

Measurement of Frontal Cortex Brain Activity Attributable to the Driving Workload and Increased Attention

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ABSTRACT

Functional magnetic resonance imaging (fMRI) and functional near-infrared spectroscopy (fNIRS) were used to measure subjects' cerebral blood flow in order to investigate higher-order human brain function activity associated with cognition and attention while operating a vehicle. As a first step, the effects of the fundamental driving environment on brain activity was investigated on the basis of fMRI measurements, with simultaneous measurement of the frontal region by fNIRS. The experiments involved the presentation of visual stimuli by video clips and the execution of simple individual tasks corresponding to steering wheel and pedal operations. As a second step, a driving simulator was used to reproduce narrow road driving and car-following driving situations requiring cognition and attention. Drivers' mental activity under these conditions involving different levels of attention was measured by fNIRS. The results showed that the level of activity in the lateral frontal region rose as the relative difficulty of the tasks increased based on subjective evaluations. In addition, under the narrow road driving condition, greater activation in the prefrontal region attributable to increased attention was found in a comparison with the results for ordinary driving tasks.

INTRODUCTION

Drivers of motor vehicles obtain visual information on the surrounding environment, recognize and judge that information suitably and then control their vehicle through steering wheel, accelerator and brake pedal operations. Human brain activity functions to control all of these processes. In situations where it is necessary to predict unexpected danger, it is thought that a driver's brain activity strengthens the cognition function by spontaneously raising the level of attention. In the course of developing driver support systems, it is important to have a clear understanding of human brain activity in such driving situations. Toward that end, drivers' brain activity must be measured.

One method of measuring brain activity is functional magnetic resonance imaging (fMRI), a noninvasive technique that uses a magnetic field to monitor an increase in cerebral blood flow based on a reduction in the concentration of deoxygenated hemoglobin. Because measurements must be made with a subject in a supine position, fMRI is a highly restrictive method that can also impose limitations on the experimental conditions. Although fMRI is not well suited to the observation of temporal changes, its high spatial resolution allows activated areas of the brain to be identified with good accuracy.

In contrast to fMRI, functional near-infrared spectroscopy (fNIRS) has attracted attention in recent years as a technique that uses near-infrared light to monitor changes in the levels of oxygenated and deoxygenated hemoglobin in the cerebral cortex. While fNIRS has low spatial resolution for identifying activated areas of the brain, it has the advantage of enabling continuous monitoring of changes in cerebral blood flow because of its higher temporal resolution. It also involves few restrictions because monitoring can be done by simply attaching to the subject's head the optical fibers for emitting and receiving NIR light. Additionally, it is not influenced by muscle electric activity and imposes relatively few restrictions on a subject's posture and movement.⁽¹⁾ For these reasons, it is expected to be used in medical rehabilitation and medical welfare⁽²⁾ as well as in engineering applications such as for measuring the brain activity of train drivers⁽³⁾ and drivers of motor vehicles.

The authors used an fNIRS device to measure brain activity while subjects performed mental arithmetic and observed that activation in the lateral frontal region corresponded to the relative difficulty of the calculations. The fNIRS results also coincided with fMRI measurements.⁽⁴⁻⁵⁾ Ebe et al.⁽⁶⁾ used fNIRS to reveal that changes in the oxy-Hb concentration in the frontal region were larger when subjects searched for an unfamiliar place on a map than when they searched for a familiar place. Although they showed that fNIRS can be applied to measure brain functions, they did not touch on the measurement of the higher-order brain activity involved in driving a vehicle, which is associated with attention, learning and other processes.

In this study, fMRI was first used to measure brain activity when operations equivalent to those of basic driving actions were applied and while varying the relative difficulty of assigned tasks that involved finding specified targets under a condition where visual stimuli corresponding to the driving environment were presented. Simultaneous with the fMRI measurement, fNIRS was used to confirm the activation state of the frontal region. A driving simulator was then used to generate an experimental protocol that created a condition requiring spontaneous attention while driving. An attempt was made to use fNIRS to identify drivers' brain activity attributable to the driving workload level and increased attention.

BRAIN ACTIVITY RELATED TO FUNDAMENTAL DRIVING OPERATIONS AND STIMULI

BRAIN ACTIVITY RELATED TO VISUAL STIMULI - Drivers direct their eyes toward various objects in the external environment while driving, though they may not be so conscious of doing so. They are constantly inputting visual information from outside the vehicle, and external visual stimuli constitute the fundamental environment for driving. In addition to these visual stimuli, drivers also perceive and pay attention to other vehicles and pedestrians which might pose a potential risk.

In order to investigate drivers' brain activity with respect to fundamental visual stimuli, the subjects in this study were shown video clips of actual driving scenes to which visual tasks were assigned and measurements were made of their brain activity. Brain activity was measured by fMRI (Symphony 1.5T MRI Scanner, Siemens) and especially frontal brain activity was also measured by fNIRS (OMM3000, Shimadzu).

Six male subjects, aged 22-55, took part in the experiments. The subjects were put in the fMRI scanner in a supine position and performed the assigned tasks while watching video images projected on a small screen over their head. As shown in Fig. 1, the video images shown were actual scenes of the forward view photographed during driving on public roads.



Fig. 1 Video image of actual driving scene

Three different levels of difficulty were defined for the assigned visual stimulus tasks and the subjects' brain activity was compared for each of the various conditions. One task was simply to look at the driving scene. As a second task that was designed to increase the subjects' visual attention, they were instructed to count the number of oncoming vehicles that were seen in the video clip. As a third task that was designed to increase their visual attention further, the subjects were told to count both the number of oncoming vehicles and the number of pedestrians that they saw. The subjects were instructed not to move their arms and legs as they watched the screen in the resting supine position. In addition, they were told not to count the number of oncoming vehicles or pedestrians aloud.

The six subjects' cerebral blood flow was measured by fMRI under each of the visual stimulus conditions. The measured results were averaged and images were made of the state of brain activation related to each task as shown in Figs. 2-4.

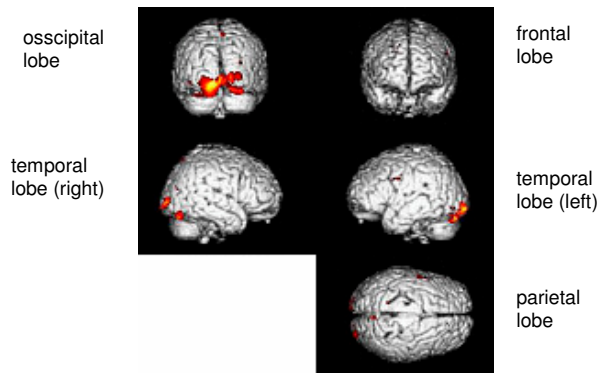


Fig. 2 Results when looking at the driving scene

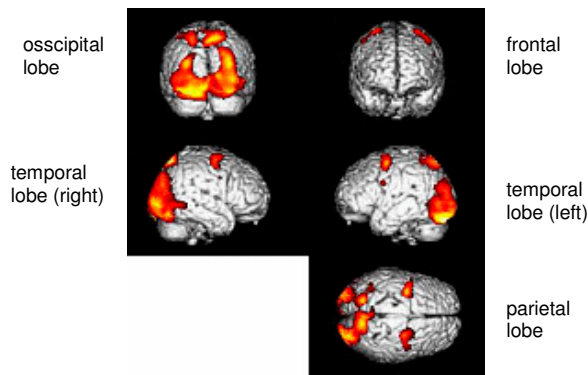


Fig. 3 Results when counting oncoming vehicles while looking at the driving scene

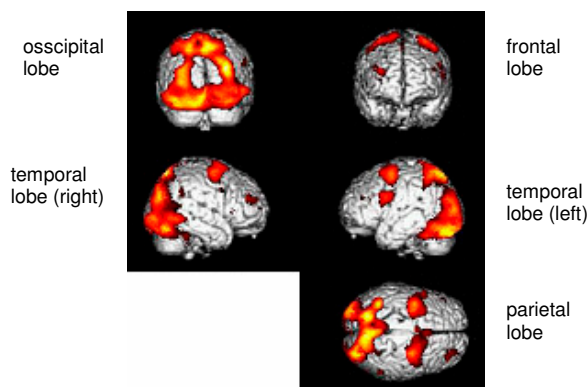


Fig. 4 Results when counting oncoming vehicles and pedestrians while looking at the driving scene

Activation of the brain in the visual cortex of the occipital region can be observed in the fMRI images. It is also seen that the size of the activated area in the occipital region differed according to the conditions of the assigned visual tasks. However, virtual no activation of brain function is seen in the prefrontal region regardless of the visual task conditions. Although not shown in the figures, the simultaneous fNIRS measurements showed the same result, with only slight changes seen in the concentration of oxygenated hemoglobin in the frontal region. Presumably, the reason for this result is that

ordinary visual stimuli which are constantly being input during driving do not induce pronounced brain function activity in the frontal region. In other words, the visual stimuli in simple driving scenes do not influence frontal brain activity.

BRAIN ACTIVITY INFLUENCED BY BASIC DRIVING OPERATIONS - Cerebral blood flow was also investigated in the same way when the subjects operated a pedal located near their feet in the supine position and a lever controller located near their hands. Simultaneously with the fMRI measurement, fNIRS probes were attached to the frontal region of the subjects' head so that their cerebral blood flow could be measured by fNIRS. Brain activity was observed in the motor area of the parietal region in the results measured by fMRI, but prefrontal blood flow was not influenced (Figs. 5 and 6).

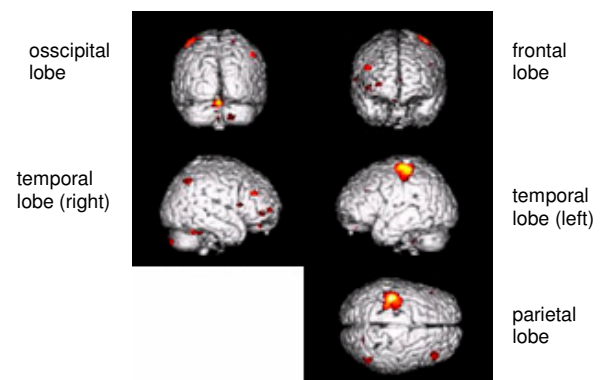


Fig. 5 Blood flow when turning the steering wheel

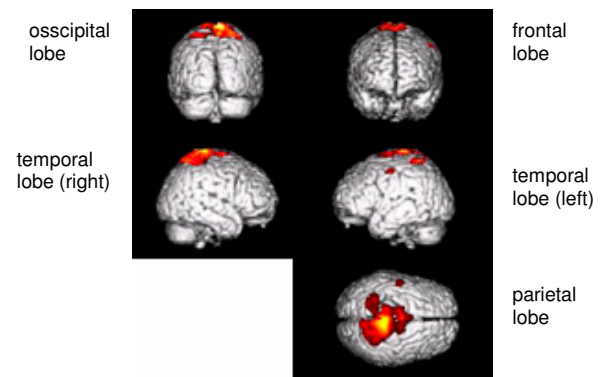


Fig. 6 Blood flow when operating a pedal

NOTE - The foregoing results confirmed that ordinary basic driving behavior such as visual confirmation of the surrounding environment and the execution of fundamental driving operations like turning the steering wheel and operating pedals does not influence drivers' prefrontal brain activity. Although not shown in the figures here, fMRI measurements of cerebral blood flow were also made when the subjects performed secondary actions such as holding their breath. No activation of prefrontal blood flow was seen in the results. Simultaneous fNIRS measurements revealed the same