Functional Brain Mapping During Actual Car Driving: A FDG-PET Study

VIII. 3. Functional Brain Mapping During Actual Car Driving: A FDG-PET Study

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INTRODUCTION

The invention of automobiles has provided high-speed travel on the ground, which requires processing of multimodal perceptions of sensory, visual, auditory, balance, and proprioceptive information. All of the information is constantly changing and needs to be revised in real time. In addition to sensory information processing, control of muscles is needed as well as referring to a space-map in memory. Despite this overwhelming amount of information to be processed and risks of car accidents, few people decide to abandon driving. This is because driving is not only convenient, but also a pleasure. All of these physical and psychological factors imply that the brain's role in driving is complicated but important.

Modern technology is being used to understand brain functions. Nuclear medicine techniques provide functional brain imaging using regional cerebral blood flow or metabolism as markers. However, imaging of brain function during car driving has been restricted due to technical limitations. Using an electroencephalogram (EEG) has been the only choice to record brain function on the road[1)]. However, the low spatial resolution of EEG is not sufficient to localize brain activations related to driving.

Recently, Walter et al. employed functional MRI (fMRI) technique to map brain substrates engaged in driving simulations[2,3)]. They found broad activations in occipital and parietal brain regions bilaterally. However, manipulating a driving simulator is not totally the same as actual car driving.

^{18}F-labeled-fluoro-deoxy-glucose (FDG) has been used for measurement of glucose

metabolism in the brain. FDG, which is trapped in the cells after conversion to FDG-6-phosphate by hexokinase, works as a molecular memory of cellular energy metabolism. The trapping phase lasts around 45 minutes after intravenous injection of FDG. Using this advantage, functional brain imaging is possible outside of laboratories. In this experimental design, we employed FDG-PET to visualize the roles of the brain during car driving.

MATERIALS AND METHODS

Thirty healthy male volunteers, all right-handed, aged 20 to 56 years, participated in this study. A written informed consent was obtained from each subject after full-explanations of the protocol. The study was approved by the Clinical Review Committee on Radioisotope Studies at Tohoku University Postgraduate Medical School. The volunteers were divided into three groups: (A) driving group; 10 subjects with mean age of 35.8 years (SD ±12.2) who drove on an ordinary road; (B) passenger group, 10 volunteers (34.8±13.1 years) participated as a passenger in the front passenger seat; and (C) control group, 10 volunteers (32.7±9.6 years), remained in a comfortable seat inside an experiment room.

The driving group drove a car with automatic transmission for 30 minutes around a university campus immediately after intravenous injection of ^{18}F-FDG, average 40.7 MBq (1.1 mCi). After micturition and preparation for a PET scan they were scanned with PET as described below. The same procedure was used for the passenger group, except that they sat silently facing forward beside the driver during driving. The control group were injected with FDG, average 40.7 MBq (1.1 mCi), and remained in a lit PET waiting room with their eyes open and without earplugs for the same period of time as the task groups. The driving route was in hilly suburbs with limited moving vehicles and a few traffic signals. The car speed was kept fairly constant at 40-km per hour. The driving route was not explained to the drivers beforehand but directed to the drivers on sites by an instructor sitting in the rear seat. Both the passengers and drivers were requested not to converse throughout the car ride.

Data Analyses

Driving-related brain activations were evaluated using the Statistical Parametric Mapping technique (SPM2, Wellcome Department of Cognitive Neurology, London, UK)[4,5]. Brain images were anatomically normalized to a standard brain template

(FDG-PET version adapted to the MNI-MRI template by Montreal Neurological Institute[6] by linear (Affine) and non-linear transformations to minimize inter-subject anatomical variations using a SPM routine. The brain images were then smoothed using a 11 mm isotropic 3D Gaussian filter to increase the signal to noise ratio. Indices of global activity were modeled as a confounding covariate (after normalization of the brain global value to 50 ml／100ml／min) using ANCOVA[7]. Linear contrasts were used to test for regionally specific condition-related effects, producing *t*-statistic maps in the Talairach standard space[8]. These *t*-statistics were transformed to corresponding Z maps, which constituted the statistical map (SPM {Z}). The peak voxel-based significance of statistics was chosen at $p < 0.001$ ($Z > 3.18$) without corrections for multiple comparisons.

RESULTS

The plasma glucose level of all subjects taken before FDG injection was within the normal range (101.2±9.4 mg/dl, mean±SD). When brain images in the driving group were compared with the resting group, significant activations were found in the primary and secondary visual areas, primary sensorimotor areas, parietal association areas (precuneus) and in the cerebellum (Table 1, Fig. 1A and 2). Activations were almost symmetrical between hemispheres. The comparisons between the passengers and the control groups identified similar brain areas as drivers in the motor, visual, and parietal areas but with little cerebellar activation (Table 2, Fig. 1B and 3). The direct comparison between the driver and the passenger groups identified only a part of the cerebellum, which was more active in the driver group than the passenger group.

DISCUSSION

As far as we know, no report has been published on the details of regional brain physiology during car driving or being a passenger on actual roads. Our results have confirmed activations of the visual and sensorimotor areas and parietal lobe by a car-driving task.

De Jong et al[9]. using a $H_2{}^{15}O$ activation study, reported areas of activation in the dorsal cuneus (area V_3), the latero-posterior precuneus (or superior parietal lobe), the occipito-temporal ventral surface, and fusiform gyrus during perception of forward motion. Similar brain areas were detected when subjects watched complex scenes on a monitor screen[10]. These brain areas were strongly activated in our study in both the drivers and

passengers. These remarkable activations in the visual areas supported our belief that perception and processing of visual information are essential components for car driving.

The posterior parietal cortex is thought to play a crucial role in the integration of limb (body) and field (visual) coordinates[11]. These areas were activated in our study. Sensory inputs from visual, somatosensory and vestibular systems need to be integrated before appropriate actions are made. The parietal cortex is regarded as an area for multimodal sensory integrations as seen in studies that showed a retina adjusting to visual inputs, both environmental world coordinates and body-oriented inner coordinates[12,13]. During driving the brain needs to calibrate and match visual images of the environmental space to the driver's egocentric coordinate continuously in real time. This collaboration is reportedly carried out in the posterior parietal cortex (BA 7)[14]. Previous brain mapping studies on limbs' movements disclosed that the primary somatosensory area and primary motor cortex were mostly responsible, but the premotor, supplementary motor areas and the parietal cortex aided them[15]. Therefore, the extensive brain activation in the parietal regions observed in our study reflects highly demanding data processing including the integrations and calibrations of multi-modal information, which is crucial for car driving.

Tashiro et al.[16] reported that activations of sensory brain areas including visual areas were more pronounced than those of motor areas in a running task using similar FDG brain mapping protocol. This agrees with previous observation that the sensory component of the neural processing circuitry was more energy demanding than the motor component in an ergometer task[17]. This sensory overload was confirmed during car driving also in this study.

Calhoun et al.[3] and Walter et al.[2], using simulated driving experiments, found similar activation sites as in this study; namely sensorimotor cortex and cerebellar regions. However, the visual cortices (BA 17/18) activation were not remarkable or found only by Calhoun et al.[3]. This suggests that visual stimulations were more pronounced in actual driving than simulated driving and that brain mapping by virtual driving experiments should be confirmed by an actual driving study.

In this experiment, regional brain metabolism was compared between conditions as a driver and a passenger. We could find similar brain activations in the visual areas because the subjects in both conditions saw exactly the same scenery. However, unexpectedly, the passengers showed similar brain activations in the motor areas despite the fact that they did not engage in any motor tasks. Activations in the parietal lobule were similarly active in the passenger group. These findings support the fact that the passengers

were not at rest during car driving but were engaged in virtual car driving beside the driver. In the case of drivers, the pattern of regional brain metabolism was clearly contrasted, e.g., activations in the motor and parietooccipital brain areas with deactivations in the prefrontal and temporal brain. This contrast was similar but less in the passenger group. A possible explanation for this difference between drivers and passengers is the level of concentration between the two groups.

CONCLUSION

This study demonstrated how the brain works while driving or being a passenger. The results suggested that visual perception and its integration with motor control were the main brain functions while driving. FDG technique is useful for brain mapping while subjects are performing daily activities.

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Table 1. Brain areas activated by driving.
The main effect of driving was tested by inter-group comparison between the driving group (n = 10) and a resting control group (n = 10).

Region	Brodmann's area	side	Talairach coordinates at peak activation x	y	z	Z-score
Cuneus	18	left	-2	-77	8	5.51
Cuneus	17	left	-12	-98	-2	5.01
Cerebellum		right	22	-51	-24	4.71
Gyrus fusiformis	18	left	-18	-91	-12	4.69
Gyrus postcentralis	4	right	38	-27	57	4.20
Gyrus occipitalis medius	18	right	32	-90	1	4.19
Gyrus fusiformis	19	right	30	-48	-8	4.02
Gyrus occipitalis inferior	18	right	22	-89	-9	3.97
Gyrus temporalis medius	39	right	36	-68	20	3.81
Precuneus	7	left	-10	-49	63	3.67
Precuneus	18	right	24	-78	28	3.57
Gyrus occipitalis medius	18	right	38	-90	-16	3.54
Gyrus precentralis	4	left	-10	-22	64	3.40
Gyrus postcentralis	3	left	-44	-18	52	3.40
Thalamus		right	16	-17	1	3.36
Gyri occipitales	18	left	-28	-77	1	3.31
Gyrus cinguli	24	right	10	-7	41	3.27
Gyrus parahippocampi	35	left	-18	-36	-2	3.18

The statistical threshold is $P < 0.001$ (uncorrected)

Table 2. Brain areas activated by being a passenger.
The main effect of passenger was tested by inter-group comparison between the passenger group (n = 10) and a resting control group (n = 10).

Region	Brodmann's area	side	at peak activation x	y	z	Z-score
Gyrus lingualis	18	right	8	-76	4	4.84
Gyrus occipitalis medius	18	right	34	-93	-1	4.61
Gyrus fusiformis	18	left	-20	-90	-12	4.43
Cuneus	17	left	-8	81	7	4.43
Gyrus occipitalis inferior	18	right	30	-88	-12	4.42
Gyrus fusiformis	19	left	-22	-58	-12	3.98
Cerebellum		left	-24	-59	-12	3.90
Gyrus lingualis	19	left	-14	-43	-1	3.83
Precuneus	7	left	-4	-54	51	3.79
Gyrus temporalis medius	19	right	38	-73	22	3.58
Cuneus	18	right	16	-98	20	3.51
Gyrus precentralis	4	right	36	-28	64	3.47
Gyrus fusiformis	37	right	30	-48	-8	3.31
Gyrus postcentralis	3	right	42	-15	62	3.23

The statistical threshold is $P < 0.001$ (uncorrected)

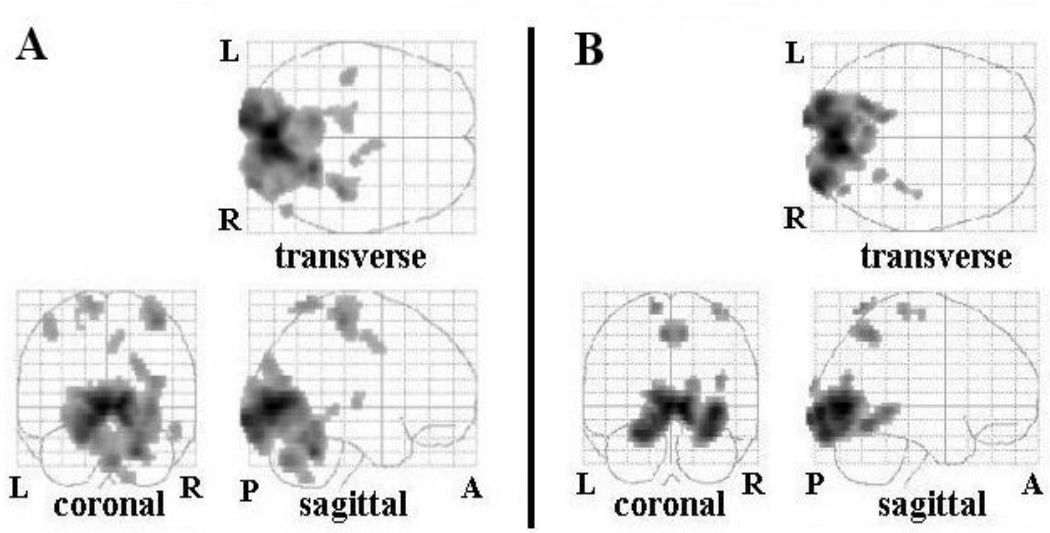

Fig. 1. The main effects of driving(A) and passenger groups(B) with resting control group as a reference tested using SPM2. Activations in the bilateral primary and secondary visual areas were most notable in the both conditions. Cerebeller activations were found in the driving condition only. The activation sites are displayed in three orthogonal directions, sagittal (top left), coronal (top right), and transverse (bottom), thresholded at $Z > 3.18$, $k > 20$ pixels (160 mm^3), $p < 0.001$ (uncorrected).

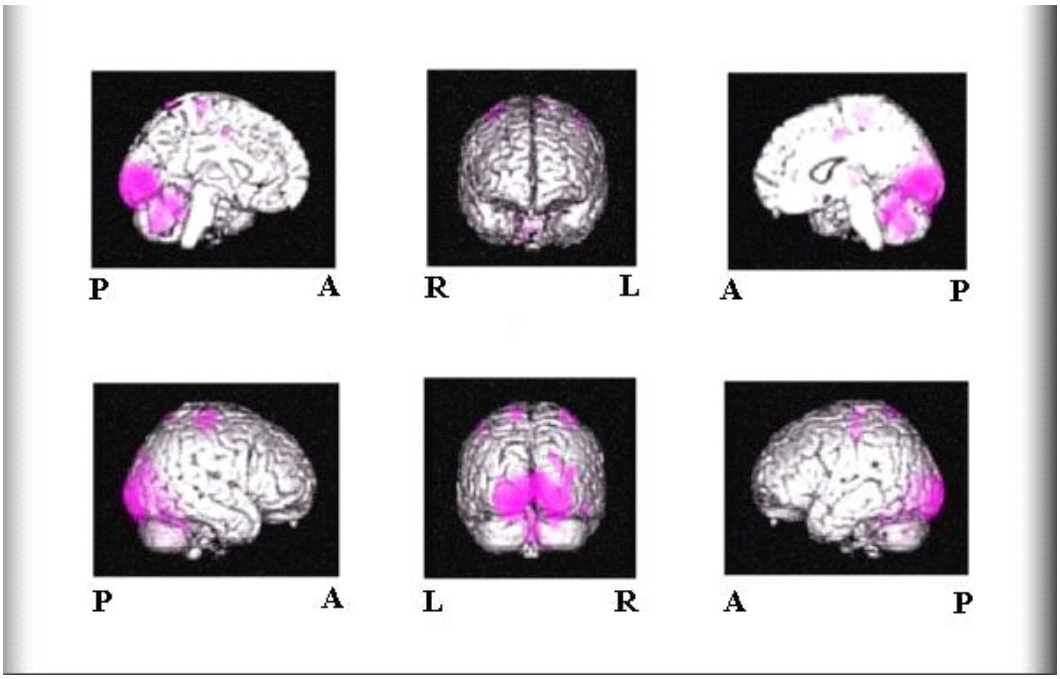

Fig. 2. Brain images for the main effects of driving which is the contrast between driving and resting conditions ($Z > 3.18$, $k > 20$, $p < 0.001$ uncorrected) rendered on a standard brain template. The data are same as in Fig.1A. From the left top to the right bottom panel, left medial, frontal, right medial, right lateral, occipital, and left lateral surface.

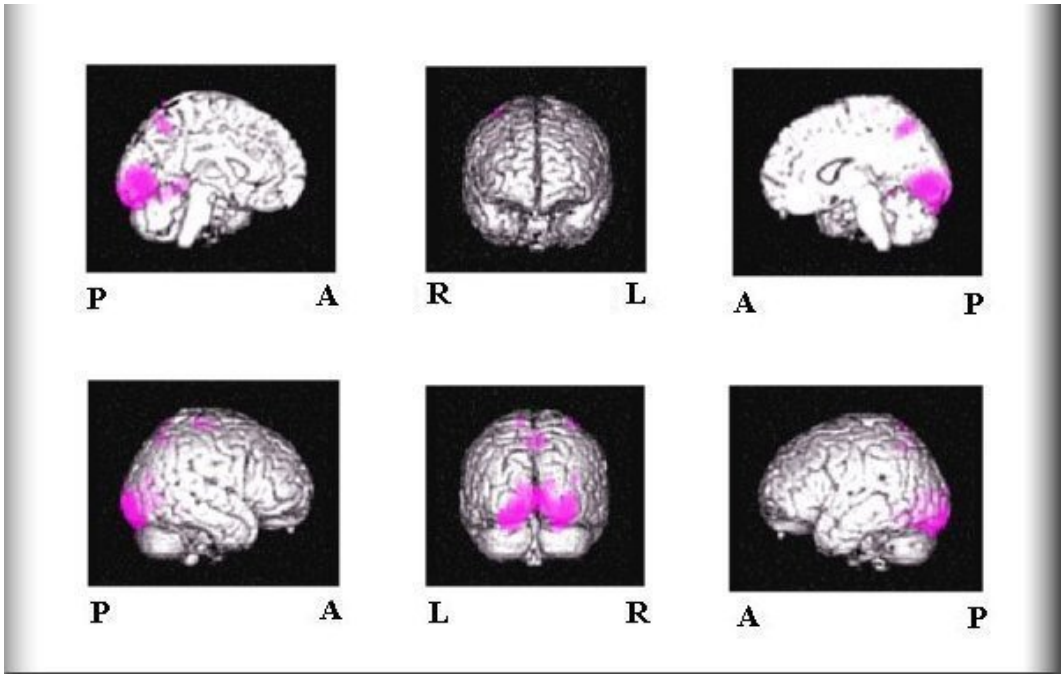

Fig. 3. Brain images for the main effects of being a passenger ($Z > 3.18$, $k > 20$, $p < 0.001$ uncorrected) rendered on a standard brain template. The data are same as in Fig.1B.