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The neural correlates of driving performance identified using positron emission tomography

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Abstract

Driving is a complex behavior involving multiple cognitive domains. To identify neural correlates of driving performance, $[^{15}O]H_2O$ positron emission tomography was performed using a simulated driving task. Compared with the resting condition, simulated driving increased regional cerebral blood flow (rCBF) in the cerebellum, occipital, and parietal cortices. Correlations between rCBF and measurements of driving performance were evaluated during simulated driving. Interestingly, rCBF in the thalamus, midbrain, and cerebellum were positively correlated with time required to complete the course and rCBF in the posterior cingulate gyrus was positively correlated with number of crashes during the task. These brain regions may thus play roles in the maintenance of driving performance.

Keywords: Driving; Cerebral blood flow; Positron emission tomography; Performance; Cingulate gyrus; Thalamus; Midbrain

1. Introduction

Automobile driving represents a primary means of mobility in modern developed societies. Driving involves complex behaviors including processing of sensory information, attention, orientation, judgement, decision-making, and motor skills. Precise understanding of the neuropsychological processes in driving is necessary for traffic safety. Numerous studies have analyzed the internal processes necessary to control driving behaviors (Groeger, 2000; Ranney, 1994). These studies have generally used psychological or behavioral approaches. Functional neuroimaging has recently been used to analyze the neural correlates of driving. Walter et al. (2001) reported that the sensorimotor cortex, cerebellum, occipital and parietal regions were involved in driving behavior. Another functional magnetic resonance imaging (fMRI) study observed that activation in the anterior cingulate cortex decreased proportional to driving speed (Calhoun et al., 2002). However, few studies have examined the neural correlates of driving performance. Among several psychological processes, level of attention and vigilance represents one of the major factors affecting traffic safety on the road (Campagne, Pebayle, & Muzet, 2004). In fact, impaired vigilance during driving is associated with a high rate of automobile accidents in subjects taking sedative or hypnotic drugs and patients with sleep apnea syndrome (Barbone et al., 1998; Connor, Whitlock, Norton, & Jackson, 2001). A previous

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functional neuroimaging study has demonstrated the potential role of the midbrain reticular formation and thalamic intralaminar nuclei in attention and vigilance (Kinomura, Larsson, Gulyas, & Roland, 1996). These brain regions are thus postulated to be closely associated with maintenance of driving performance.

The purpose of the present study was to identify brain regions associated with driving performance. Correlations between four measurements relevant to driving performance and regional cerebral blood flow (rCBF) were examined during a simulated driving task using $[^{15}O]H_2O$ and positron emission tomography (PET).

2. Methods

2.1. Subjects

Subjects comprised 15 healthy males with a mean age of 27.6 ± 7.0 years (range, 20–45 years) and mean 8.7 ± 6.5 years of driving experience. Subjects were all right-handed with normal or corrected-to-normal vision, and no history of neurological or psychiatric disease. All subjects had been licensed car drivers for more than 1 year. Subjects all had little or no experience with video games before the study, and no experience with the specific software used in this study. The study protocol was approved by the Clinical Research and Ethics Committee of Tohoku University. All subjects provided written informed consent to participate in the study.

2.2. Task

A commercially available driving game software for PC (Gekisou 99, Twilight Express, Japan) was used for the driving simulation. The visual aspect of this software was presented using a head mount display (HMD; Glasstron PLM-S700, SONY, Japan), through a scan converter from XGA to video signals. The display was fitted to the subject's head in a comfortable position using surgical tape. Motion parallax and visual acuity were adjusted using the HMD-equipped adjusting system. Although images were converted from the original VGA signal to a composite video signal, subjects were able to watch realistic traffic scenes. The traffic scene in the software was created from digitalized scene images of actual traffic environments in Tokyo. Field-of-view for the subject was largely limited to vehicles on the driver's side of the road. The scene included 1–3 lanes of traffic in one direction, with an occasional car coming from the opposite direction. Subjects performed simulated driving using a commercially available game controller (Sidewinder Force Feedback Wheel, Microsoft, USA) with a steering wheel and acceleration pedals. The steering wheel was set at chest height using a height-adjustable stand. The acceleration pedals were located underfoot. Subjects were able to practice this software in the scanner for several minutes before PET was initiated.

The $[^{15}O]H_2O$ PET was performed under three conditions: (1) resting condition; (2) simulated driving condition; and (3) passive viewing condition. In the resting condition, subjects were instructed to rest with eyes closed and remain calm, without dwelling on anything, until the signal ending the session. Under simulated driving task conditions, subjects operated the driving simulation game. Instructions given were to drive quickly and safely using the same assumptions as in daily driving. The passive viewing session represented a perceptual control task. Subjects just watched a recorded video of their actual driving that was performed during simulated driving session. Basically, the visual stimulus was the same as that in the driving task. Subjects were instructed to maintain their grip on the steering wheel, but not to steer the wheel or use the pedals during passive viewing.

2.3. Evaluation of driving performance

The instructions used in the driving simulation were for the subject to drive as they do during daily life. This induced wider individual differences in operation strategies for the driving game software. Common behavioral factors effective for evaluating driving performance should thus be defined. For this purpose, we selected four factors: (1) time required to complete the course, (2) number of crashes, including crashes into other cars, guard rails and objects; (3) number of slow driving periods, defined as $<10\,km\,h^{-1}$; and (4) number of excessive lane changes, defined as changing the course of the car by more than the width of one lane using a steering operation.

2.4. Image acquisition

Three-dimensional PET was obtained using a SET-2400W scanner (Shimadzu, Kyoto, Japan) in accordance with previously described methods (Okamura et al., 2000). Briefly, subjects were scanned for 70 s after intravenous administration of approximately 5 mCi (185 MBq) of $[^{15}O]H_2O$ through an antecubital vein. All three tasks were performed in the supine position. Resting scans were performed in the first session of each study, followed by at least two pairs of simulated driving and passive viewing scans. Driving and passive viewing tasks were started 40 s before PET was initiated, and finished after the end of the scan.

2.5. Statistical analysis

Statistical parametric mapping software (SPM99, Welcome Department of Cognitive Neurology, London, UK) was used for image realignment, normalization, smoothing and to create statistical maps of significant