原 著 論 文

Spatial and temporal distribution of category-specific brain areas visualized through resting-state fMRI signals

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Abstract

Functional MRI (fMRI) studies have demonstrated that different brain areas specialize in various perceptual and cognitive functions. These include primary sensory functions such as visual and auditory processing and higher-order functions such as emotion and language processing. However, each identified brain area provides only static information in terms of signal processing in the brain. To clarify how the active brain processes information, knowledge regarding the temporal characteristics of brain activity is required. In this study, we examined the possibility of estimating latency distribution among category-specific brain areas across the whole brain through resting-state fMRI signals. Latency differences were found between the primary visual/auditory areas and other high cognitive areas, such as those involved in attention, emotion, and word processing. These results suggest a potential use of resting-state fMRI data for temporal or dynamic brain maps.

Keywords : resting state fMRI, temporal characteristics, latency, dynamic brain

Introduction

For clarification of the information processing mechanism of the brain, the temporal characteristics reflecting activity patterns or the timing of activation signal changes in various areas of the brain as well as spatial information related to functional specificity and selectivity were examined. Several functional MRI (fMRI) studies using tasks have focused on the latter. They have identified brain areas involved in specific functional characteristics, resulting in producing spatial functional brain maps providing static aspects of brain function [1-10]. However, the brain is not a static system, but a dynamic one that is constantly active. Therefore, obtaining information on the dynamic activities from each area of the brain or signal flow between brain areas is key to understanding how the brain works [11-20]. In recent years, the spatial resolution has been improved by high magnetic field MRI, but basically there is no change in the meaning of measuring the spatial characteristics on the function of the brain [10, 21]. To acquire the temporal information needed to make brain maps reflecting dynamic information, this study examined the possibility of estimating the latency distribution among category-specific brain areas across the whole brain via resting-state fMRI (rs-fMRI) signals. This did not require a number of tasks or scan time to acquire that kind of information by utilizing task fMRI. Resting-state fMRI signals reflect various aspects of the functional characteristics of the brain [21-25]. One of our previous studies reported that functional brain networks reflecting human characteristics were identified using rs-fMRI data [26]. In this study, by analyzing the rs-fMRI data acquired in the previous study, the spatial and temporal relationship among the brain areas involved in categorically specific information processing related to perception and cognition could be examined.

Materials and Methods

Resting-state fMRI data from 153 subjects acquired in a previous study [26] were used for analysis. The brain areas involved in perception and cognitive processing were identified from Neurosynth. This is a platform for the large-scale, automated synthesis of fMRI data [27]. Several keywords such as visual, auditory, emotion, memory, attention, language, etc. were used for the identification of category-selective brain areas. Estimation of latency distribution was examined by correlation analyses for the identified brain areas on the basis of the time at the maximum positive peak value at time courses in each brain area.

Results and Discussion

Ninety-six brain areas were identified from Neurosynth and were related to visual, auditory, emotion, memory, attention, language, etc. Table 1 shows the coordinates and functional categories of these brain areas. A correlation map was created from the time courses in these brain areas for each subject. The correlation maps corresponding to 153 subjects were averaged. The averaged correlation map showed several clusters of brain areas with high within/between-category correlation. The red circles in Figure 1 represent specific clusters reflecting different functional characteristics. The clusters showed differences in their sizes depending on function, and the largest cluster was the one consisting

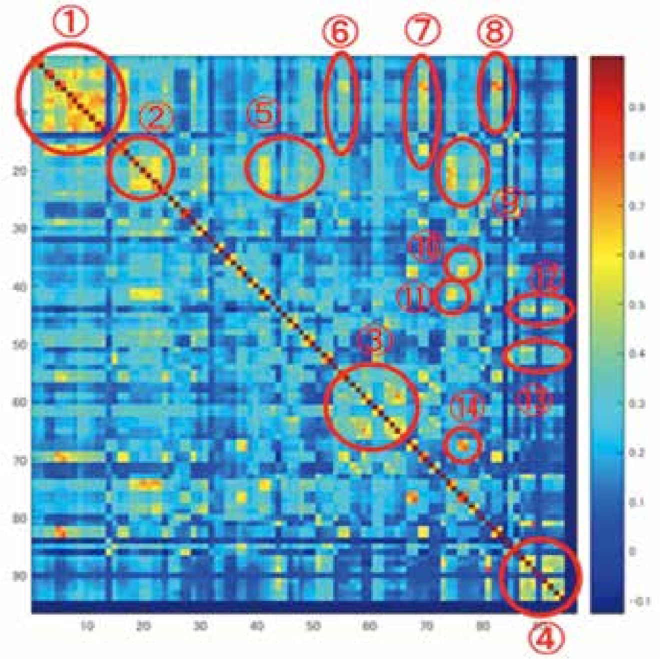

Figure 1. Correlation map of resting-state fMRI signals among the brain areas involved in processing information related to perception and cognition. Clusters surrounded by red circles indicate high correlation values（r > 0.6）. ① for visual areas, ② for auditory areas, ③ for memory areas, ④ for emotion areas, ⑤ for language areas related to auditory processing, ⑥ for short-term memory areas related to visual processing, ⑦ and ⑧ for attention areas related to visual processing, ⑨ for attention areas related to auditory processing, ⑩ for attention areas related to olfactory processing, ⑪ for language areas related to phonetic processing, ⑫ for emotion areas related to word and sentence processing, ⑬ for emotion areas related to sensory memory, and ⑭ for other functions related to mental processing.

of visual areas. Latencies were estimated for the time points around the positive maximum value of the brain areas, and a representative brain area such as the primary visual area was used as a reference area. The time course signals from the brain areas related to visual, auditory, attention, language, emotion, and social cognition were used to estimate the latency. Figures 2-5 show the latency differences between some of the visual areas, the latency differences between the auditory areas and the word processing areas, the latency differences between the auditory areas and the attention areas, and the latency differences between the emotion areas and the word processing areas, respectively. These figures show a tendency of latency delay from low to high levels.

The difference in latency estimated from rs-fMRI time courses suggests the possibility of functional causality related to signal flow in a basal state, and this information is potentially used to examine the functional dynamics of the brain. Further studies are needed to elucidate the functional causality of rs-fMRI signals among these brain areas.

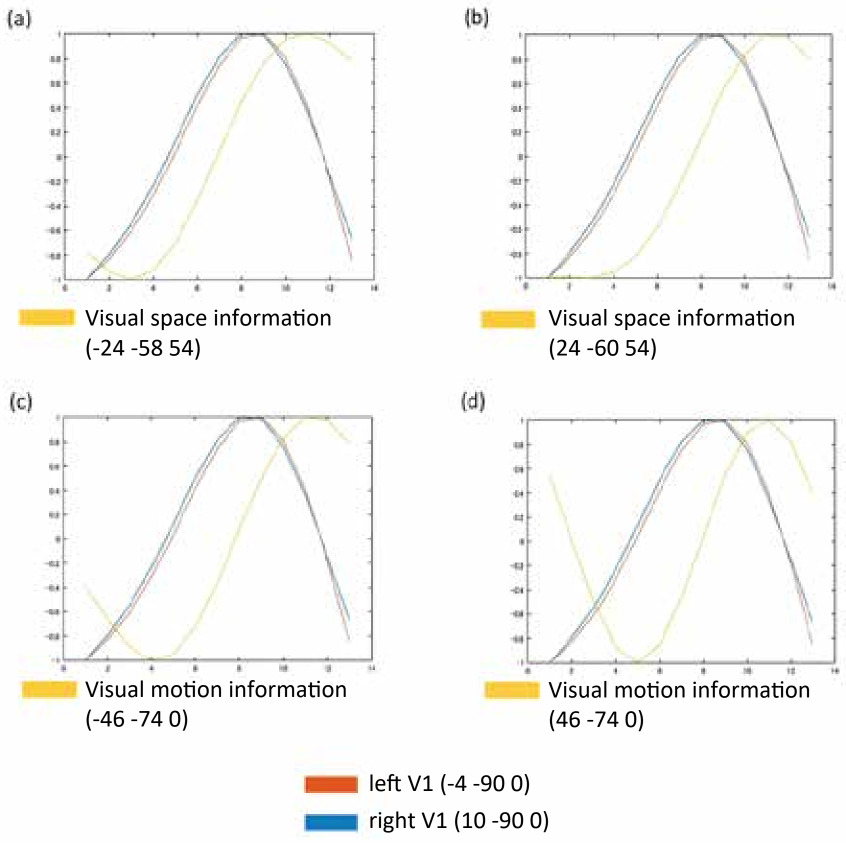

Figure 2 | Rs-fMRI signals of brain areas related to visual information.

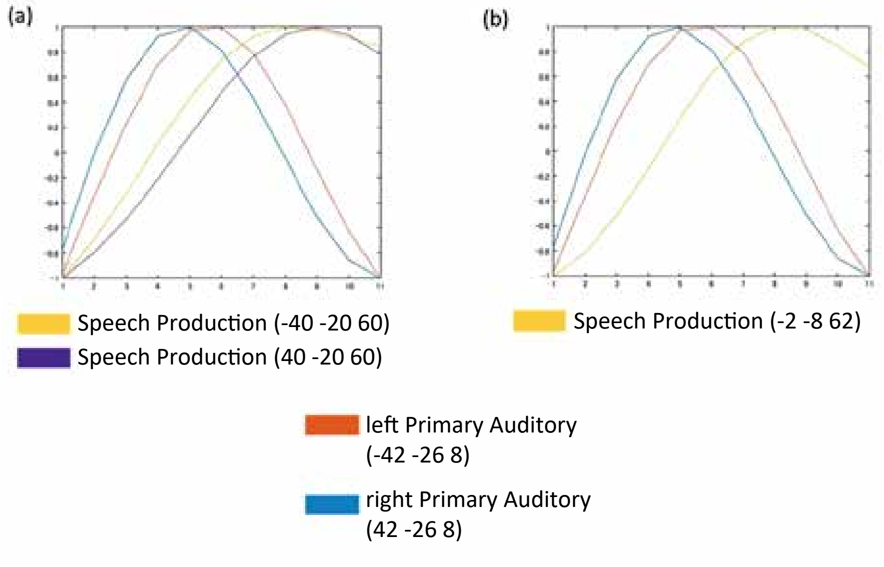

Figure 3 Rs-fMRI signals of brain areas related to Auditory and Language information.

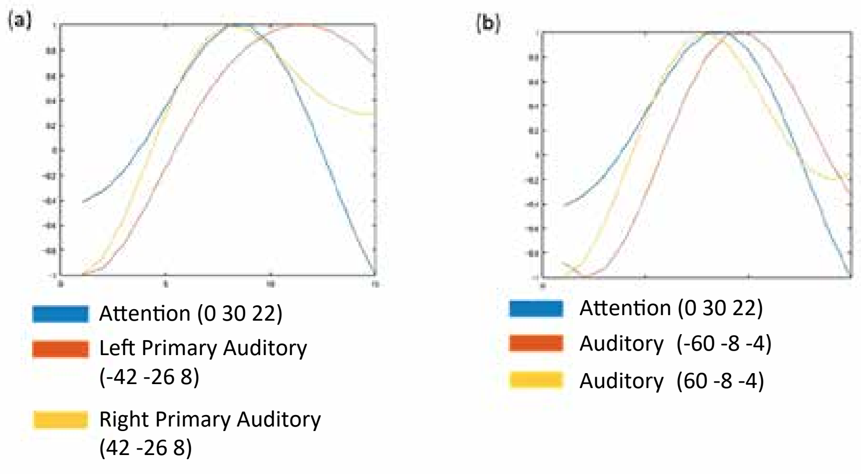

Figure 4 | Rs-fMRI signals of brain areas related to auditory and attention.

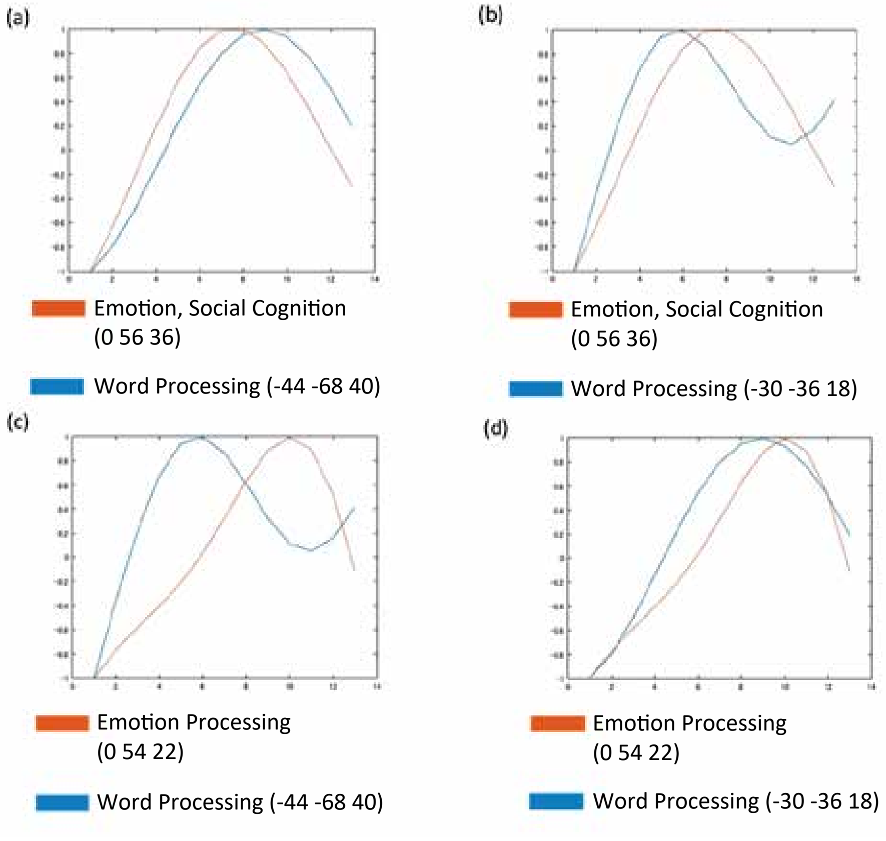

Figure 5 Rs-fMRI signals of brain areas related to emotional information and word processing.

Conclusions

Resting-state fMRI signals are likely to reflect intrinsic spatial and temporal information related to higher cognitive function as well as primary sensory information. We demonstrated temporal differences between category-specific areas. Our results suggest the potential use of rs-fMRI data for temporal/dynamic brain maps.

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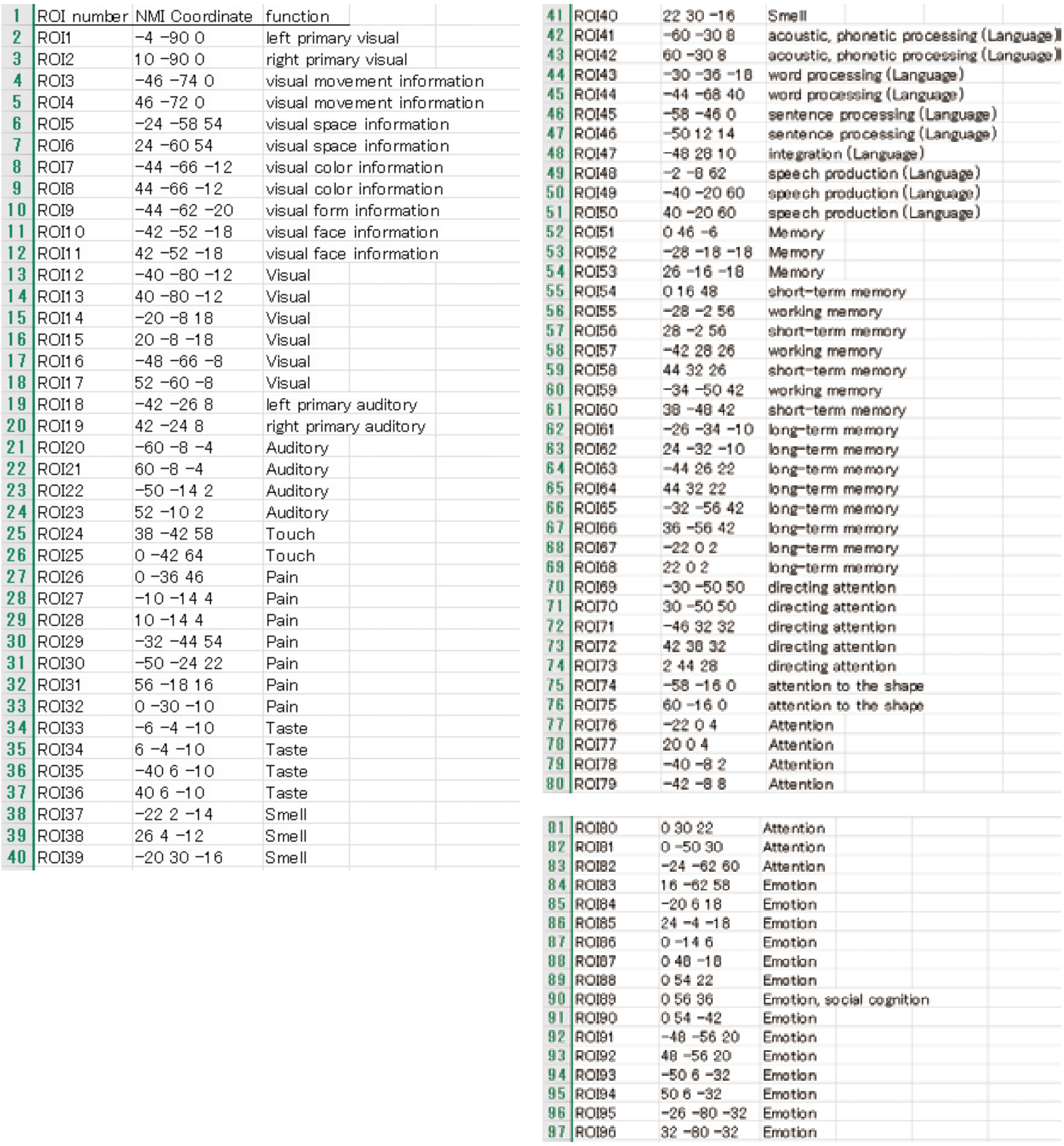
Table 1. List of brain areas with functional selectivity



1	ROI number	NMI Coordinate	function
2	ROI1	−4 −90 0	left primary visual
3	ROI2	10 −90 0	right primary visual
4	ROI3	−46 −74 0	visual movement information
5	ROI4	46 −72 0	visual movement information
6	ROI5	−24 −58 54	visual space information
7	ROI6	24 −60 54	visual space information
8	ROI7	−44 −66 −12	visual color information
9	ROI8	44 −66 −12	visual color information
10	ROI9	−44 −62 −20	visual form information
11	ROI10	−42 −52 −18	visual face information
12	ROI11	42 −52 −18	visual face information
13	ROI12	−40 −80 −12	Visual
14	ROI13	40 −80 −12	Visual
15	ROI14	−20 −8 18	Visual
16	ROI15	20 −8 −18	Visual
17	ROI16	−48 −66 −8	Visual
18	ROI17	52 −60 −8	Visual
19	ROI18	−42 −26 8	left primary auditory
20	ROI19	42 −24 8	right primary auditory
21	ROI20	−60 −8 −4	Auditory
22	ROI21	60 −8 −4	Auditory
23	ROI22	−50 −14 2	Auditory
24	ROI23	52 −10 2	Auditory
25	ROI24	38 −42 58	Touch
26	ROI25	0 −42 64	Touch
27	ROI26	0 −36 46	Pain
28	ROI27	−10 −14 4	Pain
29	ROI28	10 −14 4	Pain
30	ROI29	−32 −44 54	Pain
31	ROI30	−50 −24 22	Pain
32	ROI31	56 −18 16	Pain
33	ROI32	0 −30 −10	Pain
34	ROI33	−6 −4 −10	Taste
35	ROI34	6 −4 −10	Taste
36	ROI35	−40 6 −10	Taste
37	ROI36	40 6 −10	Taste
38	ROI37	−22 2 −14	Smell
39	ROI38	26 4 −12	Smell
40	ROI39	−20 30 −16	Smell
41	ROI40	22 30 −16	Smell
42	ROI41	−60 −30 8	acoustic, phonetic processing (Language)
43	ROI42	60 −30 8	acoustic, phonetic processing (Language)
44	ROI43	−30 −36 −18	word processing (Language)
45	ROI44	−44 −68 40	word processing (Language)
46	ROI45	−58 −46 0	sentence processing (Language)
47	ROI46	−50 12 14	sentence processing (Language)
48	ROI47	−48 28 10	integration (Language)
49	ROI48	−2 −8 62	speech production (Language)
50	ROI49	−40 −20 60	speech production (Language)
51	ROI50	40 −20 60	speech production (Language)
52	ROI51	0 46 −6	Memory
53	ROI52	−28 −18 −18	Memory
54	ROI53	26 −16 −18	Memory
55	ROI54	0 16 48	short-term memory
56	ROI55	−28 −2 56	working memory
57	ROI56	28 −2 56	short-term memory
58	ROI57	−42 28 26	working memory
59	ROI58	44 32 26	short-term memory
60	ROI59	−34 −50 42	working memory
61	ROI60	38 −48 42	short-term memory
62	ROI61	−26 −34 −10	long-term memory
63	ROI62	24 −32 −10	long-term memory
64	ROI63	−44 26 22	long-term memory
65	ROI64	44 32 22	long-term memory
66	ROI65	−32 −56 42	long-term memory
67	ROI66	36 −56 42	long-term memory
68	ROI67	−22 0 2	long-term memory
69	ROI68	22 0 2	long-term memory
70	ROI69	−30 −50 50	directing attention
71	ROI70	30 −50 50	directing attention
72	ROI71	−46 32 32	directing attention
73	ROI72	42 38 32	directing attention
74	ROI73	2 44 28	directing attention
75	ROI74	−58 −16 0	attention to the shape
76	ROI75	60 −16 0	attention to the shape
77	ROI76	−22 0 4	Attention
78	ROI77	20 0 4	Attention
79	ROI78	−40 −8 2	Attention
80	ROI79	−42 −8 8	Attention
81	ROI80	0 30 22	Attention
82	ROI81	0 −50 30	Attention
83	ROI82	−24 −62 60	Attention
84	ROI83	16 −62 58	Emotion
85	ROI84	−20 6 18	Emotion
86	ROI85	24 −4 −18	Emotion
87	ROI86	0 −14 6	Emotion
88	ROI87	0 48 −18	Emotion
89	ROI88	0 54 22	Emotion
90	ROI89	0 56 36	Emotion, social cognition
91	ROI90	0 54 −42	Emotion
92	ROI91	−48 −56 20	Emotion
93	ROI92	48 −56 20	Emotion
94	ROI93	−50 6 −32	Emotion
95	ROI94	50 6 −32	Emotion
96	ROI95	−26 −80 −32	Emotion
97	ROI96	32 −80 −32	Emotion