

Research report

A functional MRI study of high-level cognition. I. The game of chess

Michael Atherton^a, Jiancheng Zhuang^b, William M. Bart^a, Xiaoping Hu^b, Sheng He^{c,*}

^aDepartment of Educational Psychology, University of Minnesota, Minneapolis, MN 55455, USA

^bCenter for Magnetic Resonance Research, University of Minnesota, Minneapolis, MN 55455, USA

^cDepartment of Psychology, University of Minnesota, 75 E. River Rd. Minneapolis, MN 55455, USA

Accepted 6 June 2002

Abstract

Chess is a game that involves many aspects of high level cognition and requires sophisticated problem solving skills. However, there is little understanding of the neural basis of chess cognition. This study employed functional magnetic resonance imaging (fMRI) to identify cortical areas that are active during the analysis of chess positions compared with a spatial task with matched visual stimuli. Bilateral activation was revealed in the superior frontal lobes, the parietal lobes, and occipital lobes. Some small areas of activation were observed unilaterally in the left hemisphere. The left hemisphere showed more activation than the right. Results are discussed in relation to a similar brain imaging study on the game Go.

© 2002 Elsevier Science B.V. All rights reserved.

Theme: Neural basis of behavior

Topic: Cognition

Keywords: Cognition; Magnetic resonance imaging; Neural processing

1. Introduction

The game of chess has a long history in Western intellectual culture. In contrast to many forms of physical games, it taxes the mental resources of the player. Because of this role, the cognitive processes involved in the game of chess have intrigued psychologists for decades [11,18]. Although there is a rich history of psychological investigations of chess playing, such as de Groot's [5] research on memory and expertise, there is very limited understanding of the neural bases of this complex process and what evidence does exist is sometimes contradictory [3]. This dearth of findings in neuroscience is surprising given that chess has been the focus of ongoing artificial intelligence research for half a century [14], yet is understandable given that chess playing is a cognitive task that cannot be studied in nonhuman primates. The emergence of noninvasive functional imaging techniques changed the picture, literally. The present functional magnetic resonance imag-

ing (fMRI) study is intended as an exploration to identify the major cortical areas involved in the analysis of chess positions and strategy formation. We believe that the identification of the common areas involved in high-level cognitive processes such as chess playing can help identify similarities and differences between different tasks. The results of this study can provide the foundation necessary for future imaging research to focus on particular regions and functions, thereby helping to constrain the formation of theories of these cognitive processes.

In the past, researchers had to rely on indirect evidence (e.g. handedness, brain lesions) to make inferences about the underlying neural basis of chess cognition. For example, Cranberg and Albert [3] hypothesized that chess ability is specialized in the right hemisphere, partly because they found high rates of left-handedness among serious players. A more recent PET study [15] measured blood flow differences among color discrimination, spatial discrimination, rule retrieval, and checkmate judgment. Activation from each of these tasks was subtracted from each other in a hierarchical pair-wise sequence (i.e. spatial discrimination–color discrimination; rule retrieval–spatial discrimination; checkmate judgment–rule retrieval). Pre-

*Corresponding author. Tel.: +1-612-626-0752; fax: +1-612-626-2079.

E-mail address: sheng@tc.umn.edu (S. He).

sumably, the subtraction between checkmate judgment and the rule retrieval (determination of whether a piece could be taken in a single move) simulated one of the essential components of chess playing. This subtraction revealed bilaterally activated areas in the occipital and parietal lobes (areas 7, 18 and 20), an area in the superior frontal lobe (area 8), and two prefrontal regions (left orbito-frontal cortex and the right prefrontal cortex).

Studies such as the one by Nichelli et al. [15] can help to identify cortical areas related to the subcomponents of a task. However, sometimes the whole is more than the sum of the parts. In this study, we attempted to study cortical processes when subjects were engaged in a task closely resembling that of a real chess playing situation and then compared the areas activated by chess cognition to activity generated by a visual search task that also engages visual object recognition and attention with matched stimuli.

Although there is still a long way to go from knowing which areas are active to understanding the specific neural mechanisms of a cognitive process, neuroimaging can provide a global view of the activation patterns. This wider perspective allows us to compare general characteristics of cognitive tasks. For example, by comparing a pattern of activations produced by the analysis of a chess game, with a pattern generated by playing Go, one can identify common and different features between them. In fact, the comparison between the cortical activations during chess playing and Go playing (see Discussion and the companion paper for a short introduction to Go) is an important aspect of the current study. In short, through mapping active cortical areas during chess playing, the present study attempts to answer the following questions. Is chess playing more demanding on frontal lobe executive processes or on spatial attention? Based on the Nichelli et al. study [15] and other research on executive and working memory processes we would expect to see a high degree of frontal lobe involvement [12,13]. Are the recently proposed general intelligence areas important for chess play-

ing? A recent study by Duncan et al. [7] has found evidence that general intelligence is localized to regions of the lateral prefrontal cortex. Is this process lateralized? According to Cranberg and Albert's correlational findings we would expect the right hemisphere to exhibit more activation compared to the left [3]. Are the areas activated when playing chess similar to those activated when playing Go? Although we are not aware of any studies directly comparing the neurocognition of chess and Go, we would expect them to share many cognitive components since both are strategic spatially oriented board games, but also to exhibit some differences. Answers to these questions will help provide a solid base and directions for future research.

2. Methods and materials

2.1. Subjects

Seven male novice chess players, all right handed and aged between 24 and 33, volunteered in this study. A novice player was defined as one who knew rules, simple strategy, and at one time had played the game regularly. The data from one of the subjects was discarded because of significant motion artifact. Subjects were recruited from the student population of the University of Minnesota, Twin Cities campus. They were informed of the procedures before the experiment and all provided written consent under the guidelines of the University of Minnesota's human subject review committee.

2.2. Design

Subjects were presented with three stimuli: a blank chessboard, a board with pieces placed randomly, and a middle-game position, examples of these stimuli are shown in Fig. 1. Each individual presentation of these stimuli

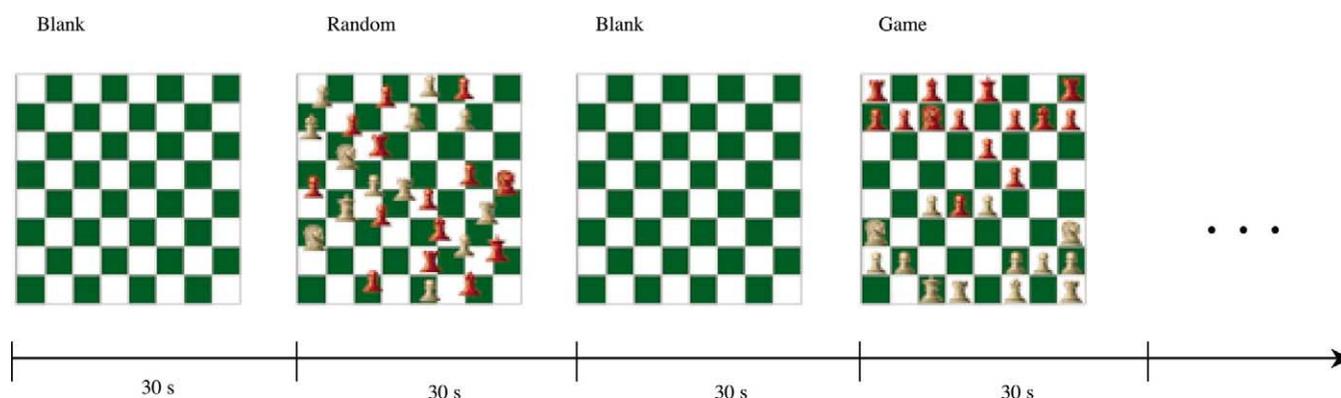


Fig. 1. Examples of the three stimuli presented to subjects in separate blocks. The blank board was used as a baseline condition. The random board was used to control for shared cognitive tasks. The game board was designed to isolate activation associated with chess playing. The sequence displayed above was repeated three times in the same order during one scan, but with a new stimulus in each game or random block. Each board was displayed for 30 s for a total scan time of 6 min. The order of the random and game boards was reversed for alternate scans.

constituted one 30 s block of a block-design paradigm. The random and game positions were presented in an alternating sequence, separated by presentations of the blank board (Fig. 1). This sequence was presented three times during each scan. Three functional scans were taken of each subject, each time with new stimuli and with the order of game and random blocks reversed.

2.3. Materials and procedure

2.3.1. Blank board condition

A blank chessboard was used as a baseline condition during which subjects were asked to look at the center of the board.

2.3.2. Game condition

Middlegame positions were selected from De Firmian and Korn [4] by an experienced player who judged them to be of approximately equal complexity. The total number of pieces per board ranged from 25 to 30 with an average of 27.1 pieces per presentation. The total number of pieces was equal for each contemporaneous pair of game and random presentations. Subjects were asked to determine the next best move for White.

2.3.3. Random condition

Pieces were positioned in a randomly dispersed pattern on the board. The placement of pieces in the middle of squares was avoided, because during pilot testing subjects indicated that such placement initiated thoughts of possible moves. Several pieces of each color were marked with a low contrast embedded five-pointed star. Subjects were asked to search and identify those star-marked pieces.

2.3.4. Presentation

Images were projected onto a translucent screen which subjects viewed from inside the scanner through a mirror positioned above their eyes at a 45° angle. The stimuli extended a visual angle of 6° in both the horizontal and vertical dimension. The timing and sequencing of stimuli was controlled with a personal computer.

2.4. MRI acquisition

Images were acquired with a 1.5T Siemens Vision MR system (Siemens Medical Systems, Iselin, NJ, USA). Depending upon the anatomy of the subject, fourteen to sixteen sagittal slices were taken. T2* weighted images were taken using a single-shot echo-planar imaging (EPI) sequence (TR/TE 3 s/55 ms, matrix: 64×64, and FOV varying between subjects from 24×24 cm² to 26×26 cm²). The duration for a complete functional scan was 6 min. T1-weighted images of the same slices as the T2* images were taken for anatomical overlay and stereotaxic transformation.

2.5. Data analysis

Data analysis and registration were performed using the software package BRAINVYAGER 4.2.0 [8,9,21]. Before image coregistration, the time series of functional images were aligned for inter-slice time delay. The 2-D functional statistical parameter map and the 3-D anatomical map were then co-registered and transformed into Talairach space [20]. For each voxel, the time series was also temporally bandpass filtered, with the limiting frequencies at 3 and 39 cycles/scan. Idealized boxcar predictor waveforms for the random and game conditions were convoluted with a linear model of hemodynamic response. Contrasts between these two predictor waveforms were computed using the general linear model (GLM) using preprocessed and z-normalized time courses.

3. Results

In a blocked design, subjects were presented with three stimuli in alternating blocks: a blank board, a board with pieces arranged randomly, and a board with a middlegame chess position. In the blank condition, subjects were asked to fixate in the center of the board. In the random condition, subjects were asked to identify pieces marked with a five pointed star among randomly arranged pieces. In the game condition, subjects were asked to think of the next best move for White. Many cortical areas were active during the scan, but the analyses focus on contrasts between the random and game conditions.

For six chess players, their cortical activations in different experimental conditions were compared using a fixed effects analysis after data were spatially normalized into a common stereotaxic space [20]. The group results of a subtraction between game condition and the random condition ($r > 0.37$, $P < 0.0005$) identified the regions depicted in Fig. 2. Their Talairach coordinates and relative sizes are listed in detail in Table 1. In general, there are bilateral activations in the premotor area of the frontal lobes, the parietal lobes, and occipital lobes. A large posterior continuous pattern of activation was observed that extends bilaterally across Brodmann's areas (BA) 7, 19, 39, and 40. In addition to the bilateral activations, there are additional areas that were active only in the left hemisphere. These additional areas are distributed in the left hemisphere (BA 6, 8 and 9) and the left hemisphere of the cerebellum.

To illustrate the differences in activations in the different blocks during the scan, Fig. 3 shows two example time courses for two regions, one in the frontal lobe and one in the parietal area. Both time courses show a clear pattern of activation associated with the blank (gray), random (green) and game (red) conditions. The time course for the frontal region shows a higher activation during the game condition, a lower activation during the random condition, and

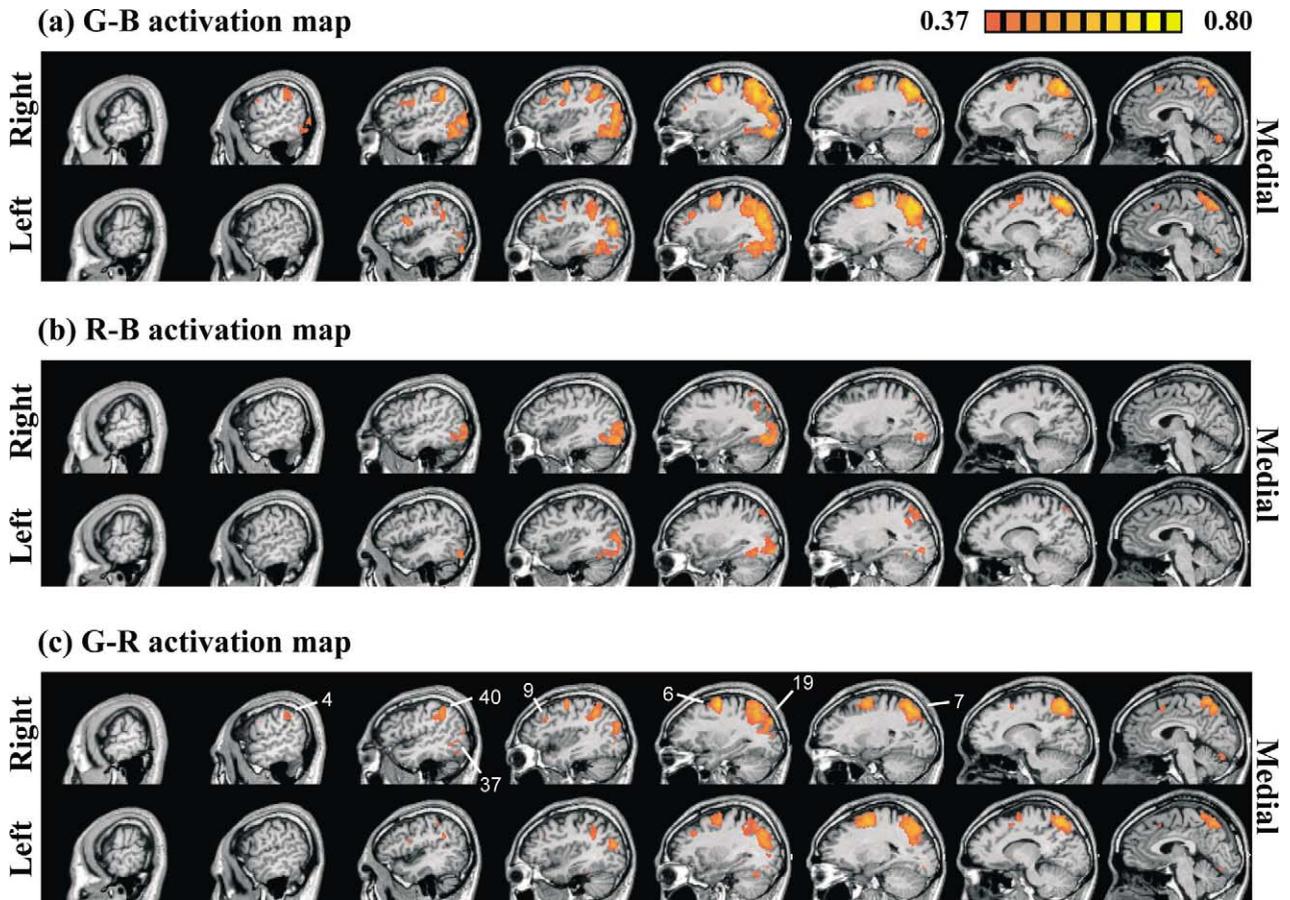


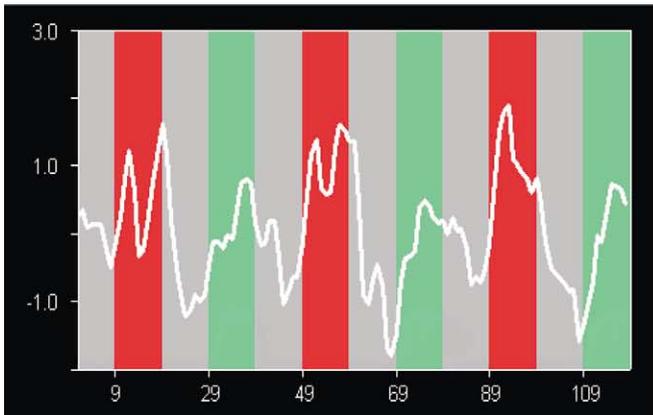
Fig. 2. Sagittal slices showing activation revealed by the three paired comparisons (G–B, R–B, G–R) from cross subject analysis. Selected Brodmann’s areas are labeled with numbers in the G–R maps.

Table 1
Active clusters and coordinates^a

Hemisphere	N	x	y	z
Right	559	27	-59	-233
	172	40	-54	-2
	659	30	30	34
	6	29	58	1122
	29	38	-31	-19
	23	27	-38	-7
	2322	23	-77	-13
	77 022	<i>1,33</i>	<i>-12,119</i>	<i>41,65</i>
25 742	<i>1,43</i>	<i>-83,-38</i>	<i>-2,66</i>	
RH total: 47.4%	34 565			
Left	854	-1	-72	-20
	15	-24	-76	-17
	40	-34	51	-1
	804	-36	24	32
	239	-41	-53	-4
	83	-42	-62	-15
	446	-43	-65	1
	6852	<i>-1,-41</i>	<i>-12,16</i>	<i>41,67</i>
29 906	<i>-1,-58</i>	<i>-29,-85</i>	<i>4,65</i>	
LH total 52.6%	38 385			

^a N is the number of voxels (each voxel is 1 mm³). Talairach coordinates indicate the center of an area, except for the largest clusters in each hemisphere which is specified by their boundaries. BA indicates the Brodmann’s areas touched by an active cluster of voxels. Italicized coordinates represent the boundaries of a large connected area which spans a number of Brodmann’s areas. Total numbers of activated voxels include only those for the cerebrum.

A. Bilateral Frontal Area (BA 6)



B. Bilateral Parietal Area (BA 7)

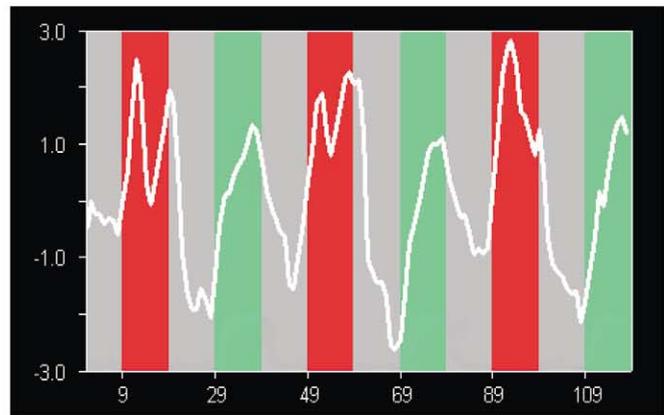


Fig. 3. Sample time courses for one subject. Red bars label the game condition and the green bars label the random condition.

even lower activation during the baseline condition. The time course for the region in the parietal lobes exhibit a similar activation pattern, but with a higher amplitude.

4. Discussion

The pattern of activations in Fig. 2 is consistent with the involvement of a number of general cognitive processes in chess play. It also provides tentative answers to some important questions. It is reasonable to ask if chess is primarily a logical/computational skill or a spatial one. The high degree of activation in the parietal areas and the lack of activation in the left lateral frontal lobe, normally associated with traditional measures of intelligence and logical reasoning [7,10], are surprising and may suggest that chess cognition is primarily spatial. This inference is also supported by the high degree of activation in the occipital/parietal lobes, which may indicate preliminary spatial and visual processing. Conversely, it may also suggest that the parietal areas may be capable of more than just spatial orientations but also more complex spatial computations involving the interaction of stored knowledge and incoming spatial information. This interpretation is supported in part by research showing that areas of the parietal lobes are involved in numeric comparison [16] and approximation [6], as well as complex spatial tasks such as mental rotation [17]. Much of the activation in the parietal lobes could be related to the mental imagery involved in checking plausible moves, and the superior frontal areas may be involved in the maintenance [2] and possibly the selection of spatial patterns within the posterior regions.

There was little activation observed in the temporal lobe in contrast to the findings in the chess imaging study by Nichelli et al. [15]. This discrepancy may be explained by the fact that subjects in the current study were asked to identify pieces in the control condition and the object recognition processing normally associated with inferior

temporal areas may have been factored out in the game–random subtraction.

The most interesting finding is the paucity of activation in the frontal lobes. Although these results may be due to a lack of statistical power, we believe that they accurately reflect the cognitive characteristic of chess cognition. If our conclusion is correct, then it is especially intriguing given Duncan et al.'s study [7] hypothesizing that general intelligence is localized in the lateral frontal cortex of one or both hemispheres. In particular they hypothesized that Spearman's *g*, which is characterized as a single factor underlying performance on cognitive tasks (rather than drawing on a diverse set of skills), is restricted to specific areas in lateral frontal cortex. Although we did find scattered activations in the frontal lobes, these seem to be localized in Brodmann's areas 6 and 8 rather than the prefrontal cortex areas in the vicinity of 45 and 46 identified by Duncan et al. An analysis of individual subject's scans in the current study verified that areas 45 and 46 do not show significant activations which rules out the possibility that individual differences in anatomy may have caused these activations to be lost in the averaged data. A possible conclusion is that there may be complex problem solving skills (such as chess) that are not associated with *g* and are supported by areas other than the lateral prefrontal cortex. This inference is corroborated by an imaging study of the cognitive processes involved in the complex Chinese board game Go [1]. Go is also a strategic spatially orientated board game, but differs from chess in that there is no differentiation of individual pieces other than that between players (black vs. white). However, in Go as in chess, strategy is determined by varying configurations of pieces on the board. The Go study, which used the same basic methodology as the current study (realistic game positions for the game condition and randomly dispersed pieces for the random condition), found activations in similar areas as those identified for chess and the same lack of frontal activations. Indeed, the main differ-

ence between the two studies was activation observed in area 44 for some of the Go subjects. This activation in an area normally associated with speech production might occur because Go players maybe more familiar with the names of strategic positions than chess players [22]. Another important result is the lack of significant hemispheric lateralization in the current study. At the gross level, cross-subject analysis in this study shows that approximately 52.6% of the voxels revealed in the game–random contrast are located in the left hemisphere. Similar lack of hemispheric lateralization was also found in the Go study. This is especially surprising given that the right hemisphere has been demonstrated to be contributing more to spatial processing [19].

To delineate the specific functions of these individual areas, future research may need to adopt an event-related design to trace the dynamics of the activities. The lack of activation in lateral prefrontal areas remains a puzzling observation and needs to be supported with converging evidence. Overall, we believe that the current study provides tentative answers to important questions regarding high-level cognition and problem solving, and lays a solid foundation for future explorations in this complex area.

Acknowledgements

This research is supported by grant MH55346 to XH and a Sloan Foundation Research Fellowship and a McKnight–Land grant professorship to SH.

References

- [1] X. Chen, D. Zhang, X. Zhang, Z. Li, X. Meng, Functional MRI study of high-level cognition: Go, *Cogn. Brain Res.*, (this issue).
- [2] S.M. Courtney, L. Petit, J.M. Maisog, L.G. Ungerleider, J.V. Haxby, An area specialized for spatial working memory in human frontal cortex, *Science* 279 (1998) 1347–1351.
- [3] L.D. Cranberg, M.L. Albert, The chess mind, in: L. Kober, D. Fein (Eds.), *The Exceptional Brain: Neuropsychology of Talent and Special Abilities*, The Guilford Press, New York, 1988, pp. 156–190.
- [4] N. De Firmian, W. Korn (Eds.), *Modern Chess Openings: MCO-13*, 13th Edition, David McKay, New York, 1990.
- [5] A.D. De Groot, *Thought and Choice in Chess*, Basic Books, New York, 1965.
- [6] S. Dehaene, E. Spelke, P. Pinel, R. Stanescu, S. Tsivkin, Sources of mathematical thinking: behavioral and brain-imaging evidence, *Science* 284 (1999) 970–974.
- [7] J. Duncan, R.J. Seitz, J. Kolodny, D. Bor, H. Herzog, A. Ahmed, F.N. Newell, H. Emslie, A neural basis for general intelligence, *Science* 289 (2000) 457–459.
- [8] R. Goebel, D. Khorram-Sefat, L. Muckli, H. Hacker, W. Singer, The constructive nature of vision: direct evidence from functional magnetic resonance imaging studies of apparent motion and motion imagery, *Eur. J. Neurosci.* 10 (1998) 1563–1573.
- [9] R. Goebel, D.E.J. Linden, H. Lanfermann, F.E. Zanella, W. Singer, Functional imaging of mirror and inverse reading reveals separate coactivated networks for oculomotion and spatial transformations, *NeuroReport* 9 (1998) 713–719.
- [10] V. Goel, R.J. Dolan, Anatomical segregation of component processes in an inductive inference task, *J. Cog. Neurosci.* 12 (2000) 110–119.
- [11] D.H. Holding, *The Psychology of Chess Skill*, Lawrence Erlbaum, Hillsdale, 1985.
- [12] R. Levy, P.S. Goldman-Rakic, Segregation of working memory functions within the dorsolateral prefrontal cortex, *Exp. Brain Res.* 133 (2000) 23–32.
- [13] E.K. Miller, The prefrontal cortex and cognitive control, *Nature Rev. Neurosci.* 1 (2000) 59–65.
- [14] M. Newborn, Deep Blue’s contribution to AI, *Ann. Math Artif. Intell.* 28 (2000) 27–30.
- [15] P. Nichelli, J. Grafman, P. Pietrini, D. Alway, J.C. Carton, R. Miletich, Brain activity in chess playing, *Nature* 369 (1994) 191.
- [16] P. Pinel, S. Dehaene, D. Riviere, D. LeBihan, Modulation of parietal activation by semantic distance in a number comparison task, *NeuroImage* 14 (2001) 1013–1026.
- [17] W. Richter, K. Ugurbil, A. Georgopoulos, S. Kim, Time-resolved fMRI of mental rotation, *NeuroReport* 8 (1997) 3697–3702.
- [18] P. Saariluoma, *Chess Players’ Thinking: A Cognitive Psychological Approach*, Routledge, New York, 1995.
- [19] S.P. Springer, G. Deutsch, *Left brain, right brain: perspectives on cognitive neuroscience*, 5th ed., Freeman, New York, NY, 1998.
- [20] J. Talairach, P. Tournoux, *Co-planar Stereotaxic Atlas of the Human Brain*, Thieme, Stuttgart, 1988.
- [21] L. Trojano, D. Grossi, D.E.J. Linden, E. Formisano, H. Hacker, F.E. Zanella, R. Goebel, F. Di Salle, Matching two imagined clocks: the functional anatomy of spatial analysis in the absence of visual stimulation, *Cerebral Cortex* 10 (2000) 473–481.
- [22] A. Yoshikawa, T. Kojima, Y. Saito, Relations between skill and the use of terms—an analysis of protocols of the game of Go, *Lect. Notes Comput. Sci.* 1558 (1999) 282–299.