nonchess control task.

To illustrate the activation levels in the brain areas that show a main effect of expertise in the chess task, we extracted the parameter estimates in these areas for each condition in both chess and control tasks and plotted the averages in Figure 5 (see Poldrack & Mumford, 2009). As expected, given that all of these areas were selected on the basis of their showing a significant main effect in

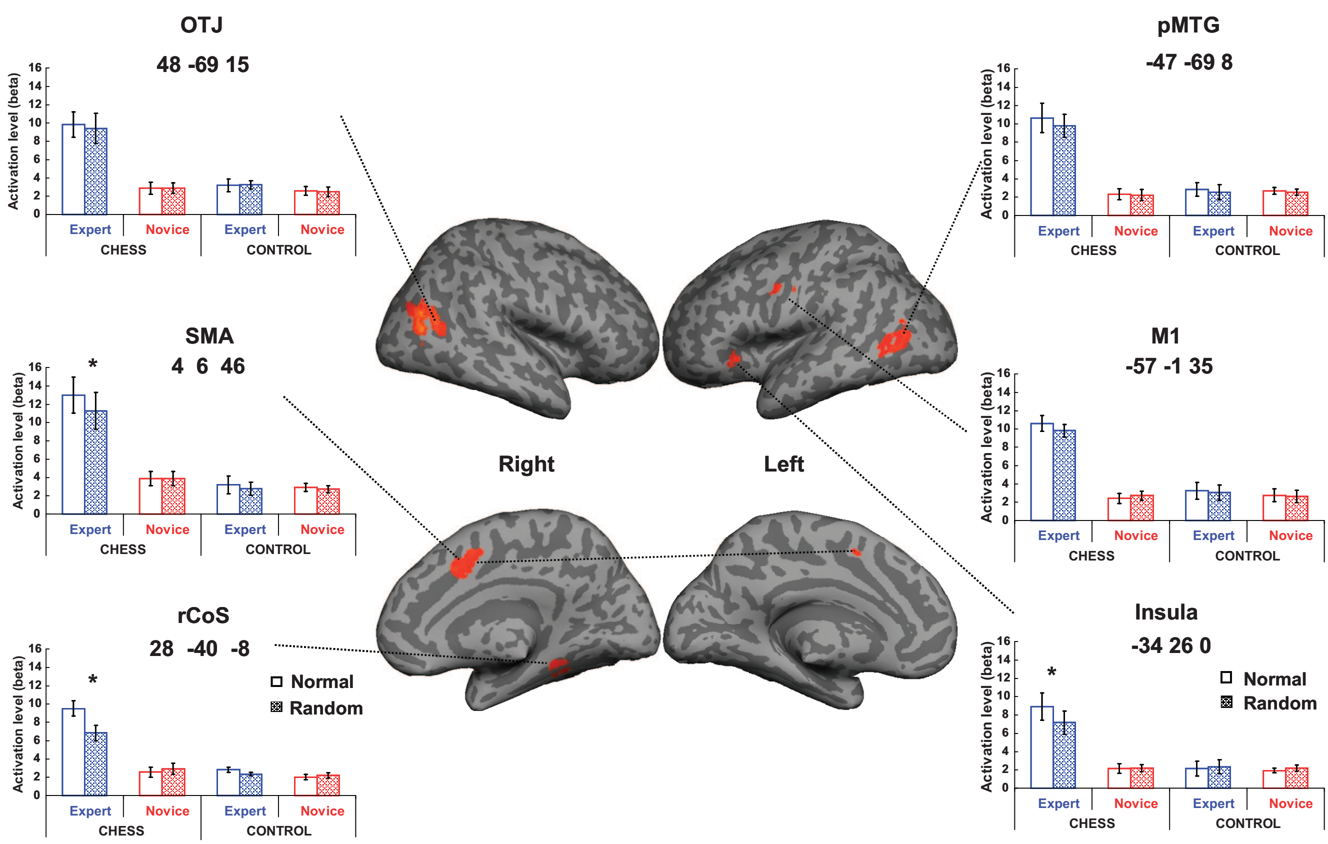

Figure 5. Brain regions more activated in experts than in novices in the chess tasks (main effect of expertise, whole brain analysis; $p < .05$ corrected for multiple comparisons [familywise error], containing at least $k = 5$ voxels) presented on the lateral (top) and medial (bottom) surface of an inflated brain (middle part of the figure). The activation from these regions is extracted and presented in the graph for both chess and control tasks. rCoS = right collateral sulcus (Montreal Neurological Institute coordinates: $X = 28$, $Y = -40$, $Z = -8$); pMTG = left middle temporal gyri ($X = -47$, $Y = -69$, $Z = 8$); OTJ = occipitotemporal junction ($X = 48$, $Y = -69$, $Z = 15$); SMA = supplementary motor area ($X = 4$, $Y = 6$, $Z = 46$); M1 = primary motor cortex ($X = -57$, $Y = -1$, $Z = 35$); Insula = left anterior insula ($X = -34$, $Y = 26$, $Z = 0$). Blue color represents experts; red color represents novices. Error bars indicate the standard error of the mean. $^{*}p < .05$ in a two-tailed t test for dependent samples.

the whole-brain fMRI analysis of differences between experts and novices in the chess task, each single area also showed this main effect (see the supplemental materials for specific comparisons). The same regions were then selected for examining expertise and type-of-position effects in the nonchess control task. Here, the ANOVA yielded neither an expertise effect, an effect of position type, nor an interaction in any area of interest. The disappearance of the expertise effect in the control task implies that the effect is the consequence of the task executed and not of the stimuli, which were the same in both tasks (but see footnote 1).

The significantly higher activations in the frontal lobe (insula, M1, and SMA) probably result from experts' general higher efficiency in the chess task. Although there were no differences in the eye movement parameters in the first second modeled in the fMRI analysis, experts identified more objects of interest in that second than did novices, which lead to (a) an increased counting frequency (inner speech) and (b) more frequent motor preparation, as the trials were more often closer to completion. SMA and M1 activations are generally attributed to processing or preparation of motor responses (Nachev, Kennard, & Husain, 2008), whereas the insula is activated during motor and speech preparation (Ackermann & Riecker, 2004). The analogous differences between normal and random positions in the chess task confirm these assumptions. In all cases, normal positions elicited more activation than did random ones in experts, whereas they did not differ in novices.

The activations in the temporal lobe (OTJ, pMTG, and CoS) are probably related to the advantage that experts have over novices in object and pattern recognition. The activations in the pMTG and OTJ were similar on the normal and random positions among the experts in the chess task, whereas normal positions activated more right CoS than did random ones. Given that the left pMTG and OTJ were not differently activated in normal and random positions, they are most likely responsible for the discrimination between pieces, which was necessary in both normal and random positions. In contrast, the right CoS was sensitive to the randomization, which indicates that it is most likely engaged in pattern recognition: possible on normal positions but difficult, if not impossible, on random positions.

The whole-brain analysis of the interaction between expertise and position type in the chess task supports the claim that the right CoS is involved in pattern recognition. Beside the part of the right middle CoS area that was also significant in the main expertise effect, the equivalent part of left middle CoS also showed sensitivity to the interaction (see Figure 6A). Just like in the previous analysis, we extracted the average activation levels relative to baseline across all voxels activated in these two regions to examine the pattern of results in more detail (see the Method section). As expected, the randomization influenced the activation of this CoS region among experts but not among novices in the chess task (see Figure 6B). When dealing with normal positions, experts' CoSs

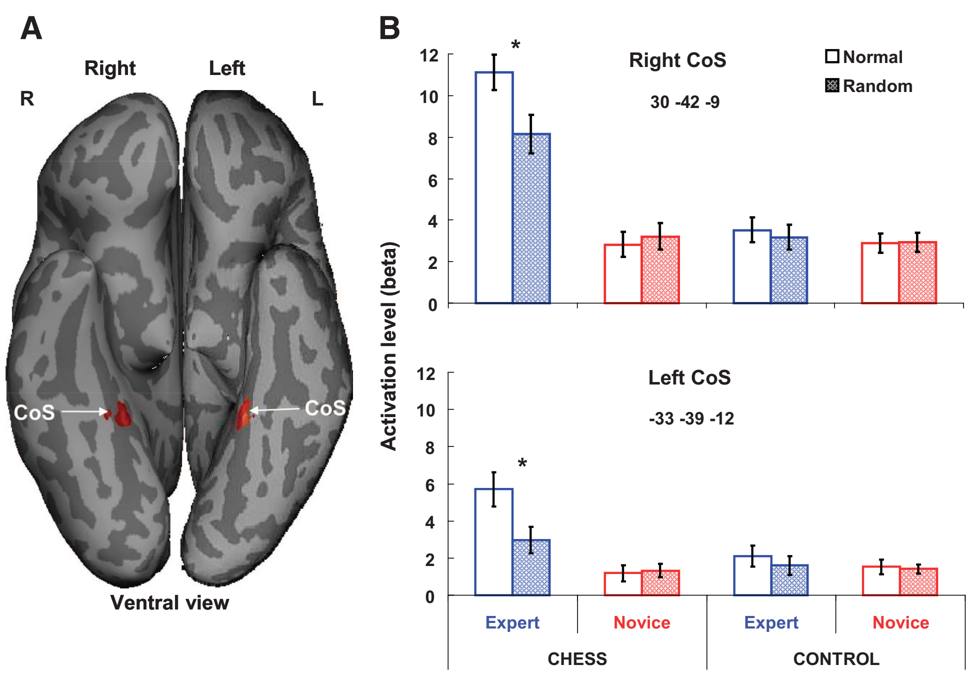

Figure 6. A: The collateral sulci (CoSs) presented on the ventral surface of an inflated brain. The areas on both sides were significant at $p < .05$ (familywise-error corrected) when the whole-brain analysis was performed on the interaction Expertise × Type of Stimuli in the chess task. The areas were used to extract the activation patterns in the chess and nonchess control tasks for each type of position. The exact Montreal Neurological Institute coordinates for the peak values of activated areas in the chess task were $X = -33$, $Y = -39$, $Z = -12$, and $X = 30$, $Y = -42$, $Z = -9$, for the left and right CoSs, respectively. There were 16 voxels activated in the left CoS and six voxels in the right CoS. B: Activation levels (betas) in the left and right CoSs in the chess and control tasks for experts and novices depending on the type of position. Blue color represents experts; red color novices. Error bars indicate the standard error of the mean. * $p < .05$ in a two-tailed t test for dependent samples.

were more activated than when dealing with random positions. In contrast, there was no such difference in the novices.

This pattern of results just confirms the whole-brain analysis, which identified that only these bilateral regions were significantly sensitive to the use of complex chess knowledge (interaction between expertise and position type in the chess task). Of crucial importance, however, is that the same regions did not show the same pattern of results in the nonchess control task featuring the same stimuli. The randomization did not have an effect on the activation of the CoS, nor was the activation greater for experts than novices in the CoS (see Figure 6B). This indicates that the significant differences among experts on normal and random positions in the chess task are not a consequence of greater familiarity with normal positions. Experts were also more familiar than novices were with the normal positions in the control task, but their CoSs were not differently sensitive to normal and random positions. Consequently, the difference in the CoSs activation between normal and random positions in experts is the consequences of the cognitive demands in the chess tasks, that is, the application of complex pattern recognition processes.

The activation changes in the left pMTG, right OTJ, and bilateral CoS followed the pattern of behavioral and eye movement results. Although it is tempting to treat these three levels of evidence as independent measures (e.g., Henson, 2005), a reasonable question is how they are related. It is highly probable that the activations in the inferior and lateral temporal lobe are a consequence of the differences in behavioral and eye-movement responses. We do not believe, however, that the brain activations are solely related to the differences in time and attended parts of the stimuli among experts and novices. Although it is difficult to prove, given the correlational nature of the relationship between behavioral, eye-movement, and fMRI data, our results point out a close and plausible connection between brain activations and specific cognitive processes applied to the stimuli. The brain activations are related to the first second of each trial and not its full duration, during which the largest differences in time and amount of attended material were found. There were no differences in the number and duration of fixations between experts and novices on both position types in the chess task during the first second (see the supplemental materials). Although experts and novices looked at different parts of the stimuli, because experts were focusing more closely on the objects of interest, both groups looked at the same kind of stimuli (chess objects on a chess board). And yet, there were marked differences in the activity levels in the temporal regions between experts and novices in the domain-specific task. This result is difficult to explain without assuming that the cognitive processes were responsible for the differences in the pattern of eye movements. When these processes were of no use in the control task, the differences disappeared. Note that even in the control task, experts and novices also attended to different parts of the stimulus, depending on their strategies. Nevertheless, there were no differences in the activation levels, and the activations among experts tended to be much smaller than in the chess task. This pattern of results indicates that the differences in brain activity were probably related not to the differences in stimulus familiarity per se or to attending to different aspects of the stimuli but most likely to the cognitive processes that produced these differences.

General Discussion

In this study, we used the classic expertise approach along with a mixture of behavioral and neuroimaging techniques to uncover the cognitive mechanisms and neural underpinnings of skilled object and pattern recognition. Experts' superiority in simple object recognition enabled them to be more efficient than novices in a task that required enumeration of certain types of objects. Eye movement analyses suggested that experts' knowledge about individual objects is responsible for their superior performance. Experts do not necessarily need to fixate directly on domain-specific objects to identify them but can make use of their parafoveal vision. Brain imaging suggested that this superiority in simple object recognition is closely related to bilateral activity in the vicinity of the occipitotemporal junction. At the same time, experts' superiority on the chess task was also related to their extensively developed knowledge structures on domain-specific patterns. Experts were particularly efficient in normal positions, where the relations between pieces were intact. Once we disturbed these relations by placing the chess pieces in random positions, experts' performance dropped significantly, indicating that experts could not use their superior complex pattern recognition processes anymore. The recordings of eye movements exposed the highly efficient mechanism that drives experts' superior performance on normal positions. Whereas experts' superior pattern recognition enabled them to exclusively focus on relevant features, novices examined the whole situation to arrive at the same result. The neural correlates of this remarkably efficient skill were found bilaterally in the middle part of the CoS.

Although the randomization of stimuli played a role in experts' performance in the enumeration task, it affected them to a lesser extent than has been found in other paradigms such as recall tasks (e.g., Chase & Simon, 1973; Gobet & Simon, 1996a). Pattern recognition is arguably a more complex and more important process, but its purpose is often inextricably related to object recognition. In the chess enumeration task, pattern and object recognition were both required: Pattern recognition guided the fast and efficient initial orientation toward objects of interest, whereas object recognition enabled their efficient identification. Our results thus underline the importance of object recognition processes that have often been neglected in theories of expertise (e.g., Chase & Simon, 1973; Gobet & Simon, 1996b).

Experts' superiority in chess-specific object identification did not seem to be related to the differences in activity in the posterior IT cortex and fusiform gyrus, brain structures generally believed to be connected to the processing of visual features and even identification of whole isolated objects (e.g., Epstein & Kanwisher, 1998; Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999; Kanwisher, McDermott, & Chun, 1997). Instead, experts' superiority was connected to the bilateral temporal areas. It is known that the left pMTG supports the recognition of verbally or visually presented manmade objects, such as tools, with characteristic action-related function (Noppeney, Price, Penny, & Friston, 2006; Tranel, Martin, Damasio, Grabowski, & Hichwa, 2005). Individual chess objects have functions reinforced through chess rules. Our fMRI findings thus confirm previous behavioral tests (Kiesel et al., 2009; Saariluoma, 1990) in that experts' superiority in the recognition of individual objects mainly comes from their greater functional knowledge of chess objects, not knowledge about specific form.

This implication supports the view that the knowledge about the function of an object plays an important role in its recognition (Allport, 1984; Shallice, 1988; Warrington & Shallice, 1984). Our results also indicate that the left pMTG is important in the recognition of objects that are not tools but that have clearly specified functions. The direct implication is that the pMTG is not important for the category of tools but rather for object properties such as their function (Boronat et al., 2005; Canessa et al., 2008).

However, our results imply that experts' development of object-recognition processes is associated not only with left lateral areas but also with additional right lateral areas around the OTJ. This is a surprising finding given that the right lateral hemisphere, unlike its left counterpart, is usually not engaged in the recognition of everyday manmade objects (e.g., Lewis, 2006). One possibility is that the development of the ability to recognize objects and their functions does not stop with the left lateral areas commonly found for everyday objects people familiar with to a similar extent. In other words, truly superior object recognition found in experts may require qualitatively different cognitive processes that engage additional brain areas. This intriguing possibility remains a speculation that requires further studies using the expertise approach and manmade objects. The notion is, however, consistent with similar discussions about the relationship between increased task difficulty and the additional recruitment of homologous regions of the opposite hemisphere in other cognitive domains such as attention (e.g., Helton et al., 2010; Nebel et al., 2005).

The bilateral middle parts of the CoS were identified as the neural basis of chess-specific pattern recognition, which enables experts to focus on the relevant and ignore the irrelevant aspects of a complex stimulus. The CoS is part of IT, which, in general, supports visual recognition processes but, in particular, supports those with multiple elements (Haxby et al., 1991; Lerner, Hendler, Ben-Bashat, Harel, & Malach, 2001). The areas of IT responsible for visual expertise are developed and fine-tuned by maturation processes that are inextricably linked to stimulus exposure and learning (Grill-Spector, Golarai, & Gabrieli, 2008; Wong, Palmeri, Rogers, Gore, & Gauthier, 2009). Chess is a complex visual game that requires years to master (Campitelli & Gobet, 2008; Charness, Tuffiash, Krampe, Reingold, & Vasyukova, 2005), and our results indicate that the development of chess expertise is also tied to a particular brain region in the inferior temporal lobe. The middle part of the CoS belongs to the parahippocampal cortex (PHC), which is important for episodic memory (Diana, Yonelinas, & Ranganath, 2007). However, the middle CoS also forms a part of the parahippocampal place area (PPA), which is involved in the perception of places and scenes (Epstein, 2008; Epstein & Kanwisher, 1998).

There is currently a controversy about the exact function of the PHC/PPA. According to one theory, the PHC/PPA is particularly activated in a scene because it encodes its spatial layout, independent of its component elements and their identity (Epstein, 2008). Another theory argues that the PHC/PPA is not specifically related to scenes per se but to the activation of relations that the elements in those places and scenes form (Aminoff, Schacter, & Bar, 2008; Bar, 2004; Bar & Aminoff, 2003; Bar, Aminoff, & Ishai, 2008; Bar, Aminoff, & Schacter, 2008). On the one hand, Bar et al. showed that the PPA is more responsive to scenes with numerous objects than to scenes with only a handful of objects (Bar, Aminoff, & Schacter, 2008). Moreover, isolated objects elicit even less activation in the PPA, but there are subtle contextual differences between different objects. Objects (e.g., a cow) found in typical contexts (e.g., valley, grass) that are strongly associated with other objects through their relations elicit more activation than do objects that do not form specific relations (e.g., a personal camera, which can be found almost anywhere). Epstein and Ward (2010), on the other hand, demonstrated that these effects were absent when the presentation time of objects was rather short, which may indicate that visual imagery processes may be responsible for the contextual effect.

We believe that our experiment provides an example of how fMRI studies featuring the expertise approach in conjunction with behaviorally well characterized cognitive processes may inform researchers about the function of the brain areas related to the above-mentioned processes. Chess stimuli have similarities with places and scenes in that both are composed of variable multiple elements. Scenes and places include individual objects, whereas chess positions have an 8×8 chess board and individual chess pieces located on it. Just like the individual elements in scenes, chess pieces in positions are never found in isolation, and they inevitably form relations. These relations are used to form representations of these complex stimuli (e.g., a light switch is usually not located on the ceiling and a bedroom usually does not contain a washing machine) and present essential knowledge about the world (Biederman et al., 1982; Gobet et al., 2001; Shank & Abelson, 1977). The main characteristic of every visual expertise is the recognition of patterns of relations formed by domain-specific elements (Gobet & Simon, 1996b). This enables experts to grasp the essence of the situation in seconds and inevitably leads to appropriate actions (e.g., a person will not look at the floor if he or she wants to switch on the light in a room). The use of clearly specified tasks enabled us to disentangle the mere perception of chess stimuli in the control task from the use of complex expertise skills through processing of complex relations between objects in the chess task. When experts could use this complex pattern-recognition process in the chess task, the CoSs were clearly more activated than when experts were merely perceiving the same stimuli in the control task (see Figure 6B). When these relations between pieces were disturbed on the random positions, the CoSs were significantly less activated in the chess task among experts. Specifically, this suggests that the function of this part of the brain is related to the complex pattern recognition processes in chess. More generally, it means that this area is closely connected to encoding and retrieving the objects and their relations in their typical environment.

There is indirect evidence that the PPA/PHC indeed supports relations between environmental elements. Campitelli et al. (2007) used the classic recall paradigm to show that only the left side of the middle CoS was differently sensitive to normal and random chess positions in experts. In other words, a different paradigm, a gold standard in the expertise research for identifying knowledge structures (Chase & Simon, 1973; Gobet & Simon, 1996b), found an almost identical location for the utilization of pattern recognition. There is also evidence that scrambled places engage the PPA significantly less than intact ones do (Epstein & Kanwisher, 1998). Another indication that the PPA is responsible for relations between individual objects is the finding that the interior of rooms filled with furniture elicited the most activation in the PPA, even more than naturalistic settings (see Figure 6 in Bar & Aminoff, 2003). Moreover, rooms with typical objects elicit more PPA activation than do empty rooms (Bar, Aminoff, & Schacter, 2008; Epstein & Kanwisher, 1998). A reasonable explanation would be that people are much more familiar with rooms and in particular with relations between objects typically found in them than with any particular naturalistic setting. A definitive verdict on this controversy would need a direct manipulation of object relations in the environment (see, e.g., Mandler & Johnson, 1976; Mandler & Parker, 1976; Mandler & Ritchey, 1977) together with an independent localizer (see Friston, Rotshtein, Geng, Sterzer, & Henson, 2006; Saxe, Brett, & Kanwisher, 2006).

There are certainly many aspects in skilled performance of complex cognitive tasks, such as search strategies (Bilalić, McLeod, & Gobet, 2008a; Burns, 2004; van Harreveld, Wagenmakers, & van der Maas, 2007) or the decision-making process (Bilalić et al., 2008b, 2008c, 2009; Forstmann et al., 2008; Gobet et al., 2004; van der Maas & Wagenmakers, 2005), that need to be considered when trying to make a complete picture of expertise. Most researchers agree, however, that pattern recognition based on previously stored knowledge is one of the main engines behind experts' superior performance (Chase & Simon, 1973; De Groot, 1978; Ericsson & Lehmann, 1996; Gobet & Simon, 1996b; Saariluoma, 1995). Our results show that object recognition, a basic process that is often neglected, also plays an important role in experts' performance. Most important, our study demonstrates the advantage of the concurrent application of different techniques in investigating the interplay of these perceptual and mnemonic mechanisms, which form the core of human cognition (Biederman et al., 1982; Gobet et al., 2001; Shank & Abelson, 1977). The reaction-time and eye-movement data enabled us to demonstrate the cognitive mechanisms behind one of the most impressive skills, whereas fMRI data substantiated them by pinpointing their neural basis. Using differently skilled individuals, we were able to gain important insights into the functioning of human cognition. Experts' object recognition may engage new brain regions in addition to those commonly associated with everyday object recognition. The middle part of CoS seems to be the place where the human brain accommodates the highly efficient pattern-recognition mechanism in chess experts, but it may also be the area that is generally associated with the encoding and retrieval of complex relations between individual elements in a complex environment.

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