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Knowing that You Know and Knowing that You don't Know: A fMRI Study on Feeling-of-Knowing (FOK)*

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Abstract Neural correlates of feeling-of-knowing (FOK) were investigated by event-related fMRI and unrelated word-pairs in a standard Recall-Judgment-Recognition (RJR) procedure. According to performance in post-scan criterion test, FOK trials were categorized as "PP" (positive-FOK, positive/"hits"-recognition), "NN" (negative-FOK, negative/"misses"-recognition), "NP" (negative-FOK, negative-recognition), and "PN" (positive-FOK, negative-recognition). Contrasts between accurate FOK predictions (PP, NN) and inaccurate ones (NP, PN) revealed no difference. Further analysis indicated PP and NN were different; combining them together might conceal differences. Specifically, PP was associated with left prefrontal activities in BA 8 or BA 47 relative to NN or NP respectively. This observation queried the conventional view that regarded PP and NN as the same kind of "accurate FOK predictions", and called for dissociations between feeling-of-knowing (PP) and feeling-of-not-knowing (NN).

Key words feeling-of-knowing, event-related fMRI, metamemory.

1 Introduction

Hart[1] studied feeling-of-knowing (FOK) in 1965. In a typical Recall-Judgment-Recognition (RJR) paradigm of FOK, subjects were asked to answer a specific question (e.g., the capital of a country) or to recall the "target word" that had been associated with the "cue word" in learning phase. If subjects failed to recall the correct answer, they were asked to estimate the possibility to recognize the correct answer among several lures. Finally, subjects performed a criterion recognition test in which they recognized the targets from the lures. There were significant (but not very high) correlations between subjects' FOK judgments and their recognition performance. This implied subjects could still have a feeling of knowing on the stored memories even when they could not directly access them. Since Hart, there have been substantial researches on this topic.[2] Two major theories were proposed to account for FOK, "trace-access mechanism" and "inferential mechanism".[2] The typical version of "trace-access mechanism" proposed that FOK was based on partial retrieval of target information (the "partial retrieval hypothesis")[3], whereas the typical version of "inferential mechanism" proposed that FOK was based on the familiarity with the cue ("cue-familiarity hypothesis")[4]. However, the neural correlates of FOK is still unknown. Shimamura and Squire found subjects of Korsakoff's syndrome were impaired on FOK predictions[5]. Since Korsakoff patients are known to suffer from general cerebral atrophy, and frontal atrophy in particular, it is reasonable to propose FOK is based on frontal functions. Souchay et al[6] also found the function of frontal cortex was closely related to FOK accuracy. But there were also evidences showing brain areas other than the frontal cortex (i.e., temporal lobe) subserving FOK.[7,8]

In the present research, participants were scanned by fMRI when they did cued-recall and FOK judgments to the cue words, after they learned the list of cue-target word pairs. The trials of positive-

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FOK, positive/ "hit"-recognition [PP] and trials of negative-FOK, negative/ "miss"-recognition [NN] (these two kinds of trials were regarded as "accurate FOK predictions") were contrasted with the trials of positive-FOK, negative-recognition [PN] and trials of negative-FOK, positive-recognition [NP] (these two kinds of trials were regarded as "inaccurate FOK predictions"). Furthermore, detail contrasts were calculated among trials of PP, NN, and NP.

2　Materials and Methods

2.1　Participants

Six healthy, right-handed undergraduates (20～22 years, three females) recruited from University of Tsukuba participated in this experiment. They were interviewed several days before they attended the fMRI experiment and provided informed consent in accordance with the MRI ethics committee of Electrotechnical Laboratory (ETL, now reorganized as AIST).

2.2　Cognitive tasks

The experiment procedure followed the RJR paradigm. There were three phases in the entire session: learning phase, cued-recall and FOK phase, and recognition phase. Imaging was carried out in the cued-recall and FOK phase. To familiarize subjects with the procedure and speed of this task, they were trained with another set of similar materials in the same procedure before the formal experiment.

Learning Phase. Subjects learned 80 unrelated Japanese Kanji word pairs which consisted of two characters, low frequency words, at a pace of 2.5 sec per pair (2 sec for item presentation, 0.5 s for unfilled delay) in the learning phase. Subjects learned the list twice in a randomized order and then instructed to memorize each word pair in order to recall the target word (the right word of each pair) when given the cue word (the left word).

Cued-recall and FOK judgments Phase. Seven minutes after the end of the learning phase, the cued-recall and FOK phase started with fMRI scanning. The cue words were presented at a pace of 6.6 sec per item (2 sec for cue presentation, 4.6 sec for cross viewing). During the presentation of the cue word, subjects were asked to recall the target word that had been paired with it. If they successfully recalled the corresponding target word, the subjects were asked to press the left key of the response box with the right index finger, which was attached to right leg. When they could not recall the target, they were to press the middle key with right middle finger if they felt they would be able to recognize the correct answer among several candidates later (the positive/yes FOK), or, to press the right key by right ring finger if they felt they wouldn't (the negative/no FOK). In the key-pressing condition in which an asterisk was presented at the same speed as in cued-recall and FOK judgment; subjects were asked to press the left, middle, and right keys alternatively, that is, to press the left key to the first asterisk they saw, the middle key to the second, the right key to the third, and the left key again to the fourth etc. Four asterisk items presented successively and this formed a key-pressing block. Ten cued-recall items presented successively and formed a cued-recall and FOK block. There were 16 blocks in all. Eight of them belonged to the cued-recall and FOK condition, eight of them to the key-pressing condition.

Cues were presented in a randomized order relative to the order in the learning phase. The types of responses, but not the response time (RT), were recorded during scanning.

Recognition Phase. Seven minutes after the end of the cued-recall and FOK phase, subjects went out from the MRI machine and did a recognition test, in which 298 word pairs were presented in a randomized order and subjects made old/new judgments to these items. 80 items of them were targets, 218 were lures. Among the lures, 80 were "new cue, new target" pairs, 40 were "new cue, old target" pairs, 40 were "old cue, new target" pairs, and 58 were "incorrectly combined old cue, old target" pairs. These interference lures were used to increase the sensitivity of the criterion test in detecting the FOK predictability.

Sorting of the items. Based on types of responses in the cued-recall and FOK phase (a. successful cued-recall, b. unsuccessful cued-recall and positive FOK, and c. unsuccessful cued-recall and negative FOK) and in the recognition phase ("hits" or "misses"), items in the cued-recall and FOK phase were categorized into 5 types: PP items (positive-FOK, positive/ "hit"-recognition); NN items (negative-FOK, negative/ "miss"-recognition); PN items (positive-FOK, negative-recognition); NP items (negative-FOK, positive-recognition) ; and SC items (successful cued-recall, positive-recognition). In addition to the KP items (key-pressing baseline), there were 6 types of events in all.

2.3 fMRI scans

All scanning was performed on a 3.0 T MRI Scanner (GE Signa) equipped with EPI capability. Eighteen axial slices (5.5mm thick, interleaved) were prescribed to cover the whole brain. A T2 weighted gradient echo EPI was employed. The imaging parameters were TR = 3 sec, TE = 32 ms, FA = 70 degrees, FOV = 20 20 cm (64 64 mesh). To avoid head movement, subjects wore a neck brace and were asked not to talk or move during scanning. Motion correction was also performed in a standard realign process in SPM99.

2.4 Image analysis

Images were pre-processed (timeslice adjusted, realigned, normalized and smoothed) by SPM99. Then, imaging data of six subjects were estimated by fixed effect model, using the Event Related Analysis of SPM99. Because there was no enough number of trials in PN and SC (less than ten) in some subjects, the main effects of accurate FOK predictions were examined by collapsing across PP and NN (the accurately predicted trials), and PN and NP (the inaccurately predicted trials) respectively. The events of PP, NN, and NP, which have provided enough number of trials in each subject (≥ 11), were contrasted with each other and with KP baseline respectively. The threshold was set at $p < 0.05$ (corrected for multiple comparisons) with ten or more continues voxels ($T \geq 4.19$, $K \geq 10$ voxels). The SPM coordinates for the standard brain from Montreal Neurological Institute (MNI) were converted to Talairach coordinates by a non-linear transform method (Image Homepage, //www.mrc-cbu.cam.uk/Imaging/mnispace.html) and projected into Talairach pictures (Talairach Space Utility Homepage, http://www.ihb.spb.ru/~pet-lab/TSU/TSUMain.html)

3 Results

3.1 Behavioral results

FOK judgments had significant predictability on the later recognition performance. The Gamma correlation between the FOK judgments and the recognition performance on later criterion test is 0.55. It was significantly above chance level (95 % CI Upper: 0.76; 95 % CI Lower: 0.35).

3.2 Image results

The general neural networks underlying PP, NN, and NP. Relative to the KP baseline, PP was associated with activations in left superior frontal gyrus (Brodmann area [BA] 8 and 10), left middle frontal gyrus (BA 9, 6, and 11), bilateral inferior frontal gyrus (BA 45 and 47), bilateral lingual gyrus (BA 18 and 19), and left cuneus (BA 18); NN was associated with activations in left superior frontal gyrus (BA 6 and 10), left middle frontal gyrus (BA 46), and left inferior frontal gyrus (BA 47); NP was associated with activations in left superior frontal gyrus (BA 6), left inferior frontal gyrus (BA 45), and left middle frontal gyrus (BA 6). See Table 1 and Figure 1.

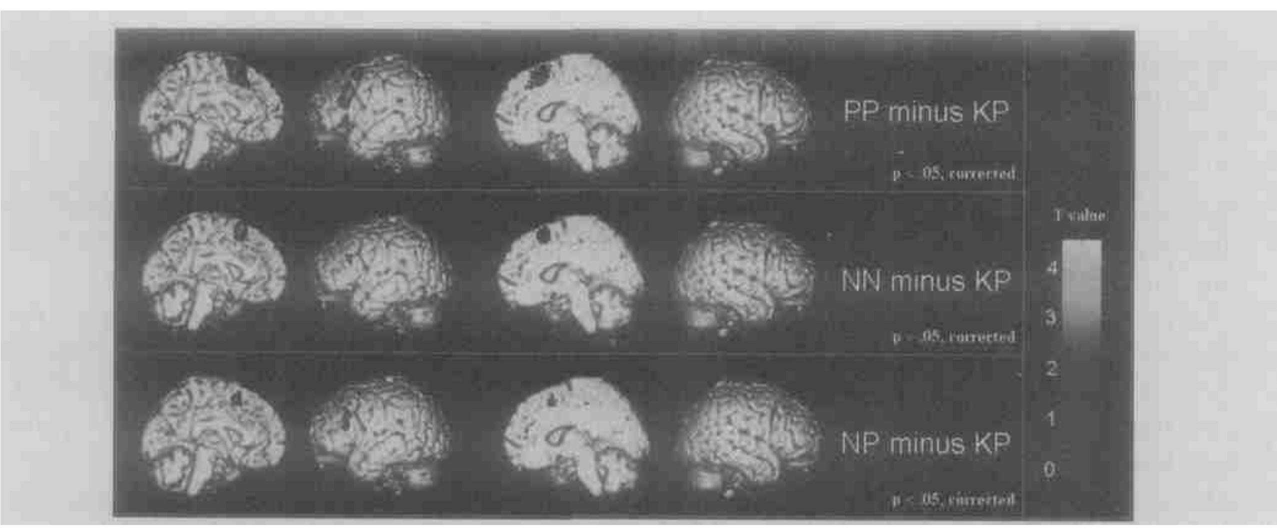

Figure 1 Rending of group-averaged activities revealed in the contrasts of "PP minus KP" (above), "NN minus KP" (middle), and "NP minus KP" ($p < 0.05$, corrected, $K_E \geq 10$). The bar denotes T value.

Table 1 List of activations

Contrast	K_E	T value	x	y	z	Area
PP - KP	290	8.61	-30	56	-1	Left Superior Frontal Gyrus, BA 10
		4.34	-18	67	10	Left Superior Frontal Gyrus, BA 10
	716	8.6	0	16	53	Left Superior Frontal Gyrus, BA 8
	500	7.25	-50	21	32	Left Middle Frontal Gyrus, BA 9
		5.71	-53	26	19	Left Inferior Frontal Gyrus, BA 45
	208	6.95	-38	12	53	Left Middle Frontal Gyrus, BA 6
	362	6.63	-44	32	-12	Left Middle Frontal Gyrus, BA 11
		5.96	-34	25	-10	Left Inferior Frontal Gyrus, BA 47
	122	5.7	40	19	-9	Right Inferior Frontal Gyrus, BA 47
	20	4.86	20	-64	-4	Right Lingual Gyrus, BA 19
	24	4.8	-20	-72	-3	Left Lingual Gyrus, BA 18
	38	4.77	-4	-77	8	Left Cuneus, BA 18
NN - KP	348	6.92	-2	20	56	Left Superior Frontal Gyrus, BA 6
	77	5.79	-30	58	1	Left Superior Frontal Gyrus, BA 10
	40	4.91	-46	23	23	Left Middle Frontal Gyrus, BA 46
	31	4.77	-42	27	-11	Left Inferior Frontal Gyrus, BA 47
NP - KP	144	5.62	-2	14	49	Left Superior Frontal Gyrus, BA 6
	178	5.15	-48	24	21	Left Inferior Frontal Gyrus, BA 45
	15	4.51	-36	11	55	Left Middle Frontal Gyrus, BA 6
PP - NN	18	4.60	-40	12	53	Left Middle Frontal Gyrus, BA 8
PP - NP	40	5.25	-46	36	-9	Left Middle Frontal Gyrus, BA 47
NN - PP						No super - threshold activation
NN - NP						No super - threshold activation
NP - PP						No super - threshold activation
NP - NN						No super - threshold activation

Note: (cluster-level [K_E], local maxima T scores, stereotactic coordinates [x, y, z], and approximate anatomical localizations) revealed in each contrast ($p < 0.05$ corrected, $K_E \geq 10$).

Neural correlates of accurate FOK prediction. The contrast between the accurately predicted events (PP, NN) and the inaccurately predicted events (PN, NP) revealed no significant difference. Then, the contrast of "PP versus NN", "PP versus NP", and "NP versus NN" were calculated respectively (Table 1). Two left prefrontal activities were exhibited. Relative to NN, PP was associated with an activity in left middle frontal gyrus peaked in BA 8 and extended into BA 6 and 9 (Figure 2). Relative to NP, PP was associated with an activity in left middle frontal gyrus peaked in BA 47 (Figure 3).

4 Discussion

4.1 The general neural networks underlying cued-recall and FOK judgments

Different from Maril et al.'s observation that the tip-of-tongue (TOT) items were associated with right-lateralized prefrontal activities relative to the no-TOT items[9], our results revealed robust left-lateralized prefrontal activities not only when the cued-recall and FOK trials were contrasted with the key pressing baseline trials ("PP - KP", "NN - KP", and "NP - KP"), but also when the cued-recall and FOK trials were contrasted with each other ("PP - NN" and "PP - NP"). Compared with the semantic knowledge retrieval in Maril et al.'s, the episodic retrieval in this experiment might call for more reflective and systematic processing, and lead to more left prefrontal activities[10]. Specifically, the left ventral prefrontal cortex (BA 47/11) exhibited in "PP - KP" and "NN - KP" has been proved to subserve semantic selections[11]. The left dorsolateral prefrontal cortex (BA 46/9) observed in "PP - KP", "NN - KP", and "NP

- KP" has been observed to be associated with recall of non-imaginable word relative to recall of imaginable word[12], recognition of deeply

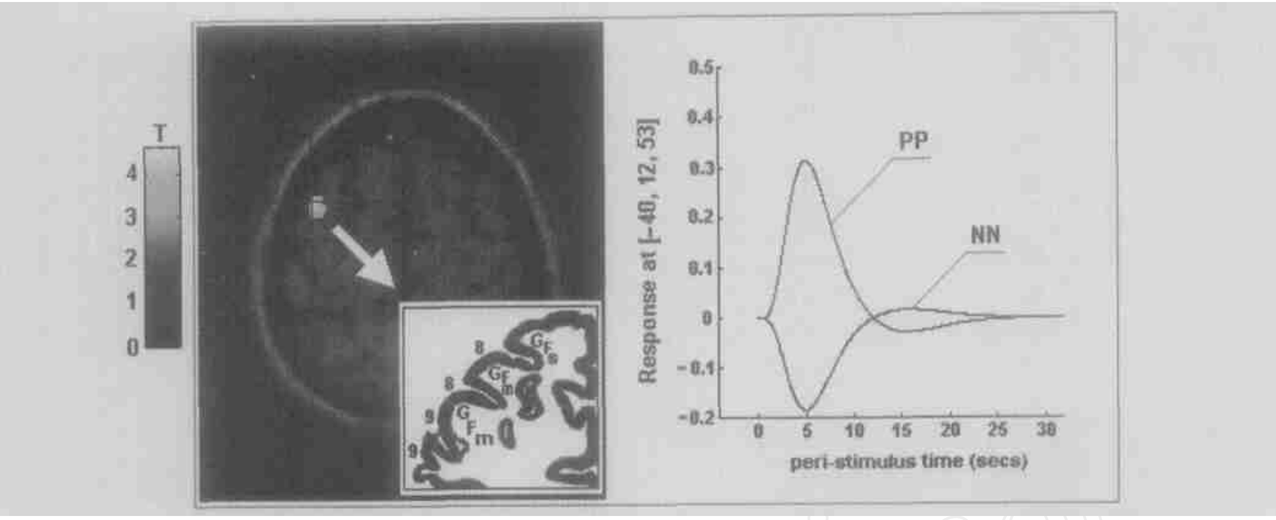

Figure 2 Group-averaged left prefrontal activation revealed in the contrast of "PP minus NN". Thresholded at $p < 0.001$ (uncorrected) for demonstrations. Left: the SPM coronal section showing the territory of activation; the blue cross marks the voxel that has the peak value in the contrast. Talairach coronal section showing the territory of activation is also given in the right bottom of the picture. The bar denotes t value. Right: the event-related plots showing the averaged signal change (%) of the best-fitting canonical hemodynamic response function (HRF) from the peak voxel (X = -40, Y = 12, Z = 53) marked by the blue cross in the left picture.

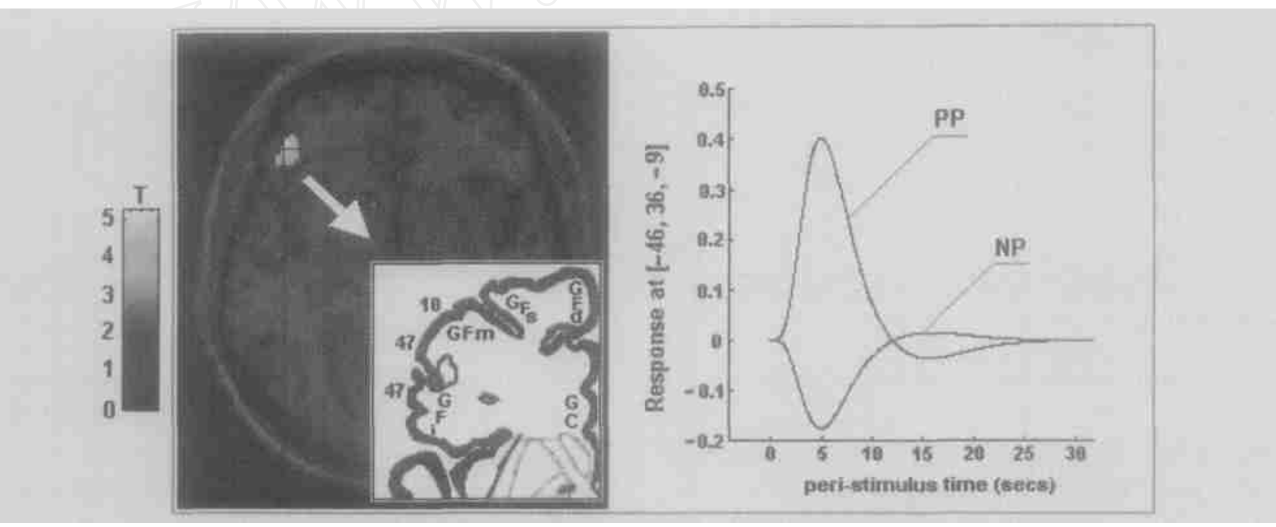

Figure 3 Group-averaged left prefrontal activation revealed in the contrast of "PP minus NP". Thresholded at $p < 0.001$ (uncorrected) for demonstrations. Left: the SPM coronal section showing the territory of activation, the blue cross marks the voxel that has the peak value in the contrast. Talairach coronal section showing the territory of activation is also given in the right bottom of the picture. The bar denotes t value. Right: the event-related plots showing the averaged signal change (%) of the best-fitting canonical hemodynamic response function (HRF) from the peak voxel (X = -46, Y = 36, Z = -9) marked by the blue cross in the left picture.

studied items relative to recognition of shallowly studied word[13], and rejection of the conjunction lures that made from a conjunction of two previously learned items (e.g., the probe "nosedive" after studying "nosebleed" and "skydive") relative to rejection of novel negative probes[14]. The left anterior prefrontal cortex (BA 10) observed in "PP - KP" and "NN - KP" (a more posterior and inferior activation peaked in BA 47 but near BA 10 was also observed in "PP-NP", see Figure 3) was associated with "reflective" processes engaged in episodic retrieval, left anterior prefrontal cortex was proved to be responsive to the demands of retrieving perceptually detailed information about studied objects, and generally, to be related to monitoring and evaluation of specific memory characteristics at retrieval process that is critical for accurate episodic remembering[15]. These areas highlighted the neural network that was sensitive to the process of episodic memory retrieval and metamemory monitoring.

4.2 Feeling-of-knowing and feeling-of-not-knowing

Our image results did not reveal any detectable difference between accurately predicted trials (PP, NN) and the inaccurately predicted trials (PN, NP), although the behavioral results confirmed that the FOK judgments did have above-chance predictability on later recognition performance.

One possibility was that although both PP and NN were accurately predicted trials, they might be mediated by distinct brain mechanisms. To regard them as the same type of trials (i.e., collapsing across PP and NN in analysis) might conceal some differences. There were several lines of evidences in agreement with this possibility. First, relative to NP, PP highlighted the inferior part of left prefrontal (BA 47), whereas NN did not show any super-threshold activity. Second, relative to KP, PP was associated with activities in right inferior frontal gyrus (BA 47), bilateral lingual gyrus (BA 18 and 19), and left cuneus (BA 18), whereas NN (relative to KP) was not. Third, relative to KP, PP exhibited larger volumes of activities than NN (relative to KP) in left anterior prefrontal cortex (BA 10) (290 voxels in "PP KP" versus 77 voxels in "NN KP"), left ventral prefrontal cortex (BA 47/11) (362 versus 31 voxels), left dorsolateral prefrontal cortex (BA 46/9) (500 versus 40 voxels), and left superior frontal gyrus (BA 8) (716 versus 348 voxels). Finally, the direct contrast of PP and NN revealed significant activity in left middle frontal gyrus (BA 8).

To consider PP and NN as being subserved by different brain processes has important implications on FOK studies. Contrary to the conventional point of view that regards PP and NN as the same type of "accurate FOK predictions", the differential neural correlates between PP and NN implied feeling-of-knowing (PP) and feeling-of-not-knowing (NN) might be subserved by distinct metamemory processes.

The more involvement of left prefrontal cortex in PP relative to NN implied that feeling-of-knowing was realized by a more systematic retrieval process than feeling-of-not-knowing. In particular, the left middle frontal gyrus (peaked in BA 8 and extended into BA 6 and 9) highlighted in the contrast of "PP minus NN" was observed in free recall[16], cued-recall[17], orally repeating of recognized old words[18], and retrieval success[19]. But activity in this area was less consistently activated in episodic memory retrieval than in verbal working memory retrieval[20]. Recent neuroimaging studies have bridged the gap between the episodic and working memory, based on the observation that specific prefrontal regions contributed to both episodic and working memory. It was proposed that prefrontal activation during episodic memory might reflect the recruitment of specific working memory processes in the service of episodic learning and remembering[21]. Given the function of left superior/middle frontal gyrus (BA 8) in working memory is "active maintenance" of abstract representation that goes beyond the stimulus itself[22], we proposed the activity of left middle frontal gyrus (BA 8) in PP subserved the "active maintenance" of information evoked by the retrieval cues, and embodied the manipulation of metamemory monitoring. The activation of BA 8 did not imply there were more eye movement in PP than in NN, given that a) the location of left middle frontal gyrus (BA 8/9) observed in the present research was much anterior than the observed frontal eye field in humans[23]; b) the sensorimotor requirements in PP and NN were kept equivalent; and c) no difference between PP and NN was detected in the parieto-occipital regions that was usually more sensitive to the difference in eye movement.

Relative to KP, NN activated fewer and smaller cortex areas than PP did. It was possible that feeling-of-not-knowing was realized by a "null activity hypothesis", that is, the brain made a judgment of feeling-of-not-knowing based on the fact that there was no much activity associated with the specific cue. This was not only consistent with Kolers and Palef's observation that FOK judgments could be made very rapid for negative (not knowing) judgments[24], and with Klin et al.'s observation that subjects responded to implicit "don't know" questions (i.e., no information regarding the answers was provided) faster than to explicit "don't know" questions (i.e., narratives explicitly stated that something was unknown)[25], but also generally consistent with the hypothesis that cue familiarity heuristic plays an important role in FOK judgments[3] in that feeling-of-not-knowing can be achieved by the simple process of cue familiarity/novelty heuristic.

5 Conclusion

People could still have feeling-of-knowing of stored memories even when they could not directly access these memories. Through neuroimage method, this research revealed how the brain could realize this function. Frontal activities, in particular left superior, inferior, and middle frontal gyrus, were observed to be associated in this metamemory process. The results also implied that feeling-of-knowing (PP) and feeling-of-not-knowing (NN) could be mediated by the distinct neural and cognitive processes. This observation queried the conventional view that regarded PP and NN as the same type of "accurate FOK predictions" and called for dissociations between feeling-of-knowing and feeling-of-not-knowing in future research.

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“知道自己知道”与“知道自己不知道”

——一项有关知道感(FOK)的脑成像研究

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摘　要　采用事件相关功能性磁共振成像技术(event-related fMRI)以及在 FOK(feeling-of-knowing)研究中常用的“线索回忆-FOK 判断-再认测验”(Recall-Judgment-Recognition,RJR)程序,以汉字词对为识记材料,研究了 FOK 判断中的大脑活动区域。根据 FOK 判断的正负以及其后的再认测验的对错,实验将 FOK 判断的项目分为四类:PP 项目(正性 FOK 判断,正确再认),NN(负性 FOK 判断,错误再认),NP(负性 FOK 判断,正确再认)以及 PN(正性 FOK 判断,错误再认)。脑成像的分析结果显示:准确的 FOK 预测(即 PP 与 NN 项目)与不准确的 FOK 预测(即 NP 与 NP 项目)在脑活动上没有显著的差异。而进一步分析表明,这种“无差异”的现象可能是由于 PP 项目与 NN 项目激活了不同的脑活动模式所造成的。具体地讲,相对于 NN 项目而言,PP 项目伴随有明显的左侧前额叶(BA 8 区)的活动。这一观察提示我们:知道感(PP)与不知道感(NN)可能是由不同的脑神经网络所支持、并通过不同的认知过程来实现的。

关键词　知道感(FOK),事件相关功能性磁共振成像,元记忆。
分类号　B842