Functional Neuroimaging of Actual Car-driving

VIII. 1. Functional Neuroimaging of Actual Car-driving

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Introduction

Car-driving is a combination of complex neural tasks such as attention, perception, integration of visual and somatosensory inputs, generation of motor outputs and action controls. All drivers might sometimes encounter potentially-dangerous situations induced by cognitive and psychomotor deficits due to aging and neurological disorders[1)], alcohol and other sedative drugs[2)], and mobile phone use[3)], etc. Therefore, elucidation of the brain mechanism during car-driving is important. New findings regarding neural activities during simulated car-driving have been demonstrated, using high resolution neuroimaging techniques such as functional magnetic resonance imaging (fMRI)[4-6)] and positron emission tomography (PET)[7)]. Several investigators detected brain activations in the occipital and parietal regions bilaterally as neural substrates of simulated driving[4-7)]. However, until now, no study on actual car-driving has been conducted. Therefore, our aim was to elucidate brain activation during actual car-driving using PET and [^{18}F]2-deoxy-2-fluoro-D-glucose (FDG), that has a unique property of "metabolic trapping" where neuronal activity during 30 to 60 min post-injection can be stored[8,9)].

Methods

Thirty healthy male volunteers, all right-handed, aged 20 to 56 years old, participated in the present study. All the subjects had held a driving license for at least 6 months. The study protocol was approved by Clinical Research and Ethics Committee of Tohoku University Graduate School of Medicine. Each subject provided a written informed consent for participation to the study after receiving sufficient explanation.

The subjects were divided into the following 3 groups: (1) the active driving group (n=10; mean age ± S.D.: 35.8 ± 12.2 y.o.) who drove on an ordinary road; (2) the passive driving group (n=10; mean age: 34.8 ± 13.1 y.o.) who remained seated on a front passenger seat during the driving experiment; and (3) the subjects belonging to the control group (n=10; mean age: 32.7 ± 9.6 y.o.) who remained seated on a comfortable chair in a laboratory building, looking outside of the windows. All subjects were kept in fasting state for at least 5 hours before the study.

The subjects of the active driving group were requested to start driving a testing car, with automatic transmission, shortly after intravenous injection of FDG. They were requested to keep driving for 30 min at an approximate speed of 40 km/h along a quiet driving route around Tohoku University Aoba-yama Campus. The active-driving subjects were not informed of the details of the driving route in advance, and at each square they followed the directions of an investigator sitting on the rear seat. The passive-driving subjects followed the same protocol except for the point that they were sitting on the front passenger seat simply looking at the landscape ahead of the car throughout the driving experiment. The control subjects were sitting on a soft chair similar to that of the testing car for 30 min simply looking at the landscape outside and with their ears unplugged so that they could hear normal conversation around them.

PET emission scan started 45 minutes after FDG injection using an SET-2400W scanner (Shimadzu Inc., Kyoto, Japan), with spatial resolutions of 4.0, 4.0 and 4.5 mm at full-width-half-maximum (FWHM) in radial, tangential and axial directions, respectively. The subjects' heads were fixed gently to the head-holder with a plastic spacer inflated with air to minimize the subjects' head movement. The mean radiological dose given to the subjects was 40.7 ± 7.4 MBq (1.1 ± 0.2 mCi). Three-dimensional emission scan was performed for 5 min and post-injection transmission scan was performed for 8 min using a $^{68}Ge/^{68}Ga$ external rotating line source for tissue attenuation correction. PET image data were transferred to a supercomputer at the Synergy Center, Tohoku University, for reconstruction into 128×128×63 matrices based on a filtered back-projection algorithm using the Colsher Filter with an 8 mm cut-off frequency[10]. Driving-related brain activation was examined using Statistical Parametric Mapping (SPM) software package. The peak voxel-based significance of statistics was set at $p< 0.001$ ($Z > 3.18$) without corrections for multiple comparisons.

Results

Significant brain activations in the active driving group compared with the control were found in the visual cortices (BA17-19), primary sensorimotor (BA1-4) areas, premotor area (BA6), the parietal association area (precuneus), the cingulate gyrus (BA24), the parahippocampal gyrus (BA35) as well as in the thalamus and cerebellum (Figure 1). Brain activations in the passive driving compared with the control looked similar to those of active driving except for absence of activations in the premotor, cingulate, parahippocampal areas and in the thalamus.

Discussions

The present study is, as far as the authors know, the first study that demonstrates neural correlates of actual car-driving using a high-resolution imaging technique such as PET. For this purpose, FDG is a radiotracer of choice that may allow PET scans following completion of driving tasks. As mentioned in the introduction section, neural correlates of car-driving have been studied using a driving simulator and fMRI[4-6] or PET with [^{15}O]H_2O[7]. The present study demonstrated several brain activations resembling those of the previous simulated-driving studies[4,5]; namely, the primary sensorimotor areas (BA3 and 4), premotor area (BA6), visual cortex (BA17-19), medial temporal cortex (BA39), precuneus (BA7/31) and the cerebellum. The all available neuroimaging studies, including four fMRI[2,4-6] and one PET studies[7], measured brain perfusion but not brain (glucose) metabolism. The present findings are basically consistent with the previous fMRI[4,6] and PET[7] results obtained from contrasting active and passive driving conditions.

Activations in the cingulate and parahippocampal gyri were observed during active driving in the present study. Uchiyama et al., using a specific “keep-a-safe-distance” task, reported activation in the anterior cingulate, where hemodynamic responses significantly correlated to task performance[6]. These findings suggest that actual driving is more-strongly associated with the cingulate activation since actual drivers must always be careful in keeping safe distances not only to preceding cars but also to pedestrians and guardrails etc. The activation in the parahippocampal gyrus seems to be also associated with attention and cognition during actual driving.

In summary, the actual driving experiment demonstrated similar findings to those of simulated driving in spite of several differences in methodologies and protocols[4,6,7], and the results suggested that visual perception and visuomotor coordination were the main brain functions while actual driving as well. As for autonomic responses, however, it seems

there is a significant difference between simulated and actual driving conditions possibly due to absence/presence of possible risk of actual accidents. It seems that perceptive and visuomotor components can be studied by simulation, but other components of autonomic and emotional responses should be studied using actual driving, or at least a highly-sophisticated driving simulator that can imitate vibration and acceleration, etc. For drawing a definitive conclusion, the authors should indicate the importance of future replication where the same subjects undergo both actual and simulated driving using the same protocol.

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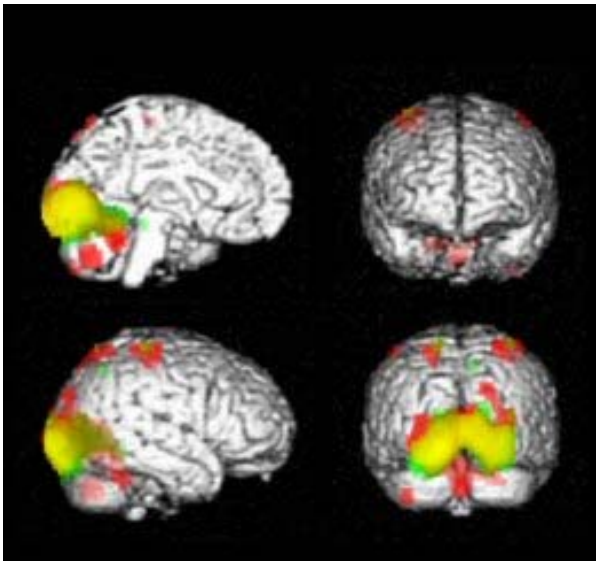

Figure 1. The main effect of car-driving was tested by inter-group comparison of the active (red) or passive (green) driving groups (n=10 for each) to the control group (n=10). Regions of common activation in the both groups are denoted in yellow color. The statistical threshold: $p < 0.001$ (uncorrected).