ELSEVIER

NeuroImage

www.elsevier.com/locate/ynimg
NeuroImage 22 (2004) 1291–1301

Selective activation and deactivation of the human brain structures between speeded and precisely timed tapping responses to identical visual stimulus: an fMRI study

Kazutoshi Kudo,[a,*] Makoto Miyazaki,[b] Toshitaka Kimura,[a] Kentaro Yamanaka,[c,d] Hiroshi Kadota,[a] Masaya Hirashima,[a] Yasoichi Nakajima,[b] Kimitaka Nakazawa,[d] and Tatsuyuki Ohtsuki[a]

[a] *Department of Life Sciences, Laboratory of Sports Sciences, Graduate School of Arts and Sciences, The University of Tokyo, Tokyo, Japan*
[b] *Department of Sensory and Communicative Disorders, Research Institute, National Rehabilitation Center for Persons with Disabilities, Tokorozawa, Japan*
[c] *Educational Physiology Laboratory, Graduate School of Education, University of Tokyo, Tokyo, Japan*
[d] *Department of Rehabilitation for the Movement Functions, Research Institute, National Rehabilitation Center for Persons with Disabilities, Tokorozawa, Japan*

Received 9 December 2003; revised 8 March 2004; accepted 9 March 2004

We investigated the difference between brain activities in speeded and precisely timed responses to identical visual stimulus using fMRI. Stimulus used was a row of seven light-emitting diodes (LEDs) lightened up one after another with constant speed within a trial but with various speeds between trials. Subjects were asked to execute finger-thumb tapping with the right hand in response to the onset of the first LED light in the reaction time (RT) task and in anticipation of the onset of the last (i.e., seventh) LED light in the timing task. In control condition, they were asked to passively view the stimulus without motor response. Results showed that various movement-related areas including contralateral cingulate motor cortex were commonly activated for both tasks relative to the control condition, suggesting these structures are involved in general perception and response execution rather than specific function for speeded or precisely timed responses. In the RT task, the presupplementary motor area extending to the cingulate sulcus was activated more strongly than in the timing task probably to focus attention to the onset of the first LED light unpredictably presented after random foreperiods. The lateral occipital area extending to the temporo-parieto-occipital junction was activated more strongly in the timing task than in the RT task; the same area was deactivated in the RT task relative to the control condition. Auditory-related areas were also deactivated in the both tasks. This inter- and intramodal task-specific modification including deactivation underscores significance of the context for perception and action and can have an important role in dexterous or skilled performance.

Keywords: Human brain activity; Skill; Timing control; Reaction time; Selective attention; fMRI

Introduction

Both quickness of response and precision of response execution timing are important features of dexterous or skilled action (Bernstein, 1996). While both quick, speeded response and precisely timed response are related to the ability of anticipation of environmental situation and preparation for forthcoming response (Schmidt and Lee, 1999), we often need to distinguish these two time-related responses from each other depending on situation. For example, Bartlett (1958) emphasized that "timing has little or nothing to do with the absolute speed at which any component response in the skill sequence is performed. Efficiency depends, more than upon anything else, upon the regulation of the flow from component to component in such a way that nowhere in the whole series is there any appearance of hurry, and nowhere unnecessary prolonged delay" (p. 15).

Behavioral properties and neural underpinnings of the speeded response and precisely timed response have been extensively investigated in human and nonhuman primates by using a variety of reaction time (RT) tasks (e.g., Sasaki et al., 1982; Tanji and Evarts, 1976; Welford, 1980) and timing tasks (e.g., Ivry et al., 1988; Sasaki et al., 1990; Shea, 1980). More recently, functional neuroimaging has revealed human brain activities underlying the speeded response (Naito et al., 2000; Sakai et al., 2000; Ullsperger and von-Cramon, 2001) and the precisely timed response (Jancke et al., 2000; Kudo et al., 2001; Lutz et al., 2000; Rao et al., 1997, 2001). For example, Naito et al. (2000) found that the regional cerebral blood flow (rCBF) in the anterior cingulate cortex (ACC) was negatively correlated to the reaction time (RT) for simple speeded response to visual, auditory, and somatosensory stimulus, suggesting the ACC might be a key structure that determines the speed in simple RT tasks. Rao et al. (2001) reported dynamic network of cortical–subcortical activation associated with temporal information processing for interval timing judgment, suggesting that the basal ganglia, the right inferior parietal cortex, the bilateral premotor cortex, and

* Corresponding author. Department of Life Sciences, Laboratory of Sports Sciences, Graduate School of Arts and Sciences, The University of Tokyo, 3-8-1 Komaba, Meguro, Tokyo, 153-8902, Japan. Fax: +81-3-5454-4317.
E-mail address: kudo@idaten.c.u-tokyo.ac.jp (K. Kudo).
Available online on ScienceDirect (www.sciencedirect.com.)

1053-8119/$ - see front matter © 2004 Elsevier Inc. All rights reserved.
doi:10.1016/j.neuroimage.2004.03.043

the right dorsolateral prefrontal cortex are associated with encoding time intervals (timekeeper), attention, temporary maintenance of time intervals, and comparison of time intervals, respectively.

While human brain activity for the speeded and precisely timed responses has been investigated separately, we compared brain activities between these two responses to gain more general understanding on anticipation and preparation for proper response in terms of time. Another aim of this study was to investigate how humans distinguish these time-related skilled responses from each other. To attain these purposes, we used identical imperative stimulus and identical motor response for both RT task and timing task. In addition, we hypothesized that not only activation of the relevant brain structures but also deactivation of irrelevant ones, which would interfere with the appropriate response, should be necessary to execute the appropriate responses to the same stimulus. There has been relatively few neuroimaging studies that investigated both activation and deactivation during perceptual and motor tasks (Allison et al., 2000; Kawashima et al., 1995, 1999; Laurienti et al., 2002; Taylor et al., 1997). Therefore, we examined both activated and deactivated areas associated to the execution of time-related skilled action, using fMRI. In the present study, we show proper execution of time-related skilled action is performed through appropriate activation and deactivation in multiple brain areas.

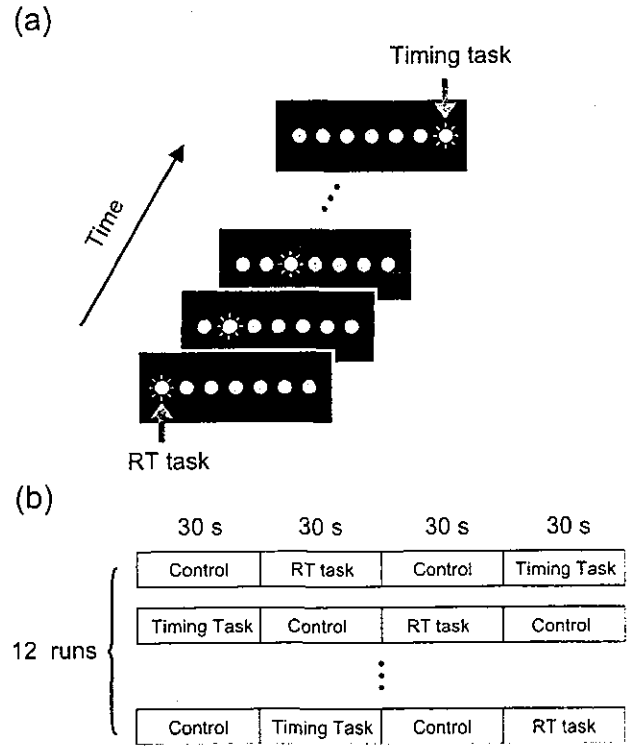

Fig. 1. (a) Stimulus used. Seven light-emitting diodes (LEDs) arrayed horizontally were lightened up one after another from side to side with constant speed within a trial. Subjects were asked to respond as soon as possible when the first LED light was presented in reaction time task and to respond in anticipation of the last (i.e., seventh) LED light presentation in timing task. (b) Experimental protocol. Subjects repeated 12 runs consisted of four blocks of trials. A run included one reaction time task block, one timing task block, and two control condition blocks, in which they only looked the LED without motor response. Each block continued 30 s, and the order of these blocks was pseudorandomized so that the reaction time and timing task conditions were separated by the control condition.

Materials and methods

Subjects

Subjects were 12 right-handed adults (11 male and 1 female). Mean laterality quotient (±SD) measured by the Oldfield's Edinburgh Handedness Inventory (Oldfield, 1971) was 91.2 (±13.0). All the subjects had normal or corrected-to-normal vision and had no history of neurological disorders. Their ages ranged from 22 to 56 years, with a median of 29.5 years. Subjects gave their informed consent. The ethical committee of the University of Tokyo approved the experiments.

Stimulus

Stimulus was presented visually by seven red-colored light-emitting diodes (LEDs) connected to a pulse generator, which was controlled by a personal computer. The LEDs were lined up horizontally and neighboring LEDs were separated by 1.5 cm. Individual LEDs were lightened up one after another from side to side (Fig. 1a). After the last (i.e., seventh) LED was lit, the same one was lit with the randomly varied intervals of 1.5–2.5 s to prevent subject from anticipating the time of stimulus onset as well as to allow them to anticipate the spatial position of the first LED onset for the next trial, and lights moved in the opposite direction. Duration of individual LED light presentation was fixed within a trial but randomly varied for 57–125 ms from trial to trial. Ten different durations were prepared. Therefore, the subject viewed apparently moving light spot back and forth with various speeds (12–26 cm · s^{-1}) during experiment. The LED row was recorded by a video camera and presented real-time through small binocular telescope-like video monitors placed on the eyes of the supine subject. Subjects saw the same visual scene with both eyes so that they perceived one visual scene. The video camera was adjusted so that the LED row was in the middle of the subject's visual field with the right and left ends of the LED row on the outer limits of the visual field when gaze was fixed on the center of the LED row.

Tasks and experimental procedure

Subjects performed RT and timing tasks. In the RT task, they were asked to tap their index finger against the thumb as soon as possible in response to the onset of the first LED light out of seven. In the timing task, they were asked to perform index finger-thumb tapping at the time they expected the last LED to light. In addition, we set control condition in which subjects were asked to passively view the stimulus without any motor response.

During the experiment, subjects lay supine facing the ceiling of the bore of magnet of the MRI apparatus with small binocular optic fiber video monitor on the eyes. Nonmagnetic conductive carbon sheets were attached to their right index finger and thumb to record the time of finger-thumb contact. Special care was taken to immobilize their heads and arms by using plastic excelsior and straps. They repeated 12 runs consisting of four blocks of trials (Fig. 1b). A run included one RT task block, one timing task block, and two control condition blocks. Each block continued 30 s, and the order of these blocks was pseudorandomized so that the RT and

the timing task conditions were separated by the control condition. The required conditions were specified visually by the label below the LED row on the monitors. The stimuli and responses were recorded simultaneously using Biopac MP100 data acquisition system (Biopac Systems Inc.); they were digitized at 1000 Hz and stored in the hard disk during the experiment. Synchronization between behavioral (i.e., stimuli and responses) recording and brain activity recording was achieved by triggering these recordings at the same time with vocal cue (i.e., 3, 2, 1, Go!).

Functional imaging

The brain activity was recorded by a 1.5-T EXELART scanner (Toshiba, Tokyo, Japan) of the whole-body MRI system equipped with a head coil. The BOLD images were collected with an FOV of 350 mm, a matrix of 64 × 64 in 14 axial planes of 8 mm thickness with a gap of 1 mm, TE/TR of 40/2000 ms, and a flip angle of 90°. Scanning took place in 12 runs of 63 scans. The first three scans of each run were discarded to allow for T1 equilibration effects. A T1-weighted high-resolution anatomical images were acquired at another run (FOV = 250 mm, matrix = 256 × 256. NS = 72 axial planes of 2 mm thickness, gap = 0 mm, TE/TR = 7/25 ms, flip/flop angle = 25°/73°). An experimental session consisted of homogenization of the magnetic fields and recording of 12 time series separated approximately 1 min rest in between. In total, a session required about 40 min.

Data processing

SPM99 (Wellcome Department of Imaging Neuroscience, London, UK) was used for fMRI data preprocessing and statistical analysis. Each image was realigned to the first image, spatially normalized to the space of the default EPI template of the SPM99 with subsampling to a resultant voxel size of 2 × 2 × 2 mm. The resultant images were spatially smoothed with a Gaussian kernel of 10.94 mm full-width half-maximum before statistical analysis (Friston et al., 1995; Turner et al., 1998).

Statistical analysis was accomplished within SPM. Statistical parametric maps were computed to characterize regionally specific effects in the imaging data using the model including terms of three conditions (RT, timing, and control conditions), the global mean value of each temporal dataset, temporal derivatives for the delayed boxcar reference waveform, and temporal smoothing using a kernel that approximates the hemodynamic response curve. The statistical model considered each run as a separate session. Specific hypotheses using a boxcar reference waveform were tested with a t value (SPM{t}) at each voxel and transformed to the unit normal distribution to give an SPM{Z} static.

For each subject, we computed SPM maps of six contrasts. To examine activation in the RT or timing tasks relative to the control condition, the following contrasts were used: (1) RT-control and (2) timing-control. To examine task-specific activation, the following contrasts were used: (3) RT-timing and (4) timing-RT. In addition, to examine deactivation we used the following contrasts: (5) control-RT and (6) control-timing.

To analyze the group effect, one sample t test was performed using SPM{Z} for each subject based on random-effect model. Statistical results given are based on a single-voxel Z (height) threshold of 4.69 (corresponding to $P < 0.05$, corrected for multiple comparisons. In this case, values on the tables are indicated in bold typeface) and 3.27 (corresponding to $P < 0.001$, uncorrected for multiple comparisons). We did not use extent threshold. To identify the Brodmann's area, we used the Electric Clinical Brain Atlas (Thieme Medical Publishers, Inc., New York).

As for behavioral data, when subjects failed to respond, or respond too early or too late due to lack of attention or any other reasons, we excluded these responses from analyses on behavioral performance. Namely, when subjects did not make any response to the imperative stimulus, we defined such an error as an omission; and when response latency was outside of ±3 SD range of within-subject response latency distribution in a given condition, we defined such an error as an exceptional response.

Results

Behavioral performance

Mean response omission rate (±SD) or the rate at which subjects did not make any response to the imperative stimulus was 0.60% (±0.91%) in the RT task and 0.66% (±0.78%) in the timing tasks. A paired t test showed that the omission rate did not significantly different between the RT and timing tasks ($t = 0.16$, $df = 11$, $P > 0.87$). Because in some subjects there were cases that they showed too early or too late responses, these exceptional responses, of which the latency was outside of ±3 SD range of the distribution, were excluded from calculation of mean response latency. The percentage of excluded response was 6.4% for the RT task and 1.5% for the timing task.

Fig. 2a shows typical distribution of response latency for the RT and timing tasks for one subject. Mean latency was longer and distribution of the latency was narrower in the RT task than in the timing task. These results were also confirmed by averaged results. The averaged response latency (±SD) across subjects was 254.0 (±23.2) ms for the RT task and 90.7 (±40.5) ms for the timing task (Fig. 2b). The averaged variable error (±SD), that is, the measure of variability of outcome (Schmidt and Lee, 1999), was 40.7 (±16.2) ms for the RT task and 56.1 (±13.3) ms for the timing task (Fig. 2c). A paired t test showed significantly longer mean response latency ($t = 11.0$, $df = 11$, $P < 0.0001$) and smaller variable error ($t = 4.2$, $df = 11$, $P < 0.05$) in the RT task than in the timing task.

fMRI results

Areas activated during the tasks

Table 1 and Fig. 3 show the brain areas with significantly stronger BOLD contrast signal during the RT or timing tasks relative to the control condition. We found significant activations in the left supplementary motor area (SMA) for both tasks at corrected $P < 0.05$ height threshold. At uncorrected $P < 0.001$ height threshold, the RT and timing tasks activated left primary sensorimotor area (SM1) including the dorsal premotor area (Figs. 3a–c and e–g), the left anterior cingulate cortex (Figs. 3c, d, g, and h and 4a and b), the right basal ganglia (globus pallidus), the bilateral cerebellum (vermis and posterior lobe), and the bilateral brainstem (Figs. 4a and b). The activity of the premotor area extended to the junction of the precentral sulcus and the superior frontal sulcus and extended laterally to the precentral gyrus (Figs. 3c, d, g, and h). Therefore, this area can involve the left frontal eye field (FEF; Milea et al., 2002; Paus, 1996; Petit et al., 1997). The activated SMA area for the RT task relative to the control condition

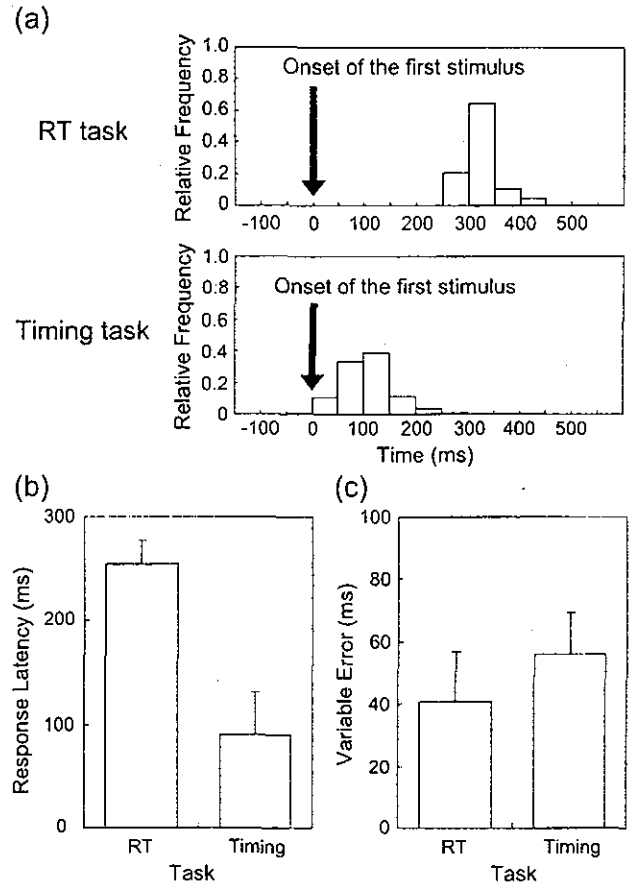

Fig. 2. (a) Typical relative frequency of response latency in reaction time and timing tasks for one subject. Vertical arrows indicate the onset of imperative stimuli. (b) Mean response latency for two tasks. Error bars represent between-subject standard deviations. (c) Mean variable error for two tasks. Error bars represent between-subject standard deviations.

was located both anteriorly and posteriorly to the coronal plane passing the anterior commissure (VCA; Figs. 3a–c and 4a). Therefore, the area was considered to include both pre-SMA and SMA proper (Picard and Strick, 1996; Roland and Zilles, 1996; Tanji, 1996). On the other hand, the SMA area activated by the timing task relative to the control condition was mainly located posteriorly to VCA (Figs. 3e–g and 4b), indicating that this area only includes SMA proper. Because these SMA areas extended to the anterior portion of cingulate sulcus, the area can involve the anterior cingulate motor cortex (Paus et al., 1993).

In addition to these areas, significant activation was found in the bilateral superior frontal gyrus, the bilateral ventral premotor area (operculum), the right middle frontal gyrus, and the left inferior parietal lobule only for the RT task; while the left precuneus around the intraparietal sulcus (IPS; Figs. 3f and g), the left lingual gyrus, and the right inferior frontal gyrus were activated only for the timing task.

Areas differentially activated by the two tasks

Table 2 shows the significantly activated areas in the direct comparison between the RT and timing tasks. The bilateral pre-SMA, the bilateral superior frontal gyrus, and the left inferior frontal gyrus showed higher activation for the RT task than for the timing task. Fig. 4c shows the significant activation of the pre-SMA extending to the cingulate sulcus in the contrast of the RT-timing tasks.

The left cuneus was activated more strongly by the timing task than by the RT task (corrected $P < 0.05$ threshold; Fig. 5a). The left cuneus and precuneus area extended from the lateral occipital area to the temporo-parieto-occipital junction; therefore, it could be considered to include human V5/MT+ (DeYoe et al., 1996; Smith et al., 1998; Tootell et al., 1995; Watson et al., 1993; Zeki et al., 1991) and kinetic occipital (KO) area (Dupont et al., 1997; Van-Oostende et al., 1997). In addition, the timing task activated areas around the bilateral intraparietal sulcus and the fusiform gyrus.

Deactivated areas in the tasks relative to the control condition

Table 3 summarizes the areas that showed a significant decrease in the BOLD contrast signal for the RT or timing tasks relative to the control condition. The left middle temporal gyrus, the right dorsal premotor area, and the bilateral anterior cerebellum (Figs. 5c and d) were deactivated in both the RT and timing tasks. Significant deactivation was also found for the RT task relative to the control condition in the bilateral rostralmost ACC (corrected $P < 0.05$ threshold; Figs. 4d and 5b), the right insula, the right uncus, the bilateral paracentral lobule, the bilateral precuneus, and the left lingual. The deactivated areas in precuneus and lingual gyrus may involve V3 and MT+ areas because they involved the area just inferior to the parietooccipital fissure and the area around temporo-parieto-occipital junction (Fig. 5b; DeYoe et al., 1996; Rees et al., 2000; Zeki et al., 1991).

Discussion

Using the identical stimulus and identical motor response, we investigated the difference at the level of behavior and brain activity for the two tasks that require specific time adjustment. In the RT task, subjects were required speeded response; while in the timing task, they were required precisely timed response. In this section, we firstly discuss the behavioral results in the two tasks and then discuss brain activation or deactivation in the distinct areas observed by the analyses using individual contrasts.

Performance

In the behavioral level, the response omission rate was small in both the RT and timing tasks, and there was no significant difference in the rate between the tasks. These results suggest that subjects could keep their vigilance level equally well in the both tasks. The response latency was longer for the RT task than for the timing task. The averaged response time was 254.0 ms for the RT (Fig. 2b). This time interval from stimulus to response (i.e., finger tapping) has been commonly observed for simple RT tasks using variable foreperiods (e.g., Luce, 1986). For the timing task, the averaged response time was 90.7 ms. Shorter response latency relative to the RT task was due to subject's anticipation of the relevant time for response execution. These tendencies have been reported by studies on the coincident timing tasks (e.g., Shea, 1980; Wrisberg et al., 1982).

The variability of the response latency (i.e., variable error) was larger in the timing task than in the RT task (Fig. 2c), suggesting that it was relatively difficult for subjects to coincide their response with the onset of the last LED stimulus due to variable stimulus duration (Ball, 1992; Wrisberg et al., 1982).

Table 1
Activation areas for the reaction time and timing tasks relative to the control condition

Area (Brodmann area)	RT – control					Timing – control				
	z	Coordinates (mm)			Size	z	Coordinates (mm)			Size
		x	y	z			x	y	z	
L Primary sensorimotor (3/4)	**5.1**	**−57**	**−27**	**44**	2596	4.6	−46	−19	49	1933
L Superior parietal (7)	4.1	−48	−36	52						
L Dorsal premotor (6)	4.0	−38	−5	52		**4.9**	**−36**	**−5**	**52**	
L Precuneus (IPS, 7)						4.6	−30	−62	51	
L Precuneus (IPS, 7)						3.1	−40	−66	47	1
L Anterior cingulate (24)						4.5	−8	4	37	577
L SMA proper (6)	**4.7**	**−8**	**2**	**50**	1611	**5.0**	**−6**	**−1**	**55**	
R Superior frontal gyrus (6)	4.2	6	11	60						
L Superior frontal gyrus (6)	3.4	−20	7	60						
L Superior frontal gyrus (8)	3.1	−22	16	51	1					
L Superior frontal gyrus (10)						3.5	−18	57	19	7
R Operculum (6/44)	4.2	46	25	−6	331					
R Operculum (45)	3.7	57	20	6						
L Operculum (6/44)	4.1	−50	12	−1	267					
R Middle frontal gyrus (6/8)	3.6	46	12	47	82					
R Middle frontal gyrus (6/8)	3.5	50	14	40						
R Middle frontal gyrus (8)	3.2	34	9	57	3					
R Inferior frontal gyrus (45)						3.6	57	11	22	9
L Inferior parietal (40)	3.2	−46	−56	43	19					
L Basal ganglia (globus pallidus)	3.8	−14	0	2	300					
R Basal ganglia (globus pallidus)	3.6	10	2	2	124	3.6	10	−5	11	107
R Basal ganglia (globus pallidus)	3.2	12	14	−1						
L Lingual (18)						4.1	−20	−92	−9	531
L Lingual (18)						3.8	−20	−97	−2	
L Cerebellum (posterior lobe)	3.4	−26	−85	−24	102	**4.9**	**−22**	**−86**	**−19**	
	3.4	−16	−88	−21						
L Cerebellum (posterior lobe)	3.2	−18	−80	−36	3					
R Cerebellum (posterior lobe)	3.6	28	55	43	67	3.2	−38	−62	−39	4
R Cerebellum (anterior lobe)						4.4	30	−54	−38	1285
R Cerebellum (nucleus)						4.4	8	−60	−29	
R/L Cerebellum (vermis)						4.0	0	−55	−21	
R Cerebellum (vermis)	3.3	10	−58	−29	70					
L/R Brainstem	3.4	−2	−28	−17	32	3.3	−4	−26	18	35

Note. Coordinate axis. *x*, dextral–sinistral (+: dextral); *y*, anterior–posterior (+: anterior); *z*, superior–inferior (+: superior); 1 voxel = 2 × 2 × 2 mm^3. Tables 1–3 list all the cortical areas including the most active voxel (maximal *z* value) and the locally most active voxels more than 8 mm apart from the most active one and from each other within a cluster of the adjoining voxels above the chosen level of significance (height threshold $P < 0.001$, uncorrected for multiple comparisons). The size refers to the total number of activated voxels in the single clusters. The reported coordinates represent the Talairach coordinates. The point (0,0,0) is the intersection of CA-CP line and VCA line of Talairach and Tournoux (1988). Because SPM outputs are in the MNI coordinates, they were converted into Talairach coordinates using a nonlinear transform (http://www.mrc-cbu.cam.ac.uk/Imaging/Common/mnispace.shtml). The values significant at height threshold $P < 0.05$ corrected for multiple comparison are indicated in bold typeface in the area and coordinates column. SMA = supplementary motor area. IPS = intraparietal sulcus.

These results indicate that subjects tried to make speeded and precisely timed responses in the RT and timing tasks, respectively, with maintaining vigilance.

Brain activation

Statistical and physiological interpretation of deactivation

We investigated both activation and deactivation in the brain structures. In SPM, the statistical method to detect significantly deactivated area is exactly equivalent to the method to detect significantly activated area. Therefore, physiologically, deactivation means decreased MRI signal intensity based on blood oxygenation level-dependent contrast. This can be interpreted as suppression of neuronal activity in a given condition relative to the control condition caused by decreased firing, decreased temporal synchronization of firing, or recruitment of neurons (Fransson et al., 1999). In addition, suppression of neuronal activity due to attentional modulation has been reported in the monkey studies (Treue and Maunsell, 1996; Vanduffel et al., 2000). These findings suggested the necessity to examine deactivation as well as activation.

However, there is another possibility to interpret negative BOLD signal. That is, Harel et al. (2002) demonstrated that negative BOLD signal can be observed as a result of reallocation of cortical blood resources for strong neural activity in neighboring areas. In this case, the reallocation overcomes a local demand for increased cerebral blood flow induced by increased neural activity. Therefore, we interpreted negative BOLD signal as an evidence for suppression of neuronal activity only when there were no strongly activated areas around the deactivated area in the opposite contrast.

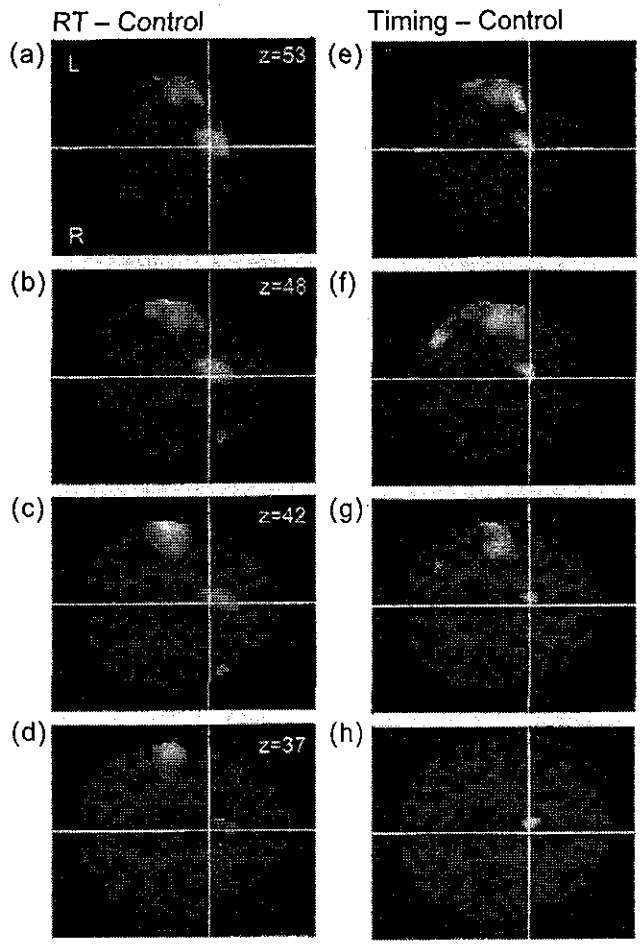

Fig. 3. Activation maps showing significant increases in the BOLD contrast revealed by individual contrast (a–h). Statistical height threshold is $P < 0.001$ uncorrected for multiple comparison. Individual slices on the same horizontal row are from the same axial position in Talairach coordinates. L = left hemisphere; R = right hemisphere. The coordinates of bounding boxes in Talairach coordinates are (−x, x, −y, y) = (−77, 77, −109, 74).

Common brain activity to the RT and timing tasks

We used the same visual stimuli for all the three conditions (i.e., the RT, timing, and control conditions); therefore, it is reasonable that neither the RT nor the timing tasks activated the primary visual area relative to the control condition.

Because overt motor response (i.e., index finger-thumb tapping) was required in both the RT and timing tasks, significantly strong activation in motor-related areas including the cerebellum was found during the both tasks relative to the control condition. That is, these tasks commonly activated the contralateral (left) SM1, the dorsal premotor area, the SMA proper extending to the ACC (Table 1, Figs. 3a–h and 4a and b), and the ipsilateral (right) posterior lobe and vermis in the cerebellum. These activations were widely recognized as the areas related to the finger tapping movement (Dettmers et al., 1995; Kawashima et al., 1996; Larsson et al., 1996) or RT tasks using fingers (Naito et al., 2000; Sakai et al., 2000).

For example, Sakai et al. (2000) reported that when the subject perform the RT task in various conditions, the activation of SMA proper was not affected either by the response or time uncertainty condition, suggesting that activation of SMA proper is related to execution of response. In addition, in the present experiment, the activated areas in the RT and the timing tasks were very similar in SM1 and the premotor areas, which probably reflects the similarity of the tapping movement per se executed in the two tasks. Though human and nonhuman primate studies have reported task-specific preparatory activity for response selection in the SM1 (Evarts et al., 1981) and the premotor area (Kurata and Wise, 1988; Sakai et al., 2000), our findings suggest that the activity of these areas is not significantly changed with the difference in terms of time adjustment (see also Sakai et al., 2000).

We also found that the ACC just inferior to the SMA proper area was commonly activated in both tasks (Figs. 3c and g and 4a and b). This result is consistent with findings that the ACC is engaged in the execution of the appropriate responses (Paus et al., 1993) or translation of intention to action (Paus, 2001) because both tasks require these functions.

Commonly activated area in the premotor area in the RT and timing tasks extended to the FEF (Figs. 3c and g). This suggests that pursuit or saccadic eye movements occurred during the tasks

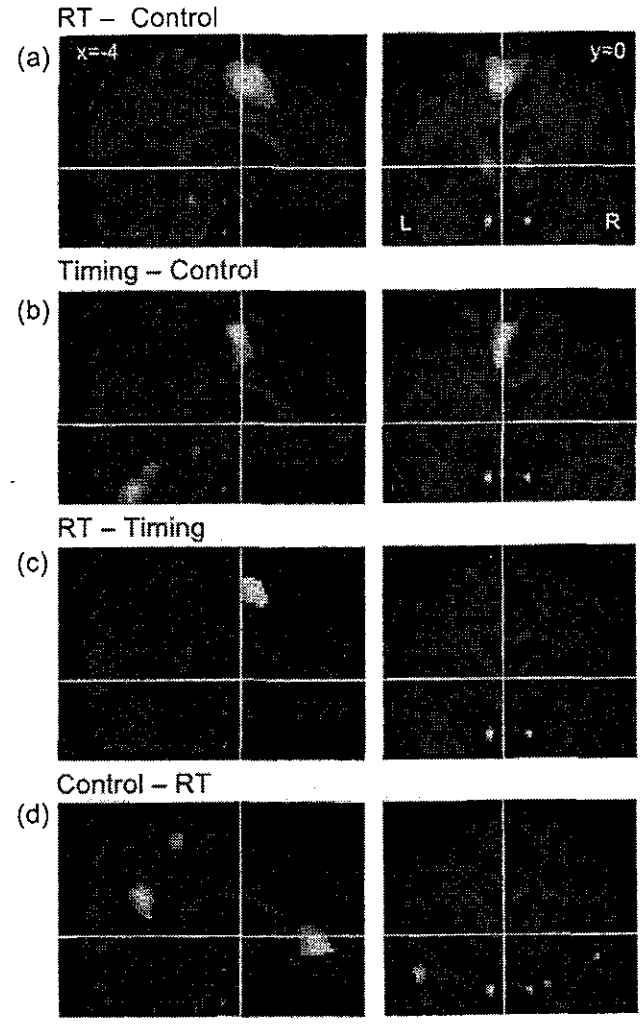

Fig. 4. Activation maps showing significant increases in the BOLD contrast revealed by individual contrast (a–d). Statistical height threshold is $P < 0.001$ uncorrected for multiple comparison. Left column, the sagittal brain slices at $x = -4$ with white vertical lines indicating the coronal plane at $y = 0$. Right column, the coronal plane at $y = 0$.

Table 2
Activation areas revealed by comparisons between reaction time and timing tasks

Comparison	Area (Brodmann area)	z	Coordinates (mm)			Size
			x	y	z	
RT – Timing	R/L SMA (6)	4.4	0	12	51	511
	L superior frontal gyrus (6)	4.3	−12	9	64	
	R superior frontal gyrus (6)	3.6	20	19	60	
	L inferior frontal gyrus (47)	3.3	−48	25	−13	33
Timing – RT	**L Cuneus (19)**	**4.9**	**−32**	**−79**	**6**	941
	L Precuneus (7)	3.2	−26	−73	26	
	L Precuneus (7)	3.3	−12	−42	57	17
	L Precuneus (7)	3.5	−26	−64	46	627
	L Precuneus (7)	4.1	−18	−77	48	
	L Postcentral sulcus (7)	4.3	−34	−44	57	
	R Superior parietal (7)	3.4	28	−61	55	117
	R Precuneus (7)	3.3	22	−60	45	
	R Fusiform gyrus (37)	3.3	42	−63	−12	15

Note. 1 voxel = 2 × 2 × 2 mm^3. SMA = Supplementary motor area. The values significant at height threshold $P < 0.05$ corrected for multiple comparison are indicated in bold typeface in the area and coordinates column.

(Anderson et al., 1994; O'Driscoll et al., 1998; Rosano et al., 2002; Sweeney et al., 1996), though we did not record the eye movements.

We found that the left middle temporal gyrus was commonly deactivated during the tasks (Figs. 5c and d). This area corresponds to the auditory association area (Roland, 1993) that is activated by the auditory discrimination task (Mazziotta et al., 1982). Because no area neighboring this area was activated either in RT control or in timing control conditions, we interpret this deactivation as a modulation of activation by shifting attention to the relevant visual stimuli and ignoring irrelevant auditory echo planar scanner noise (Ulmer et al., 1998), which had its own rhythm and could interfere with the appropriate timing regulation in the both tasks. Kawashima et al. (1999) also found that during the visual task, deactivation was observed in the auditory cortex, indicating that there exists a modality-dependent selective attention mechanism that activates or deactivates cortical areas in different ways (see also Laurienti et al., 2002).

We also found deactivation in the cerebellum, that is, the superior portion of anterior lobe of the cerebellum was deactivated bilaterally in the RT and timing condition relative to the control condition (Figs. 5c and d). There were no strongly activated areas neighboring this area either in RT-control contrast or in timing-control contrast. Recent studies have demonstrated an inhibition of the contralateral motor cortex in humans using transcranial magnetic stimulation, but only a few examined the cerebellum (Allison et al., 2000). Deactivation in the cerebellum due to motor task was found by Allison et al. (2000), who reported that self-paced sequential finger or thumb tapping for one hand deactivated the contralateral anterior cerebellum. Somatotopic motor representation of hand was also found in this portion of the anterior cerebellum (Nitschke et al., 1996). The area in which we found bilateral deactivation corresponds to this area. This difference (i.e., contralateral vs. bilateral deactivation) is probably explained by the difference of the task used. While Allison et al. (2000) used sequential finger or thumb tapping task, we used the index finger or thumb tapping task. Therefore, our subjects were required not to move the contralateral fingers and thumb as well as the other ipsilateral fingers (i.e., middle, ring, and little fingers). This may lead ipsilateral inhibition of somatotopic representation areas for these fingers. As a consequence, this contralateral and ipsilateral deactivation appeared as bilateral deactivation.

Brain activity specific to the RT task

The pre-SMA was activated more strongly in speeded response than in precisely timed response (Fig. 4c). While anatomical, electrophysiological, and neuroimaging studies have established clear distinction between the pre-SMA and SMA proper (Picard and Strick, 1996; Tanji, 1996), functional role of the pre-SMA has not been fully clear yet. Studies on human and nonhuman brain activity found that pre-SMA is activated in updating current motor plan (Matsuzaka and Tanji, 1996; Shima et al., 1996), during working memory delays (Petit et al., 1998), or in acquisition of complex motor sequences (Hikosaka et al., 1996). Our finding suggests that the pre-SMA also engaged in the time regulation of motor response, especially in the preparation of speeded response for unexpectedly presented stimulus in terms of time. Lutz et al.'s (2000) finding that in finger tapping task in synchrony with a visual stimulus appearing regularly or irregularly, the bilateral pre-SMA was more strongly activated for the irregular visual stimulus than for the regular stimulus also supports this view because their finding indicates that the pre-SMA is activated when subjects cannot exactly predict the appropriate time to respond.

The activity of the pre-SMA extended to the ACC (Fig. 4c). Naito et al. (2000) suggested that the ACC is a key structure for speeded response. However, in our study, the ACC inferior to the SMA proper was commonly activated by the RT and timing tasks, and selectively activated area in the RT task was the portion of the ACC just inferior to the pre-SMA. Therefore, our findings suggest that the ACC inferior to the pre-SMA is a specific region for speeded response and that the ACC inferior to the SMA proper is engaged in both speeded and precisely timed responses.

We found that the V3 and MT+ were deactivated in the RT task relative to the control condition (Fig. 5b). These areas are the surrounding areas of the primary visual cortex that can potentially be activated in the RT task. However, no strong activation was found in the primary visual cortex in RT-control contrast. In

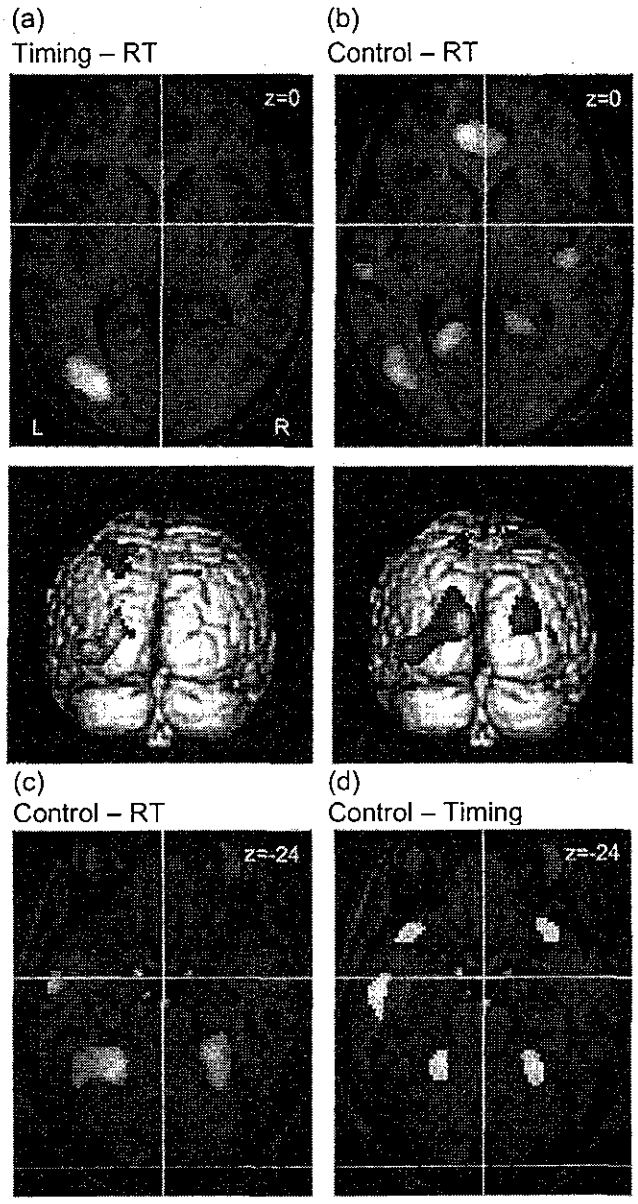

Fig. 5. Activation maps showing significant increases in the BOLD contrast revealed by individual contrast (a–d). Statistical height threshold is $P < 0.001$ uncorrected for multiple comparison. L = left hemisphere; R = right hemisphere.

addition, the Z value at this area ($Z = 4.3$) was comparable to the activation of SMA in RT-control contrast ($Z = 4.7$), while negative BOLD percent changes reported by Harel et al. (2002) were approximately one third of the positive changes. Therefore, we interpret that this negative BOLD signal indicated suppression of neuronal activity in these areas.

The V3 area has been known as one of the motion sensitive areas (Ffytche et al., 1995; Sunaert et al., 2000). The V5/MT+ is human homologue of macaque MT area (Maunsell and Newsome, 1987; Rees et al., 2000) and called the "motion center" (Zeki et al., 1991). These areas typically respond selectively to moving stimuli compared to stationary stimuli (DeYoe et al., 1996; Smith et al., 1998; Sunaert et al., 1999; Tootell et al., 1995; Watson et al., 1993; Zeki et al., 1991). Attention to speed of moving stimuli activates V5/MT+ area stronger than attention to shape or color of the same moving stimulus does (Beauchamp et al., 1997; Corbetta et al., 1990, 1991; Huk and Heeger, 2000; Orban et al., 1998). Attention to moving object also modulates the activity of direction-selective neurons in the MT area in monkey (Treue and Maunsell, 1996). While we observed the deactivation of lateral occipital area only in the left hemisphere, this does not necessarily mean there is strong hemispheric asymmetry because bilateral deactivation was observed when height threshold of uncorrected $P < 0.05$ for multiple comparison was adopted.

Though it has been pointed out that there is a possibility of deactivation in visual areas (Corbetta et al., 1991; Fransson et al., 1999) and deactivation of V1 by attention has been reported by Gandhi et al. (1999), no other studies have been published on task-specific deactivation of the V3 and V5/MT+ area, which could potentially be activated by the stimulus presented. We consider that this deactivation is a reflection of strong task demand to focus on the onset of the stimulus for speeded response.

The rostralmost ACC area was deactivated in the RT task (Fig. 5b). This area is close to the area activated by speeded response to auditory stimuli (Naito et al., 2000). Therefore, this deactivation can also suggest cross modal deactivation for the task in response to the visual stimulus.

Brain activity specific to the timing task

In the timing task, subjects were asked to tap their index finger against thumb in anticipation of the last stimulus. Because the LEDs lit one after another looked as if one light spot would move in one direction, this coincident timing task is considered as "interceptive" timing task (Kudo et al., 2001; Tresilian, 1994, 1999). While many studies have investigated the brain activity involved in "interval" timing task (Cunnington et al., 2002; Harrington et al., 1998; Jancke et al., 2000; Jueptner et al., 1995; Kudo et al., 2001; Mangels et al., 1998; Matell and Meck, 2000; Rao et al., 1997, 2001), little is known about the brain activity involved in interceptive timing task.

The interceptive timing task used in this experiment activated the IPS area relative to the RT task. Some researchers found that the IPS could be activated by perception and action that has interceptive nature such as perception of collision of the balls (Blakemore et al., 2001) or reaching for the known location (Chapman et al., 2002). Not passive view, but attentive tracking of moving targets, which is involved in the interceptive timing task, can also activate the IPS (Culham et al., 1998; Jovicich et al., 2001). Taken together, we can conclude that the IPS is important structure in executing precisely timed interceptive limb movements.

In addition, the lateral occipital area that may include the V5/MT+ area was activated in the timing task relative to the RT task (Fig. 5a). This is not because the area was significantly activated in the timing task relative to the control condition but because the area was significantly deactivated in the RT task relative to the control condition (Fig. 5b). It is reasonable that there is no additional activation in the V5/MT+ area in the timing condition because moving stimulus was presented in all of the condition including the control condition. Observation by Sunaert et al. (2000) that activity of the V5/MT+ area reflected the processing of motion rather than attention of speed also supports this view. In addition, it is also functionally relevant that the same area was deactivated because subjects had to focus on the onset of the first

Table 3
Areas deactivated in reaction time and timing tasks relative to control condition

Area (Brodmann area)	Control – RT					Control – Timing				
	z	Coordinates (mm)			Size	z	Coordinates (mm)			Size
		x	y	z			x	y	z	
L Rostral anterior cingulate (32)	**4.9**	**−10**	**44**	**−6**						
R Rostral anterior cingulate (32)	3.9	8	46	−7	906					
R Rostral anterior cingulate (32)	3.5	4	37	0						
R Dorsal premotor (6)	3.2	46	−14	34	8	3.4	51	−4	37	34
R Insula (13)	4.5	42	−13	10	416					
L Middle frontal gyrus (47)						3.5	−30	34	−15	55
R Inferior frontal gyrus (47)						3.7	34	22	−21	92
R Medial frontal gyrus (10)						3.5	10	48	−11	58
R Uncus	3.2	24	−1	28	13					
L Middle temporal gyrus (21)	3.4	−51	−4	−10	53	4.3	−55	−9	−16	
L Middle temporal gyrus (21)	3.8	−59	−3	−20	454	3.9	−59	−29	−7	635
L Middle temporal gyrus (21)	3.8	−55	−16	−6		3.8	−53	−22	−12	
L Superior temporal gyrus (38)						3.8	-40	22	−25	134
R Superior temporal gyrus (22)						3.7	48	−18	−6	77
R Middle temporal gyrus (21)						3.5	55	−4	−12	69
R Paracentral lobule (5)	4.3	20	−38	63						
L Paracentral lobule (5)	4.0	−8	−36	59	1266					
L Precuneus (7)	4.4	−14	−48	59						
L Precuneus (7)	4.3	−8	−59	27						
R Precuneus (34)	4.3	10	−55	23	4705					
L Lingual (18)	4.3	−22	−62	7						
L Cuneus (18)						3.2	−6	−77	6	5
L Cuneus (18)						3.1	−12	−81	17	5
L Cerebellum (anterior lobe)	4.1	−24	−46	−18		3.9	−24	−42	−20	254
L Cerebellum (anterior lobe)	4.4	−30	−38	−25	1008					
L Cerebellum (anterior lobe)	4.2	−40	−50	−23						
R Cerebellum (anterior lobe)						4.0	26	−44	−16	348

Note. 1 voxel = 2 × 2 × 2 mm^3. The values significant at height threshold $P < 0.05$ corrected for multiple comparison are indicated in bold typeface in the area and coordinates column.

LED light ignoring the other LED lights that were apparently moving. Therefore, this modification in the lateral occipital area suggests that this area should be highly susceptible to task-specific attentional demand for motion perception.

Limitations of the SPM analysis protocol in the present experimental design

In this experiment, we used a boxcar-type experimental protocol for simplicity. This protocol uses a model that presupposes a steady state response such as repetitive finger tapping of the regular rhythm and of the same intensity. However, the actual responses in the present experiment were steady neither in the RT task nor in the timing task due to variable intertrial intervals and intersignal intervals (i.e., stimulus speeds). Such a variation of stimulus presentation is a fundamentally important arrangement of the experimental design to extract participant's strong effort of focusing attention on the stimulus appearance in the RT task and stimulus disappearance in the timing task in this type of experiment. This can decrease BOLD signal fitting to the steady state model. Due to this limitation, the overall significance could be decreased. As a result, only a few areas were found as significantly activated or deactivated areas at corrected height threshold (i.e., $Z > 4.69$). However, major areas reported in this experiment have comparable Z values (e.g., 4.6 at primary sensorimotor cortex in timing-control contrast, 4.5 at anterior cingulate cortex in timing RT contrast, 4.4 at SMA in RT-timing contrast, and 4.3 at cuneus in control-RT contrast, etc.). Therefore, it may be considered that these major areas detected by uncorrected test were not false positive due to low threshold and have sound physiological and functional significance.

Conclusion

We demonstrated that in the RT and timing task in response to the identical visual stimulus, intermodal (i.e., visual vs. auditory) and intramodal (i.e., visual vs. visual) task-specific modification (see also Kudo and Ohtsuki, 1998) occurred in the brain activity. These findings underscore importance of context and intention for perception and action because high sensitivity to some characteristics of stimulus (e.g., motion) in a certain brain area does not necessarily mean that the area is automatically activated for the stimulus. We demonstrated that the area that is potentially be activated by a certain stimulus can be deactivated for the same stimulus depending on the context. These findings also underscore importance of selective activation or deactivation in brain activity due to selective attention or top-down attentional control (Hopfinger et al., 2000) for skilled performance, because usually in natural environment there are full of information that can potentially interfere with one another and should be selectively perceived for relevant motor execution.

Acknowledgments

We thank Ms. Saeka Tomatsu for her technical assistance in performing an experiment and two anonymous reviewers for their helpful comments.

References

Allison, J.D., Meador, K.J., Loring, D.W., Figueroa, R.E., Wright, J.C., 2000. Functional MRI cerebral activation and deactivation during finger movement. Neurology 54, 135–142.

Anderson, T.J., Jenkins, I.H., Brooks, D.J., Hawken, M.B., Frackowiak, R.S., Kennard, C., 1994. Cortical control of saccades and fixation in man. A PET study. Brain 117, 1073–1084.

Ball, C.T., 1992. The interactive effect of velocity on coincident timing performance. Percept. Mot. Skills 75, 1074.

Bartlett, F.C., 1958. Thinking. Basic Books, New York.

Beauchamp, M.S., Cox, R.W., DeYoe, E.A., 1997. Graded effects of spatial and featural attention on human area MT and associated motion processing areas. J. Neurophysiol. 78, 516–520.

Bernstein, N.A., 1996. On dexterity and its development. In: Latash, M.L., Turvey, M.T. (Eds.), Dexterity and Its Development. Erlbaum, New Jersey, pp. 1–244.

Blakemore, S.J., Fonlupt, P., Pachot-Clouard, M., Darmon, C., Boyer, P., Meltzoff, A.N., Segebarth, C., Decety, J., 2001. How the brain perceives causality: an event-related fMRI study. NeuroReport 12, 3741–3746.

Chapman, H., Gavrilescu, M., Wang, H., Kean, M., Egan, G., Castiello, U., 2002. Posterior parietal cortex control of reach-to-grasp movements in humans. Eur. J. Neurosci. 15, 2037–2042.

Corbetta, M., Miezin, F.M., Dobmeyer, S., Shulman, G.L., Petersen, S.E., 1990. Attentional modulation of neural processing of shape, color, and velocity in humans. Science 248, 1556–1559.

Corbetta, M., Miezin, F.M., Dobmeyer, S., Shulman, G.L., Petersen, S.E., 1991. Selective and divided attention during visual discriminations of shape, color, and speed: functional anatomy by positron emission tomography. J. Neurosci. 11, 2383–2402.

Culham, J.C., Brandt, S.A., Cavanagh, P., Kanwisher, N.G., Dale, A.M., Tootell, R.B., 1998. Cortical fMRI activation produced by attentive tracking of moving targets. J. Neurophysiol. 80, 2657–2670.

Cunnington, R., Windischberger, C., Deecke, L., Moser, E., 2002. The preparation and execution of self-initiated and externally-triggered movement: a study of event-related fMRI. NeuroImage 15, 373–385.

Dettmers, C., Fink, G.R., Lemon, R.N., Stephan, K.M., Passingham, R.E., Silbersweig, D., Holmes, A., Ridding, M.C., Brooks, D.J., Frackowiak, R.S., 1995. Relation between cerebral activity and force in the motor areas of the human brain. J. Neurophysiol. 74, 802–815.

DeYoe, E.A., Carman, G.J., Bandettini, P., Glickman, S., Wieser, J., Cox, R., Miller, D., Neitz, J., 1996. Mapping striate and extrastriate visual areas in human cerebral cortex. Proc. Natl. Acad. Sci. U.S.A. 93, 2382–2386.

Dupont, P., De-Bruyn, B., Vandenberghe, R., Rosier, A.M., Michiels, J., Marchal, G., Mortelmans, L., Orban, G.A., 1997. The kinetic occipital region in human visual cortex. Cereb. Cortex 7, 283–292.

Evarts, E.V., Teravainen, H., Calne, D.B., 1981. Reaction time in Parkinson's disease. Brain 104, 167–186.

Ffytche, D.H., Guy, C.N., Zeki, S., 1995. The parallel visual motion inputs into areas V1 and V5 of human cerebral cortex. Brain 118, 1375–1394.

Fransson, P., Kruger, G., Merboldt, K.D., Frahm, J., 1999. MRI of functional deactivation: temporal and spatial characteristics of oxygenation-sensitive responses in human visual cortex. NeuroImage 9, 611–618.

Friston, K.J., Ashburner, J., Poline, J.B., Frith, C.D., Heather, J.D., Frackowiak, R.S.J., 1995. Spatial registration and normalization of images. Hum. Brain Mapp. 2, 165–189.

Gandhi, S.P., Heeger, D.J., Boynton, G.M., 1999. Spatial attention affects brain activity in human primary visual cortex. Proc. Natl. Acad. Sci. U.S.A. 96, 3314–3319.

Harel, N., Lee, S.P., Nagaoka, T., Kim, D.S., Kim, S.G., 2002. Origin of negative blood oxygenation level-dependent fMRI signals. J. Cereb. Blood Flow Metab. 22, 908–917.

Harrington, D.L., Haaland, K.Y., Knight, R.T., 1998. Cortical networks underlying mechanisms of time perception. J. Neurosci. 18, 1085–1095.

Hikosaka, O., Sakai, K., Miyauchi, S., Takino, R., Sasaki, Y., Putz, B., 1996. Activation of human presupplementary motor area in learning of sequential procedures: a functional MRI study. J. Neurophysiol. 76, 617–621.

Hopfinger, J.B., Buonocore, M.H., Mangun, G.R., 2000. The neural mechanisms of top-down attentional control. Nat. Neurosci. 3, 284–291.

Huk, A.C., Heeger, D.J., 2000. Task-related modulation of visual cortex. J. Neurophysiol. 83, 3525–3536.

Ivry, R.B., Keele, S.W., Diener, H.C., 1988. Dissociation of the lateral and medial cerebellum in movement timing and movement execution. Exp. Brain Res. 73, 167–180.

Jancke, L., Loose, R., Lutz, K., Specht, K., Shah, N.J., 2000. Cortical activations during paced finger-tapping applying visual and auditory pacing stimuli. Cogn. Brain Res. 10, 51–66.

Jovicich, J., Peters, R.J., Koch, C., Braun, J., Chang, L., Ernst, T., 2001. Brain areas specific for attentional load in a motion-tracking task. J. Cogn. Neurosci. 13, 1048–1058.

Jueptner, M., Rijntjes, M., Weiller, C., Faiss, J.H., Timmann, D., Mueller, S.P., Diener, H.C., 1995. Localization of a cerebellar timing process using PET. Neurology 45, 1540–1545.

Kawashima, R., O'Sullivan, B.T., Roland, P.E., 1995. Positron-emission tomography studies of cross-modality inhibition in selective attentional tasks: closing the "mind's eye". Proc. Natl. Acad. Sci. U.S.A. 92, 5969–5972.

Kawashima, R., Itoh, H., Ono, S., Satoh, K., Furumoto, S., Gotoh, R., Koyama, M., Yoshioka, S., Takahashi, T., Takahashi, K., Yanagisawa, T., Fukuda, H., 1996. Changes in regional cerebral blood flow during self-paced arm and finger movements. A PET study. Brain Res. 716, 141–148.

Kawashima, R., Imaizumi, S., Mori, K., Okada, K., Goto, R., Kiritani, S., Ogawa, A., Fukuda, H., 1999. Selective visual and auditory attention toward utterances—A PET study. NeuroImage 10, 209–215.

Kudo, K., Miyazaki, M., Kimura, T., Yamanaka, K., Kadota, H., Hirashima, M., Nakajima, Y., Nakazawa, K., Ohtsuki, T., 2001. Differential brain activation in interval and interceptive timing tasks: an fMRI study. Neurosci. Res., Suppl. 25, 152.

Kudo, K., Ohtsuki, T., 1998. Functional modification of agonist-antagonist electromyographic activity for rapid movement inhibition. Exp. Brain Res. 122, 23–30.

Kurata, K., Wise, S.P., 1988. Premotor cortex of rhesus monkeys: set-related activity during two conditional motor tasks. Exp. Brain Res. 69, 327–343.

Larsson, J., Gulyas, B., Roland, P.E., 1996. Cortical representation of self-paced finger movement. NeuroReport 7, 463–468.

Laurienti, P.J., Burdette, J.H., Wallace, M.T., Yen, Y.F., Field, A.S., Stein, B.E., 2002. Deactivation of sensory-specific cortex by cross-modal stimuli. J. Cogn. Neurosci. 14, 420–429.

Luce, R.D., 1986. Response Times: Their Role Inferring Elementary Mental Organization. Oxford Univ. Press, New York.

Lutz, K., Specht, K., Shah, N.J., Jancke, L., 2000. Tapping movements according to regular and irregular visual timing signals investigated with fMRI. NeuroReport 11, 1301–1306.

Mangels, J.A., Ivry, R.B., Shimizu, N., 1998. Dissociable contributions of the prefrontal and neocerebellar cortex to time perception. Cogn. Brain Res. 7, 15–39.

Matell, M.S., Meck, W.H., 2000. Neuropsychological mechanisms of interval timing behavior. BioEssays 22, 94–103.

Matsuzaka, Y., Tanji, J., 1996. Changing directions of forthcoming arm movements: neuronal activity in the presupplementary and supplementary motor area of monkey cerebral cortex. J. Neurophysiol. 76, 2327–2342.

Maunsell, J.H., Newsome, W.T., 1987. Visual processing in monkey extrastriate cortex. Annu. Rev. Neurosci. 10, 363–401.

Mazziotta, J.C., Phelps, M.E., Carson, R.E., Kuhl, D.E., 1982. Tomographic mapping of human cerebral metabolism: sensory deprivation. Ann. Neurol. 12, 435–444.

Milea, D., Lobel, E., Lehericy, S., Duffau, H., Rivaud-Pechoux, S., Berthoz, A., Pierrot-Deseilligny, C., 2002. Intraoperative frontal eye field stimulation elicits ocular deviation and saccade suppression. NeuroReport 13, 1359–1364.

Naito, E., Kinomura, S., Geyer, S., Kawashima, R., Roland, P.E., Zilles, K., 2000. Fast reaction to different sensory modalities activates common fields in the motor areas, but the anterior cingulate cortex is involved in the speed of reaction. J. Neurophysiol. 83, 1701–1709.

Nitschke, M.F., Kleinschmidt, A., Wessel, K., Frahm, J., 1996. Somatotopic motor representation in the human anterior cerebellum. A high-resolution functional MRI study. Brain 119, 1023–1029.

O'Driscoll, G.A., Strakowski, S.M., Alpert, N.M., Matthysse, S.W., Rauch, S.L., Levy, D.L., Holzman, P.S., 1998. Differences in cerebral activation during smooth pursuit and saccadic eye movements using positron-emission tomography. Biol. Psychiatry. 44, 685–689.

Oldfield, R.C., 1971. The Assessment and Analysis of Handedness: the Edinburgh Inventory. Neuropsychologia 9, 97–113.

Orban, G.A., Dupont, P., De-Bruyn, B., Vandenberghe, R., Rosier, A., Mortelmans, L., 1998. Human brain activity related to speed discrimination tasks. Exp. Brain Res. 122, 9–22.

Paus, T., 1996. Location and function of the human frontal eye-field: a selective review. Neuropsychologia 34, 475–483.

Paus, T., 2001. Primate anterior cingulate cortex: where motor control, drive and cognition interface. Nat. Rev. Neurosci. 2, 417–424.

Paus, T., Petrides, M., Evans, A.C., Meyer, E., 1993. Role of the human anterior cingulate cortex in the control of oculomotor, manual, and speech responses: a positron emission tomography study. J. Neurophysiol. 70, 453–469.

Petit, L., Clark, V.P., Ingeholm, J., Haxby, J.V., 1997. Dissociation of saccade-related and pursuit-related activation in human frontal eye fields as revealed by fMRI. J. Neurophysiol. 77, 3386–3390.

Petit, L., Courtney, S.M., Ungerleider, L.G., Haxby, J.V., 1998. Sustained activity in the medial wall during working memory delays. J. Neurosci. 18, 9429–9437.

Picard, N., Strick, P.L., 1996. Motor areas of the medial wall: a review of their location and functional activation. Cereb. Cortex 6, 342–353.

Rao, S.M., Harrington, D.L., Haaland, K.Y., Bobholz, J.A., Cox, R.W., Binder, J.R., 1997. Distributed neural systems underlying the timing of movements. J. Neurosci. 17, 5528–5535.

Rao, S.M., Mayer, A.R., Harrington, D.L., 2001. The evolution of brain activation during temporal processing. Nat. Neurosci. 4, 317–323.

Rees, G., Friston, K., Koch, C., 2000. A direct quantitative relationship between the functional properties of human and macaque V5. Nat. Neurosci. 3, 716–723.

Roland, P.E., 1993. Brain Activation. Wiley, New York.

Roland, P.E., Zilles, K., 1996. Functions and structures of the motor cortices in humans. Curr. Opin. Neurobiol. 6, 773–781.

Rosano, C., Krisky, C.M., Welling, J.S., Eddy, W.F., Luna, B., Thulborn, K.R., Sweeney, J.A., 2002. Pursuit and saccadic eye movement subregions in human frontal eye field: a high-resolution fMRI investigation. Cereb. Cortex 12, 107–115.

Sakai, K., Hikosaka, O., Takino, R., Miyauchi, S., Nielsen, M., Tamada, T., 2000. What and when: parallel and convergent processing in motor control. J. Neurosci. 20, 2691–2700.

Sasaki, K., Gemba, H., Mizuno, N., 1982. Cortical field potentials preceding visually initiated hand movements and cerebellar actions in the monkey. Exp. Brain Res. 46, 29–36.

Sasaki, K., Gemba, H., Tsujimoto, T., 1990. Cortical field potential associated with hand movement on warning-imperative visual stimulus and cerebellum in the monkey. Brain Res. 519, 343–346.

Schmidt, R.A., Lee, T.D., 1999. Motor Control and Learning: A Behavioral Emphasis. Human Kinetics, Champaign, IL.

Shea, C.H., 1980. Effects of extended practice and movement time on motor control of a coincident timing task. Res. Q. Exerc. Sport 51, 369–381.

Shima, K., Mushiake, H., Saito, N., Tanji, J., 1996. Role for cells in the presupplementary motor area in updating motor plans. Proc. Natl. Acad. Sci. U.S.A. 93, 8694–8698.

Smith, A.T., Greenlee, M.W., Singh, K.D., Kraemer, F.M., Hennig, J., 1998. The processing of first- and second-order motion in human visual cortex assessed by functional magnetic resonance imaging (fMRI). J. Neurosci. 18, 3816–3830.

Sunaert, S., Van-Hecke, P., Marchal, G., Orban, G.A., 1999. Motion-responsive regions of the human brain. Exp. Brain Res. 127, 355–370.

Sunaert, S., Van-Hecke, P., Marchal, G., Orban, G.A., 2000. Attention to speed of motion, speed discrimination, and task difficulty: an fMRI study. NeuroImage 11, 612–623.

Sweeney, J.A., Mintun, M.A., Kwee, S., Wiseman, M.B., Brown, D.L., Rosenberg, D.R., Carl, J.R., 1996. Positron emission tomography study of voluntary saccadic eye movements and spatial working memory. J. Neurophysiol. 75, 454–468.

Talairach, J., Tournoux, P., 1988. Co-planar Stereotaxic Atlas of the Human Brain Georg Thieme Verlag, New York.

Tanji, J., 1996. New concepts of the supplementary motor area. Curr. Opin. Neurobiol. 6, 782–787.

Tanji, J., Evarts, E.V., 1976. Anticipatory activity of motor cortex neurons in relation to direction of an intended movement. J. Neurophysiol. 39, 1062–1068.

Taylor, S.F., Kornblum, S., Lauber, E.J., Minoshima, S., Koeppe, R.A., 1997. Isolation of specific interference processing in the Stroop task: PET activation studies. NeuroImage 6, 81–92.

Tootell, R.B., Reppas, J.B., Dale, A.M., Look, R.B., Sereno, M.I., Malach, R., Brady, T.J., Rosen, B.R., 1995. Visual motion aftereffect in human cortical area MT revealed by functional magnetic resonance imaging. Nature 375, 139–141.

Tresilian, J.R., 1994. Perceptual and motor processes in interceptive timing. Hum. Mov. Sci. 13, 335–373.

Tresilian, J.R., 1999. Analysis of recent empirical challenges to an account of interceptive timing. Percept. Psychophys. 61, 515–528.

Treue, S., Maunsell, J.H., 1996. Attentional modulation of visual motion processing in cortical areas MT and MST. Nature 382, 539–541.

Turner, R., Howseman, A., Rees, G.E., Josephs, O., Friston, K., 1998. Functional magnetic resonance imaging of the human brain: data acquisition and analysis. Exp. Brain Res. 123, 5–12.

Ullsperger, M., von-Cramon, D.Y., 2001. Subprocesses of performance monitoring: a dissociation of error processing and response competition revealed by event-related fMRI and ERPs. NeuroImage 14, 1387–1401.

Ulmer, J.L., Biswal, B.B., Yetkin, F.Z., Mark, L.P., Mathews, V.P., Prost, R.W., Estkowski, L.D., McAuliffe, T.L., Haughton, V.M., Daniels, D.L., 1998. Cortical activation response to acoustic echo planar scanner noise. J. Comput. Assist. Tomogr. 22, 111–119.

Vanduffel, W., Tootell, R.B., Orban, G.A., 2000. Attention-dependent suppression of metabolic activity in the early stages of the macaque visual system. Cereb. Cortex 10, 109–126.

Van-Oostende, S., Sunaert, S., Van-Hecke, P., Marchal, G., Orban, G.A., 1997. The kinetic occipital (KO) region in man: an fMRI study. Cereb. Cortex 7, 690–701.

Watson, J.D., Myers, R., Frackowiak, R.S., Hajnal, J.V., Woods, R.P., Mazziotta, J.C., Shipp, S., Zeki, S., 1993. Area V5 of the human brain: evidence from a combined study using positron emission tomography and magnetic resonance imaging. Cereb. Cortex 3, 79–94.

Welford, A.T., 1980. Reaction Times. Academic press, London.

Wrisberg, C.A., Hardy, C.J., Beitel, P.A., 1982. Stimulus velocity and movement distance as determiners of movement velocity and coincident timing accuracy. Hum. Factors 24, 599–608.

Zeki, S., Watson, J.D., Lueck, C.J., Friston, K.J., Kennard, C., Frackowiak, R.S., 1991. A direct demonstration of functional specialization in human visual cortex. J. Neurosci. 11, 641–649.

Special Feature

4 外傷性脳損傷患者に見る高次脳機能障害

中島八十一※
なかじま・やそいち

※国立身体障害者リハビリテーションセンター研究所
感覚機能系障害研究部部長
（〒359-8555　埼玉県所沢市並木4－1）
E-mail　yaso@rehab.go.jp

はじめに

脳の一部に傷がつくと，その部位に応じて一定の症状が現れることはよく知られています．この性質を利用して，ある特定の症状から脳神経系のどこに病巣や傷があるかを推定することを局在診断と呼びます．一方，CTやMRIなどを用いた画像診断の進歩により，病巣の細かい局在を一層明らかにすることが可能になりました．こういった時代になって，局在診断が意味をなさなくなったということではありません．なぜなら患者が持つ症状そのものが，治療や援助の対象として重要視されるようになったからです．

とくに高次脳機能障害は，近年，患者やその家族が高次脳機能障害のために日常生活を送ることが困難になったにもかかわらず，適切な訓練，援助が受けられていないと発言を始めたことにより，注目を集める結果となりました．そこに，高次脳機能障害を持っても生活ができるようにしてほしいという切実な要求を見ることができます．

高次脳機能障害とは英語のcognitive disorder（認知障害）のことであり，いわゆる精神活動の障害を神経心理学的あるいは認知科学的な面からとらえようとするときに用いられる用語です．そのなかには，失行，失語，失認に代表される巣症状（大脳皮質の部分的損傷に基づく症状）と，記憶，注意，意欲，判断などの大脳の広範な損傷による症状までが含まれます．このような症状について治療や援助が求められているのです．ここでは看護師が日常臨床のうえで遭遇する外傷性脳損傷による高次脳機能障害について，それがどのようなものか説明します．

外傷性脳損傷による高次脳機能障害について

外傷性脳損傷の後遺症としては，局所性脳損

傷による巣症状以外に大脳が広範に損傷を受けた場合の記憶，注意，遂行機能といった高度な脳機能の障害があります．どちらも高次脳機能障害であり，両方の症状を持つことも普通に見られますが，ここではびまん（広範）性脳損傷による高次脳機能障害について述べます．

びまん性軸索損傷を伴う広範な脳損傷では，発症初期では昏睡期間があり，一般にこれが長く続くほど，後遺症も重度であるとされます．寝たきり状態の重症例を除けば，次に通過症候群と呼ばれる興奮しやすい時期を経て，意識が清明になります．そのときに完全に回復する例と後遺症を残して退院が可能となる例とがあり，この後遺症のうち深刻な問題であるにもかかわらず，見逃されやすいのが高次脳機能障害です．

日本における外傷性脳損傷による高次脳機能障害については，厚生労働省が平成13年度から実施している高次脳機能障害支援モデル事業において集積されたデータが重要です．この事業では，原則18～65歳までの年齢層で，社会復帰を考えることのできる外傷性脳損傷の患者で高次脳機能障害が後遺症の中心となっている208例について分析がなされました．この事業は，このような患者を持つ家族からの，退院後「怠け者になってしまった」とか「人が変わってしまった」という訴えがきっかけになって開始され，ここに高次脳機能障害を持つ人たちが抱える問題が凝縮されています．すなわち身体機能障害がないか軽いにもかかわらず，社会生活や日常生活の場に戻って初めて事態が深刻であることに気付き，その原因が高次脳機能障害にあったということを表しています．この調査結果（**表1**）から，外傷性脳損傷の後に生活を困難にする高次脳機能障害とは，記憶障害，注意障害，遂行機能障害および一連の社会的行動障害であると言えます．それぞれの症状の簡単な解説はチェックポイントにまとめました．一方，病識欠落が62%に見られました．病識欠落はリハビリテーションを困難にするだけでなく，社会生活においてサインや印鑑が必要な書類を作るような局面ではとくに注意が必要な症状です．この調査結果を基にして，高次脳機能障害診断基準が作成されました（**表2**）．ただし，この診断基準はリハビリテーションの診療報酬や適切な支援サービスを提供するための行政的な診断基準であり，原因疾患を外傷性脳損傷のみならず，脳血管障害

表1　高次脳機能障害の症状

n=208名

記憶障害	91%
注意障害	83%
遂行機能障害	77%
社会的行動障害	
対人技能拙劣	59%
依存性・退行	55%
固執性	45%
意欲・発動性の低下	44%
感情コントロール低下	44%

表2　高次脳機能障害診断基準（行政的）

「高次脳機能障害」という用語は，学術用語としては，脳損傷に起因する認知障害全般を指し，この中にはいわゆる巣症状としての失語・失行・失認のほか記憶障害，注意障害，遂行機能障害，社会的行動障害などが含まれる．

一方，平成13年度に開始された高次脳機能障害支援モデル事業において集積された脳損傷者のデータを慎重に分析した結果，記憶障害，注意障害，遂行機能障害，社会的行動障害などの認知障害を主たる要因として，日常生活及び社会生活への適応に困難を有する一群が存在し，これらについては診断，リハビリテーション，生活支援等の手法が確立しておらず早急な検討が必要なことが明らかとなった．そこでこれらの者への支援対策を推進する観点から，行政的に，この一群が示す認知障害を「高次脳機能障害」と呼び，この障害を有する者を「高次脳機能障害者」と呼ぶことが適当である．その診断基準を以下に提案する．

診断基準

Ⅰ．主要症状等

1．脳の器質的病変の原因となる事故による受傷や疾病の発症の事実が確認されている．

2．現在，日常生活または社会生活に制約があり，その主たる原因が記憶障害，注意障害，遂行機能障害，社会的行動障害などの認知障害である．

Ⅱ．検査所見

MRI，CT，脳波などにより認知障害の原因と考えられる脳の器質的病変の存在が確認されているか，あるいは診断書により脳の器質的病変が存在したと確認できる．

Ⅲ．除外項目

1．脳の器質的病変に基づく認知障害のうち，身体障害として認定可能である症状を有するが上記主要症状（I-2）を欠く者は除外する．

2．診断にあたり，受傷または発症以前から有する症状と検査所見は除外する．

3．先天性疾患，周産期における脳損傷，発達障害，進行性疾患を原因とする者は除外する．

Ⅳ．診断

1．Ⅰ～Ⅲをすべて満たした場合に高次脳機能障害と診断する．

2．高次脳機能障害の診断は脳の器質的病変の原因となった外傷や疾病の急性期症状を脱した後において行う．

3．神経心理学的検査の所見を参考にすることができる．

なお，診断基準のⅠとⅢを満たす一方で，Ⅱの検査所見で脳の器質的病変の存在を明らかにできない症例については，慎重な評価により高次脳機能障害者として診断されることがあり得る．

また，この診断基準については，今後の医学・医療の発展を踏まえ，適時，見直しを行うことが適当である．

や低酸素脳症などの疾患でも利用できるとする一方で，変性疾患や進行性疾患は対象外としています．また，すでに身体障害者として認定可能な失語症などは別にしてあります（除外項目，表2-Ⅲ-1）．

表3　各症状に対する評価法（神経心理学的検査法を含む）

	評価方法
記憶障害	三宅式，Benton視覚記名検査，WMS-R，REYの図の再生，リバーミード行動記憶検査など
注意障害	PASAT，Trail making test，仮名拾い検査，D-CATなど
遂行機能障害	WCST，Stroop testなど
コミュニケーション障害	SLTA，WAB失語症検査など
社会的行動障害（患者の心理的問題を含む）	SDS，POMS，MMPI，社会生活困難度評価など

主要症状について

①記憶障害

外傷性脳損傷で見られる記憶障害には逆行性健忘と前向性健忘とがあります．逆行性健忘とは急激な意識障害から回復した後に，受傷時点より過去の一定期間のことを思い出せないことです．前向性健忘とは新しく経験することを覚えられないことです．責任病巣として側頭葉や前頭葉が挙げられますが，これらは混合して損傷を受けていることも多く，どちらか一方に限定することは困難であることを多く経験します．記憶に関する検査方法は多いが(表3)，後述の注意障害があると検査成績が低下することを知っておく必要があります．

②注意障害

注意障害には全般性注意障害と方向性注意障害（半側空間無視）があり，ここでは前者について述べます．注意とはある物事を選んで，これに注目し，それを続けることであり，いくつかの物事を同時に注目したり，また注目する対象を即座に他のものに変える機能も含みます．「集中力」とか「切り替え」といった日常表現に置き換えて考えることのできる脳機能です．前頭葉を含む脳のさまざまな部位の活動によって成り立っていると考えられ，注意障害を発現する脳の部位は多様です．

③遂行機能障害

遂行機能障害は実行機能障害とも言われることがあり，歴史的には比較的新しい概念です．目的を持って計画的に，かつ効率的に行動する能力が障害された状態を指します．このような障害は短時間の面接では見逃されやすく，生活を共にして初めて気付かれるものです．一方，社会生活を送るうえで支障をきたす度合いは大きいので，慎重に家族らから聞き取りをすることがその発見につながりえます．そのうえできちんと検査を受ける必要があります．前頭葉を中心にした脳機能の障害により発現すると考えられています．

④社会的行動障害

外傷性脳損傷によって日常生活や社会生活

に向けた適応行動がとれなくなった状態を上手に表現した一文を紹介します．

> 「患者は衝動的で，感情が動揺しやすく，抑制がきかず，攻撃的で，いいかげんである．障害のため，自分の感情的反応に対する内省が欠如している．したがって，身体的ならびに知的には十分回復しても，患者は人間関係や復職のうえで大きな問題を抱えている」（鈴木匡子訳）．

ここには社会的行動障害の幾つかが含まれています．このような行動上の問題も認知障害のなかに含まれます．感情コントロールの低下は，いわゆる“キレる”ことであり，固執性とはひとつのことにこだわって，次の行動に移行できないことを指します．このような特徴的な行動上の問題が見られるので，社会的行動障害としてまとめられています．社会的行動障害の病巣の局在については，外傷性脳損傷の患者では損傷部位が広く，また行動上の問題を複数持つことも普通に見られるので，おおまかに前頭葉を中心とした損傷に基づくとしておいてよいと考えられます．むしろ重要なのは，この社会的行動障害だけが顕著な一群があり，ほかの知的能力にまったく問題がないか，低下の軽微な者が少なからずいることです．このような例ではWAIS-R（ウェイスアール：代表的な成人の知能検査法）で知能指数が120以上（平均100）でありながら，まったく就学や就労が不可能といった例さえあります．また高次脳機能障害を持つ患者・障害者では，知能指数が高くても社会生活への適応が容易ではないことは普通です．

外傷性脳損傷に巣症状としての失語症が伴いうることは当然ですが，これとは別に全般性脳損傷には会話能力の障害が伴うことがあり，重症例では自発的にはまったく言葉を発しない例もあります．このような言語障害について，失語症と区別するために，コミュニケーション障害とすることもあります．

リハビリテーションと予後

一般に，外傷性脳損傷による高次脳機能障害は受傷後数カ月の間は急速に回復し，その後5年以上にわたって軽快する傾向を示し，この点で他の疾患による高次脳機能障害とは異なります．症例によっては数年後に周囲が驚くほどに改善を示すことがあります．しかし，改善傾向があるということは，最終的に何の支援もなしに，自立した社会生活が可能となることを意味しません．一定程度以上の重症度を示す症例では，むしろ後遺症としての高次脳機能障害を持った状態で生活していくことを余儀なくされると考えたほうがよいです．

リハビリテーションについては，認知リハビリテーションと呼ばれる認知障害の回復，残存機能の活用，記憶障害を補償する電子手帳に代表される装置の活用，心理的介入による作業能力の向上などを目指す訓練方法が症状に応じて実施されます．外傷性脳損傷では約半数に運動麻痺などの身体機能障害を伴う

ことから，早期リハビリテーションにおいてはこの面でのリハビリテーションも同時に実施されます．日本における認知リハビリテーションの効果については十分なデータがそろっているとは言い難いですが，意識障害の時期を脱した後に，早期にリハビリテーションを開始することと，多くの職種のスタッフがリハビリテーションに関与することが回復に寄与するとされています．この職種に看護師が含まれることは言うまでもありません．上記モデル事業の調査結果では，受傷後急性期を過ぎた後に医療機関において適切なリハビリテーションを受けた患者群では，社会生活に戻った後の社会的行動障害の発生頻度が減ったり，就労・就学率の向上が見られているので，自然回復だけではないと言えます．退院後においては，地域リハビリテーション施設において生活技能訓練や職場復帰のためのリハビリテーションが必要であり，一方で残った認知障害に対するケアが必要なことも指摘されています．看護師が，家族を含めた関係者に患者が持つ問題点を正しく伝えておくことは重要です．

Check Point

高次脳機能障害の具体的な症状

1．記憶障害：物の置き場所を忘れたり，新しい出来事を覚えていられなくなること．そのために何度も同じことを繰り返し質問したりする．
2．注意障害：ぼんやりしていて，何かをするとミスばかりする．2つのことを同時にしようとすると混乱する．
3．遂行機能障害：自分で計画を立てて物事を実行することができない．人に指示してもらわないと何もできない．いきあたりばったりの行動をする．
4．病識欠落：自分が障害を持っていることに対する認識がうまくできない．障害がないかのように振る舞ったり，言ったりする．
5．社会的行動障害：すぐ他人を頼る，子どもっぽくなる（依存，退行），無制限に食べたり，お金を使ったりする（欲求コントロール低下），すぐ怒ったり笑ったりする，感情を爆発させる（感情コントロール低下），相手の立場や気持ちを思いやることができず，良い人間関係が作れない（対人技能拙劣），固執性，意欲の低下，抑うつ，など．

参考文献

1) 国立身体障害者リハビリテーションセンター．高次脳機能障害支援モデル事業報告書－平成13年度～平成15年度のまとめ－．2004．
2) 小暮久也監訳，鈴木匡子訳．脳損傷の理解：神経心理学的アプローチ．東京，メディカル・サイエンス・インターナショナル，1993，203-56．
3) 神奈川リハビリテーション病院「脳外傷リハビリテーションマニュアル編集委員会」編．脳外傷リハビリテーションマニュアル．東京，医学書院，2001．
4) 永井肇監修．脳外傷者の社会生活を支援するリハビリテーション実践編：事例で学ぶ支援のノウハウ．東京，中央法規出版，2003．

脳神経外科速報 vol.14 no.10 1000～1004, 2004

専門医に求められる最新の知識

脳神経外科医に必要な神経内科

高次脳機能障害の最新の知識

深津玲子[1) Reiko FUKATSU

1) 国立病院機構宮城病院神経内科
〒989-2202 宮城県亘理郡山元町高瀬字合戦原100

Ⅰ. はじめに

読者の先生方は高次脳機能障害という言葉からどのような障害像を思い浮かべられるだろうか．高次脳機能障害は脳損傷に起因して生じる機能障害（impairment）のうち麻痺，知覚障害，自律神経障害などの一次的障害の上位に位置する認知障害であり，その症状は失語，失行，失認，記憶障害，遂行機能障害，空間無視など多岐にわたる．しかし，現在はこれらの機能障害によって発生する日常生活上の機能障害（disability）および社会生活上の不利（handicap）をも含めて高次脳機能障害とよび，これらの障害を有する患者を高次脳機能障害者とよぶようになっている．こういう「高次脳機能障害」という用語を使用する際のある意味でのルーズさがこの障害をますますわかりにくくしているかもしれない．

今回は，disabilityおよびhandicapとしての高次脳機能障害に対する最近の取り組みについて紹介したい．

Ⅱ. 高次脳機能障害支援モデル事業

近年，脳外傷後の高次脳機能障害者，特に復学，復職を期待される若年から中年層の障害者の深刻な実態が社会的問題となり，早急な社会制度の整備が必要との認識から，平成13年度より厚生労働省は高次脳機能障害支援モデル事業を展開し，マスコミにもこの問題が取り上げられることが多くなった．

高次脳機能障害支援モデル事業は，国立身体障害者リハビリテーションセンターと12都道府県（表1）が連携し，高次脳機能障害に対する診断，治療，機能回復訓練のほか，社会復帰支援や生活・介護支援を試行的に行い，症例を集積し，標準的な評価基準および支援プログラムの確立を図ることを目的として，平成13年4月1日にスタートした．平成15年度までにおいて高次脳機能障害の診断基準（表2）が作成され，訓練プログラムおよび支援プログラムが提唱された．

平成16年度からはこれらを活用し，国立身体障害者リハビリテーションセンターと12都道府県が指定する地方支援拠点機関とが連携して，実際に機能回復訓練，社会復帰支援や生活・介護支援および各種の制度を活用したサービスの試行的提供を行い，全国に普及可能な支援体制づくりを確立しようと活動している．

現在失語症は身体障害者手帳の申請が可能であるが，麻痺を伴わない記憶障害のみの症例などは身体障害者手帳の対象とならず，また頭部外傷など介護保険でカバーできない症例では支援の道がつかず，苦慮することが多い．

現時点では，これら身体障害者手帳の対象と

表1　地方支援拠点機関等一覧

北海道・札幌市	北海道大学医学部附属病院
宮城県	東北厚生年金病院
埼玉県	埼玉県総合リハビリテーションセンター
千葉県	千葉県千葉リハビリテーションセンター
神奈川県	神奈川県総合リハビリテーションセンター
岐阜県	木沢記念病院
三重県	三重県身体障害者総合福祉センター
大阪府	大阪府立身体障害者福祉センター
岡山県	川崎医科大学医学部附属病院
広島県	広島県立身体障害者リハビリテーションセンター
福岡県・北九州市・福岡市	産業医科大学病院
名古屋市	名古屋市総合リハビリテーションセンター
国リハ	国立身体障害者リハビリテーションセンター

ならない高次脳機能障害者に対しては精神障害者保健福祉手帳の申請が可能である．精神障害の診断は精神科医によるものを原則とするが，高次脳機能障害者についてはその疾患の性格上，脳神経外科医，リハビリテーション医，神経内科医，内科医などの主治医が必要な要件を満たす範囲において精神障害の診断または治療に従事する医師に含まれてもよいとされている．

具体的な診断書(精神障害者保健福祉手帳用)の記入方法としては，病名，主たる精神障害に高次脳機能障害（器質性精神障害），ICDカテゴリーF0とする．記憶障害や注意障害は知能障害の項目中の痴呆で代用し，そのほかの項目は患者の状態を記入する．

高次脳機能障害支援モデル事業についてはホームページ(www.rehab.go.jp/ri/brain/index.shtml)を参照されたい．

Ⅲ．症　例

前交通動脈動脈瘤破裂によるくも膜下出血後遺症として重度の記憶障害を有しながら主婦として復帰した1例を呈示する．

症　例：32歳，女性．3歳と1歳の子どもをもつ主婦

原因疾患：前交通動脈動脈瘤破裂によるくも膜下出血

病　歴：2003年2月くも膜下出血発症，同日脳神経外科にて手術．同年4月当科入院．

入院時現症：麻痺，知覚障害なし．脳神経障害なし．数ヵ月間の逆向健忘および重度の前向健忘を認める．失見当識あり．失語なし．失行なし．空間無視なし．

入院時画像所見：CT（図1）にて左前頭葉内側面および尾状核に病巣を認める．SPECTではMRIの病巣に一致して血流低下を認める．

高次脳機能検査：標準的神経心理学的検査では表3に示したとおり重度の記憶障害を認