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Research report

A functional MRI study of high-level cognition
II. The game of GO

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Abstract

GO is a board game thought to be different from chess in many aspects, most significantly in that GO emphasizes global strategy more than local battle, a property very difficult for computer programs to emulate. To investigate the neural basis of GO, functional magnetic resonance imaging (fMRI) was used to measure brain activities of subjects engaged in playing GO. Enhanced activations were observed in many cortical areas, such as dorsal prefrontal, parietal, occipital, posterior temporal, and primary somatosensory and motor areas. Quantitative analysis indicated a modest degree of stronger activation in right parietal area than in left. This type of right hemisphere lateralization differs from the modest left hemisphere lateralization observed during chess playing.

Theme: Neural basis of behaviour

Topic: Cognition

Keywords: GO; Neural basis; Functional MRI; High-level cognition

1. Introduction

GO is a traditional Chinese board game played on a square board consisting of 19 by 19 cross lines (Fig. 1). It has very simple rules [10] and is believed to be fundamentally different from chess in the mental strategies involved. During a GO game, two players, one holding white small round pieces (called stones) and the other holding black ones, take turns to place a stone onto one of many possible line intersections on the board. The player's goal is to enclose areas as large as possible and to prevent the opponent from achieving the same objective. Since the black or white stones are identical other than the difference in color, the key factor in GO playing is spatial positioning. In chess, however, it is different in that many chess pieces have their specific identities and functions, and players always try to move a proper piece to a proper position according to the game rules.

Another intriguing point about these two games is that the program running on IBM supercomputer 'Deep Blue' could compete with world chess champion Kasparov, but the best GO program has never been able to challenge even mid-level amateur players [9]. Many people believe that GO playing is intrinsically more human, the massive search-tree strategy effective for chess is not very useful for GO programming. In light of this difference between GO and chess, it is also important to examine whether GO or chess has more involvement of the recently proposed general intelligence areas [6].

Many questions remain to be answered in understanding the neural basis of GO playing. Our goal in this study is a

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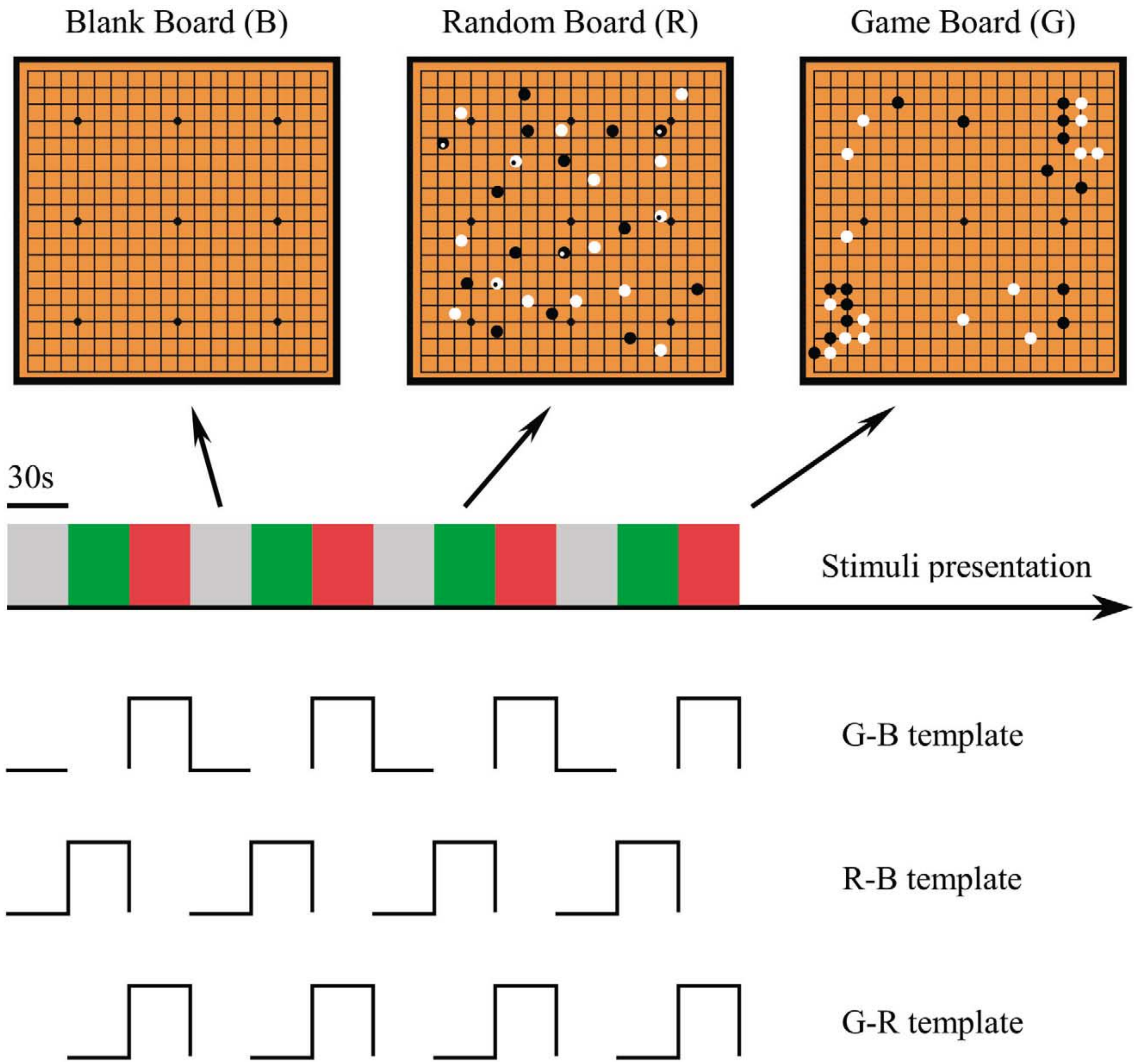


Fig. 1. (Top): Three boards presented to the subjects when they were scanned. Blank board: a blank GO board with 19 equidistant horizontal lines intersecting 19 equidistant vertical lines at a right angle; Random board: 30 stones (equal black and white ones, not on the intersections) randomly placed on the board, and six (three black, three white) of them had one low contrast dot for subjects to search for; Game board: 30 stones placed on the board at the positions of a game situation. (Middle): Stimuli presentation sequence, in which each condition was displayed for 30 s. B, blank board; R, random board; G, game board. (Bottom): Three templates used in correlation analysis. G-B template was used to identify the brain areas activated in GO playing including basic visual processing regions by comparing the game board condition with the blank board condition, R-B template to identify the areas related to visual searching including basic visual processing regions, and G-R template the areas more specific for GO playing.

modest one. First, we wanted to identify the areas that are important for this complex cognitive process. With this knowledge, we will be able to examine several other issues while comparing it with what was described in the accompanying paper on chess playing [1]: Are the same areas involved in playing GO and chess? Are there different degrees of lateralization in GO and chess? What are the roles of the general intelligence areas [6] in these two games?

2. Materials and methods

2.1. Subjects

Six male university students, all amateur players of GO with skill levels from level 1K to 1D (nonprofessional ranking) participated in the study. They were all right-handed and neurologically normal volunteers with informed consent.

2.2. Paradigm

In addition to the anatomical scans, each subject had three functional scans, each contained four cycles of the three blocked conditions described below (Fig. 1).

2.2.1. Blank board condition

Blank board without any stones. Subjects were asked to simply keep looking at the center of the board on the screen (fixating task).

2.2.2. Random board condition

The random board had 30 stones (15 black and 15 white) randomly placed off the line intersections. Six (three black, three white) of them contained a low contrast dot. Subjects were instructed to search for the stones with low contrast dots among the 30 stones (visual search task).

2.2.3. Game board condition

The game board had 30 stones placed at the legitimate positions of a realistic game situation. Subjects were instructed to work out the next reasonable position for black stone in 30 s (GO playing task). All game board designs were tested by other amateur players with similar skill levels to ensure that 30 s was a reasonable amount of time to come up with a solution.

2.3. Stimuli presentation

A computer controlled video projector presented the stimuli onto a translucent screen placed near the scanner bed. The stimuli extended a $5° \times 5°$ visual angle on the screen. Subjects viewed the stimuli through a mirror placed above his eyes. Each of the blank, random, and game conditions was displayed for 30 s in turn during the scan, which lasted for 6 min composed of four blocks of each condition (Fig. 1). The random and game conditions always had a new design for each block.

2.4. MR data acquisition

Imaging data were collected with a GE 1.5 T MR scanner (GE Medical Systems, Milwaukee, WI, USA); 16–18 sagittal slices (7 mm thick, with a 2.1-mm gap between adjacent slices) were acquired during the functional scans, using an echo-planar imaging (EPI) sequence (TE: 55 ms, TR: 3 s, FOV: 24×24 cm^2, matrix: 64×64). T1-weighted images were also acquired for anatomical overlay and stereotaxic transformation.

2.5. Data analysis

Data analysis was carried out with AFNI [5] (another software package, BrainVoyager, yielded similar results). For each subject, head movement was first corrected, correlation analysis was then carried out using three different templates to reveal modulation of cortical activation by the different pairs of conditions: G-B, R-B, and G-R templates (Fig. 1, bottom). In group analysis, after being stereotaxically transformed into a common space [18] and spatially smoothed with a Gaussian filter (FWHM=3.75 mm), all subjects' functional data were concatenated together. Fig. 2 shows the resultant maps from the correlation analysis on the concatenated data ($P \leq 0.000001$). For the areas identified by the group analysis, more detailed quantitative analysis was carried out on individual subject's data. To address the lateralization issue, *t*-test was used to compare the volume and the mean percent BOLD signal change between the homologous regions of the two hemispheres.

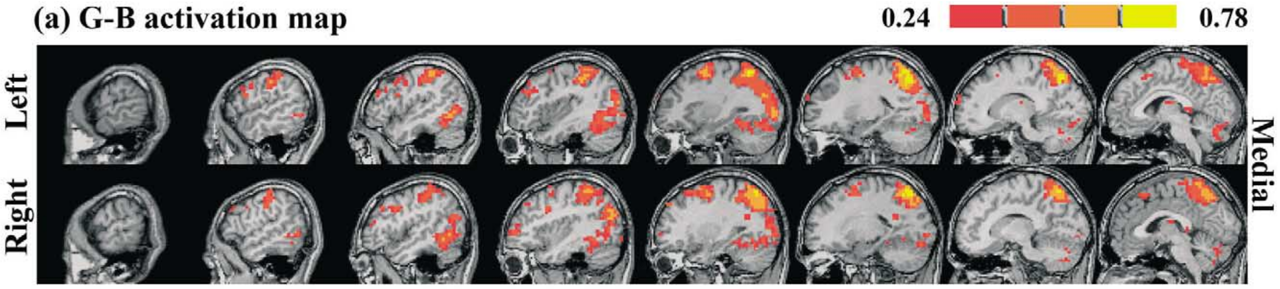
3. Results

The G-B activation map in Fig. 2a showed that the mid-dorsal prefrontal area (BA9), the dorsal prefrontal area (BA6), the parietal areas (BA7, 40), the occipital areas (BA17/18/19), the posterior temporal area (BA37), and the primary somatosensory and motor areas (BA3-1-2/4) were significantly ($P \leq 0.000001$) activated when the subject was playing GO compared to looking at a blank board. The details of these activated areas are listed in Table 1. Since the Game condition has added black and white stones on board compared to the Blank condition, the areas revealed by G-B may include those involved in basic visual processing. The R-B activation map displayed significant ($P \leq 0.000001$) activation in BA6, 7, 17/18/19, 37 (Fig. 2b and Table 1), which included the early visual areas. Therefore, areas simply responding to the visual stimulation were cancelled in the G-R comparison (Fig. 2c, $P \leq 0.000001$). In G-R contrast, most areas activated in G-B were also activated with somewhat smaller volumes, and not surprisingly BA17/18 dropped out in the G-R comparison. The activities in the posterior cingulate areas (BA30/31) were highlighted in both G-R and G-B, but not in the R-B contrast. Left BA44/45 was another ROI only revealed in the G-B and G-R but not R-B. The Talairach coordinates of the areas significantly activated in the G-R comparison are listed in Table 1. The volumes and mean percent changes of BOLD signal of the activated areas in G-B, R-B and G-R maps are presented in Table 2.

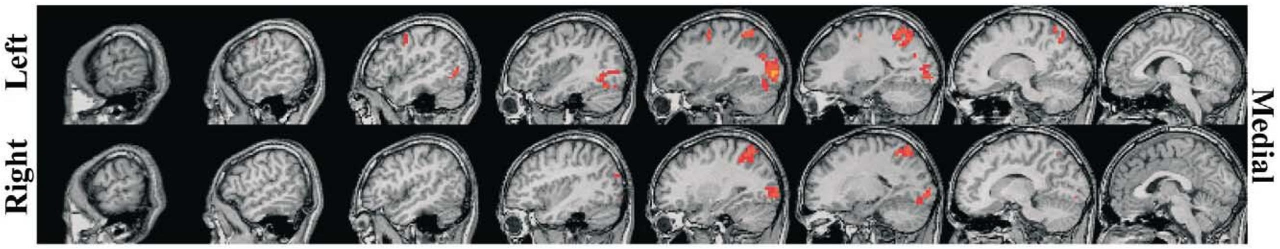
4. Discussion and conclusion

GO playing requires the participation of a network of cortical areas. As shown in Fig. 2c, these areas include the mid-dorsal prefrontal area (BA9), the dorsal prefrontal

(a) G-B activation map



(b) R-B activation map



(c) G-R activation map

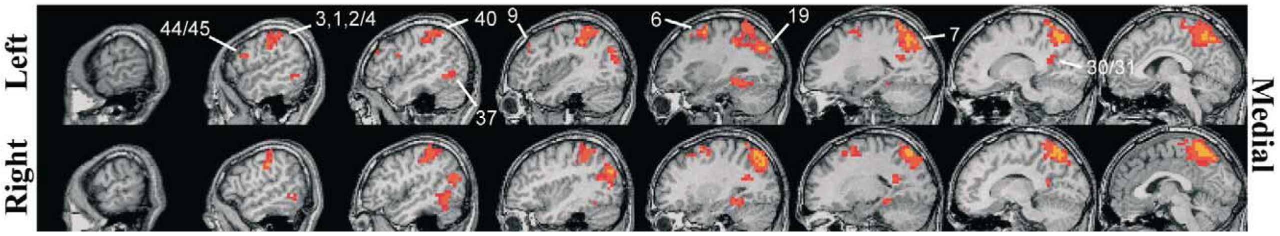


Fig. 2. G-B (a), R-B (b), and G-R (c) activation maps in group analysis showing significantly (P=0.000001) activated regions for G-B, R-B and G-R contrasts. The images were arranged from the left/right to the medial part of the brain. The scale bar indicates the correlation coefficient conveyed by different colors. Selected Brodmann areas for the significantly activated regions are labeled. (a) G-B map showing activations related to GO playing including basic visual processing in BA9, 6, 44/45, 30/31, 7, 40, 17/18/19, 37, 3-1-2/4. (b) R-B map showing activations related to visual searching including basic visual processing in BA6, 7, 17/18/19, 37. (c) G-R map showing activations more specific for GO playing in BA9, 6, 44/45, 30/31, 7, 40, 19, 37, 3-1-2/4.

area (BA6), the parietal areas (BA7, 40), the posterior cingulate areas (BA30/31), the occipital area (BA19), and the posterior temporal area (BA37). These areas are generally engaged in attention, spatial perception, imagery, manipulation and storage in working memory, retrieval in episodic memory, and problem solving [2].

Fig. 2 also showed that the primary somatosensory and motor areas (BA3-1-2/4) were more active in the GO

Table 1
Talairach coordinates of the activated areas in the G-B, R-B and G-R activation maps

	G-B activation map		R-B activation map		G-R activation map	
	L	R	L	R	L	R
BA9	47, −25, 34	−31, −35, 36	–	–	46, −24, 31	−50, −12, 31
BA6	31, −2, 58	−23, −1, 50	46, −11, 36	−46, −17, 32	30, −3, 60	−23, −10, 61
BA7	15, 68, 52	−15, 63, 60	30, 60, 56	−30, 53, 50	14, 70, 48	−15, 59, 58
BA40	47, 35, 52	–	–	–	46, 46, 52	−47, 45, 52
BA17/18	31, 85, 1	−23, 86, −9	30, 86, 2	−38, 76, 10	–	–
BA19	39, 80, 22	−39, 74, 28	46, 68, 2	−22, 85, −9	38, 74, 27	−39, 74, 29
BA37	55, 56, −5	−55, 59, 2	–	−54, 57, −1	54, 62, 1	−55, 56, 3
BA3-1-2/4	55, 19, 36	−55, 21, 45	–	–	54, 20, 42	−55, 19, 47
BA30/31	–	−17, 48, 18	–	–	14, 53, 20	−12, 49, 13
BA44/45	54, −9, 24	–	–	–	54, −11, 22	–

L, left hemisphere; R, right hemisphere.

Table 2
Volume and mean percent change of BOLD signal of the activated areas

		G-B activation map		R-B activation map		G-R activation map	
		Volume (voxels)	Signal change (%)	Volume (voxels)	Signal change (%)	Volume (voxels)	Signal change (%)
BA9	L	15.83 (16.10)	1.70 (1.47)	–	–	8.50 (8.48)	1.26 (1.20)
	R	13.67 (10.09)	2.14 (1.25)	–	–	5.83 (10.25)	0.76 (0.85)
BA6	L	30.17 (15.42)	3.10 (1.66)	6.17 (7.96)	0.94 (1.08)	19.17 (12.22)	2.20 (1.73)
	R	26.83 (15.25)	2.94 (0.97)	5.83 (4.17)	2.11 (1.34)	17.50 (16.20)	1.77 (1.03)
BA7	L	99.67 (25.11)	3.46 (0.69)	19.50 (12.41)	2.86 (0.60)	72.33 (31.97)	2.50 (1.00)
	R	106.17 (53.75)	4.18 (0.82)	18.50 (20.26)	3.11 (1.69)	71.67 (40.21)	3.37 (0.99)
BA40	L	16.17 (20.39)	1.45 (1.29)	–	–	14.17 (11.62)	2.29 (1.75)
	R	–	–	–	–	18.33 (17.86)	1.71 (1.36)
BA17/18/19	L	61.33 (34.93)	3.03 (0.96)	33.50 (22.90)	2.64 (1.40)	22.83 (19.79)	2.20 (1.75)
	R	54.67 (36.03)	3.31 (1.11)	23.50 (21.41)	3.40 (2.12)	29.33 (26.28)	2.46 (2.08)
BA37	L	16.33 (13.11)	3.58 (2.50)	–	–	11.50 (13.25)	2.52 (2.32)
	R	28.17 (20.90)	3.68 (0.84)	3.67 (3.72)	2.34 (2.08)	13.50 (9.89)	2.56 (1.47)
BA3-1-2/4	L	14.00 (14.20)	2.01 (0.85)	–	–	5.80 (7.43)	1.27 (1.38)
	R	20.20 (8.67)	2.13 (0.44)	–	–	12.00 (14.30)	2.37 (0.78)

L, left hemisphere; R, right hemisphere; data in the table are means with S.D. in parentheses.

playing task than in the control tasks. This is surprising because subjects performed their tasks without any task-dependent somatosensory stimulation and body movement. A possible explanation for this activation may be that subjects were imagining that they were picking up stones and placing them on the game board in the process of finding out the next reasonable solution in the Game condition, given that primary somatosensory and motor areas were shown activated in motor imagery tasks [3,11,13,15].

A number of issues deserve closer examination. One, is GO playing lateralized? Since spatial processing is critically important in GO playing, especially at the global level, one may expect a right hemisphere lateralization. To test this possibility, quantitative comparisons between the activated regions in homologous areas in two hemispheres were performed. The results showed that there were no significant differences in the volume and mean percent change of BOLD signal of the homologous activated regions between two hemispheres, except that the magnitude of BOLD signal (percent change) was significantly higher in right BA7 than that in left in the GO task, but not in the search task (*t*-test; G-B: $P=0.038$; G-R: $P<0.001$; R-B: $P=0.694$; Table 2). This right lateralization in BA7 in the GO task may be attributed to: (1) the storage component of spatial working memory is biased in the right parietal areas [16,19]; (2) analysis of global spatial pattern including global spatial attentional processes is biased in the right parietal areas [7]; (3) sustained spatial attention may preferentially activate right parietal areas [4,12]. Lateralized activity was also found in the left dorsal lateral prefrontal area (BA44/45): it was activated when the subjects carried out the GO playing task (Fig. 2c). Because left BA44/45 is usually involved in language functions [2], this result suggests that the subjects may be verbalizing GO terms when they were playing GO. It is also consistent with our finding that BA30/31, important for episodic memory retrieval [2], was active in the GO task.

The second issue is the involvement in GO playing of the so-called general intelligence (‘g’) areas recently proposed by Duncan and colleagues [6]. In their study, ‘g’ areas were located in the lateral frontal cortex, such as BA46 and BA6, in one or both hemispheres. Some of these areas were also involved in our GO playing task, but in contrast to the most robust activated areas in the parietal cortex, they were somewhat scattered (Fig. 2). Considering the similar activation map revealed in the accompanying study on chess playing [1], it seems that the so-called ‘g’ areas are not consistently activated in either the GO or chess cognition. A potential explanation for the lack of activation in the frontal areas is that the configurations at this point in the game are well learned by the subjects, and so the task does not require much mental effort. This is consistent with the finding that more intelligent people often show less frontal activation when they are performing analytical tasks [17]. This explanation is not very persuasive given that the subjects are amateur players with modest GO playing experience. However, it can be tested by future neuroimaging studies of professional GO players who have achieved high-level of expertise through long-term extensive training.

If the so-called general intelligence does not play an important role in GO cognition, then what kind of human intelligence is engaged in this high-level cognitive function? According to Sternberg, intelligence can be classified as analytical intelligence, creative intelligence, and practical intelligence, and Duncan’s ‘g’ areas are mainly related to analytical intelligence [17]. Does it mean that the so-called creative or practical intelligence is especially important in GO playing?

Given both the perceived difference between chess and GO and the demonstrated difference between chess and GO experts in pattern memory [14], the third issue that needs to be discussed is: What are the similarities and differences between GO and chess in their underlying neural basis? At the gross level, they seemed to share similar cognitive components based on the fact that generally similar areas were activated in our two accompanying studies. The only noticeable difference between the two games is that playing GO may involve BA44/45 but playing chess may not.

Taking the view that GO is much more difficult to program on a computer than chess, one might want to infer that GO requires more 'human specific' intelligence than chess. Given that the right parietal areas are prominent in GO playing, one may want to make the inference that the functions carried out by the right parietal areas do not present themselves to the current scheme of computer programming.

Both chess and GO are learned skills, and they all require extensive training to achieve the high level of expertise that some professional players have. Chess expertise has been a subject of many behavioral studies in cognitive science [8]. GO, on the other hand, has not received much attention in the cognitive sciences. One would hope that our imaging results will inspire and serve as a useful jumping-off point for future behavioral and neural imaging studies of GO and the acquisition of GO expertise.

Acknowledgements

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