

Change of neuronal activations induced by the passive perception of driving speed difference

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Abstract. The change of neuronal activation due to the passive perception of various driving speeds in comparison to a reference driving speed was assessed using functional Magnetic Resonance Imaging. Videos recorded in real driving conditions on the road at driving speeds of 50, 70, 90, and 110 km/h were shown as visual stimuli. An experiment consisted of three blocks, each having a control phase (50km/h) and a stimulation phase (70, 90, or 110 km/h). In the passive perception of various driving speed differences, the areas related to visual cognition and spatial attention such as temporal, occipital, parietal, frontal areas, and cerebellum were activated. As the driving speed difference increased, the number of activated voxels also increased in the areas related to visual cognition. However, the visual cognition related areas showed a different pattern from the spatial attention related area with an increase of the driving speed difference. This implies that each brain area has a different level of involvement in the passive perception of the driving speed difference, although both visual cognitions related areas and spatial attention related area are related to it.

Keywords: Driving speed difference, passive perception, visual cognition, spatial attention (vigilance)

1. Introduction

Driving is a complex task that requires a high level of cognitive processes such as perception, attention, decision making, and motor control. Among such perceptive and cognitive processes, visual cognition and spatial attention were known to be most deeply involved in driving performance [1].

Recently, functional Magnetic Resonance Imaging (fMRI) has been used for several studies on the

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change of neuronal activities relating to driving [2]. For example, the studies on the neuronal activities induced during a driving by visual cognition [3-6], spatial attention or vigilance [3, 5], and motor function [7] have been performed using fMRI. The study on the difference of visual cognition was also conducted for unfamiliar and familiar routes [8].

However, due to the requirement for an MRI compatibility, these studies had to be conducted in a simulated driving condition (e.g., a video game or a driving simulator etc) and, thus, it was hard to provide a realistic driving task for volunteers in practice. In other words, a simulated environment imposes a restraint on the correct evaluation of visual cognition, spatial attention, vigilance, and motor function in a real driving situation.

In addition, since the previous studies simply compared a rest condition with a driving condition [3, 5-7], or compared only two different driving speed cases, i.e., a low driving speed and a high driving speed [3, 6], the studies on neuronal activities relating to visual cognition and spatial attention have been rarely performed with various driving speeds.

In this study, the following three things were mainly considered to overcome the restrained aspects of the previous studies: First, a video recorded in a real driving situation on the road was used for a realistic visual stimulus. Second, for the observation of the neuronal activities induced by visual cognition and spatial attention of several driving speed differences, the driving video as a visual stimulation source was recorded with four different driving speeds such as 50, 70, 90, and 110 km/h. Third, unlike the simple comparison of a rest condition with a driving condition in the previous studies, the driving speeds of 70, 90, and 110 km/h were compared with a reference speed of 50 km/h in this study and the passive perception of the driving speed differences was evaluated in terms of the neuronal activation area and the number of activated voxels.

2. Methods

2.1. Subjects

Eight healthy male (24.7±1.8-years-of-age) and eight healthy female (22.2±1.7-years-of-age) college students participated in the study. All the subjects had an experience of driving on a regular highway and their average driving career was 2.6 ± 1.4 years. They were also confirmed to be right handed by Edinburgh Handedness Inventory test [9]. None of the participants reported having a history of psychiatric or neurological disorders. The overall experimental procedure was explained to all subjects who provided their consent for the procedure. All examinations were performed under the regulation of our Institutional Review Committee.

2.2. Experimental design

A driving video as a stimulation source was recorded with four different driving speeds (50, 70, 90, and 110 km/h) in a real driving situation on a local rural road whose vehicular traffic was rare. The video recording was done using a VPC-SH1 camcorder (Sanyo, Tokyo, Japan) with a 1920×1080 pixels spatial resolution. The camcorder was fixed at the exact center of the dashboard inside a car in order to fully cover the frontal view of a car during the recording. The recording was repeated with each driving speed for a driving time of 1.5 min. The recorded video was edited to 1 min in length. The edited video was played for the subjects through a 12×15 cm² LCD monitor attached to a head coil in a magnetic resonance (MR) system.

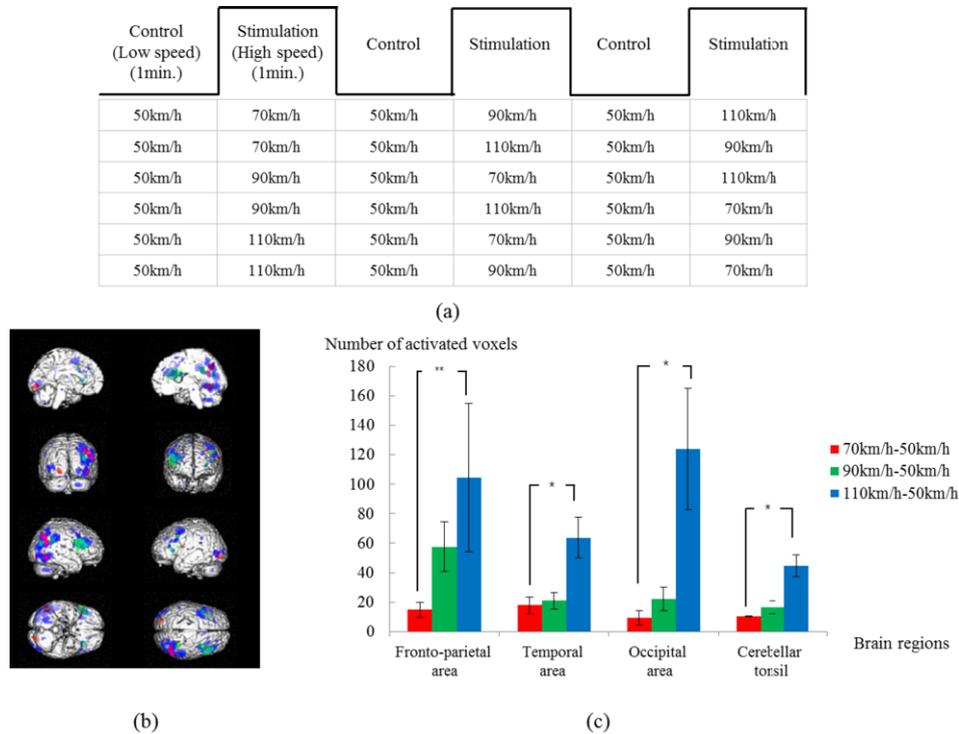


Fig. 1. (a) The stimulus protocol. (b) The brain activation areas under the conditions of 70-50 km/h, 90-50 km/h, and 110-50 km/h (corrected $p < 0.05$). (c) The number of activated voxels in the fronto-parietal area, temporal area, occipital area, and cerebellar tonsil under the conditions of 70-50 km/h, 90-50 km/h, and 110-50 km/h.

Each trial consisted of three blocks and each block included a 1 min control phase and a 1 min stimulation phase (Figure 1(a)). The video recorded with the lowest driving speed of 50 km/h was shown in the control phase. In the stimulation phase, the videos recorded with the high driving speeds (70, 90, or 110 km/h) were played. As illustrated in Figure 1(a), all the subjects participated in a total of six trials. The order of trials was counterbalanced and a 10 min break was provided between each trial.

After experiments, a subjective test was performed for evaluating whether all subjects correctly recognized the driving speed or not. In the subjective test, the volunteers were asked to choose one of the four driving speeds (50, 70, 90, and 110 km/h) in each phase when one of six trials shown in Figure 1(a) was arbitrarily selected and given to the subjects. As a result of the subjective test, there were six males (25.3 ± 1.5 years old) and four females (21.8 ± 2.2 years old) who correctly recognized all driving speeds in all phases, and the data of these 10 subjects were used for fMRI analysis.

2.3. Imaging

Imaging was conducted using a 3.0T ISOL Technology FORTE apparatus (ISOL Technology, Seoul, Korea) equipped with whole-body gradients and a quadrature head coil. Single-shot echo planar fMRI scans were acquired in 35 continuous slices, parallel to the anterior commissure-posterior commissure line. The parameters for fMRI were: repetition time/echo time [TR/TE] = 3,000/35 ms, flip angle = 60 degrees, field-of-view (FOV) = 240 mm, matrix size = 64×64 , slice thickness = 4 mm, and in-plane resolution = 3.75 mm. Five dummy scans in the beginning of each run were excluded to

decrease the effect of non-steady-state longitudinal magnetization. T1-weighted anatomic images were obtained with a three-dimensional FLAIR sequence (TR/TE = 280/14 ms, flip angle = 60 degrees, FOV = 240 mm, matrix size = 256 × 256, slice thickness = 4 mm).

2.4. fMRI data analysis

The fMRI data were analyzed with SPM 8 software (Wellcome Department of Cognitive Neurology, London, UK). All functional images were aligned with the anatomic images of the study using affine transformation routines built into the SPM 8 program. The realigned scans were co-registered to the participant's anatomic images obtained within each session and normalized to a template image in SPM 8 that uses the space defined by the Montreal Neurologic Institute, which is very similar to Talairach and Tournoux's (1988) [10] stereotaxic atlas. Motion correction was works by lagging (shifting forward) the time-series data on each slice using sinc-interpolation. Time-series data were filtered with a 240-s high-pass filter to remove artifacts due to cardiorespiratory and other cyclical influences. The functional map was smoothed with a 7-mm isotropic Gaussian kernel prior to statistical analysis [11-16]. Statistical analysis was done both individually and as a group using a general linear model and the theory of Gaussian random fields implemented in SPM 8. The brain areas activated by the passive perception of the driving speed difference between the reference speed of 50 km/h and the test speeds of 70, 90, and 110 km/h were extracted using a subtraction procedure and the number of voxels in these areas was calculated from the data of individual subjects as well as groups. Especially, not only the total number of voxels in all activated areas but also the number of activated voxels in each brain area of interest were calculated for each subject, and the analysis of one-way ANOVA (PASW 18.0) was performed for the evaluation of statistical significance. Also, Post-hoc test was used the bonferroni correction. The number of voxels in the frontal and parietal areas was calculated regarding these two areas as one, not separating each of them, because both of them are related to spatial attention or vigilance.

3. Results

The data from the group analysis of activation areas are summarized in Table 1 and Figure 1(b). The passive perception of the driving speed difference between 70 km/h and 50 km/h induced the activation of the right temporal fusiform gyrus, right superior temporal gyrus (BA 39), and right inferior parietal lobule (BA 39) areas. In the case of 90 km/h and 50 km/h, the areas such as right frontal sub-gyral, bilateral middle frontal gyrus, right inferior frontal gyrus (BA 45), right parietal sub-gyral, and right middle temporal gyrus were activated. Lastly, when the driving speed of 110 km/h was recognized in comparison to 50 km/h, the following areas were activated: right occipital fusiform gyrus, right temporal sub-gyral, right inferior parietal lobule, right superior frontal gyrus (BA 9), right frontal sub-gyral, bilateral middle frontal gyrus (right: BA 6, 8, left: BA 9, 46), right inferior frontal gyrus, left middle occipital gyrus (BA 18), left parietal supramarginal gyrus, and right cerebellar tonsil.

Figure 1(c) shows the number of activated voxels. In Figure 1(c), the fronto-parietal area includes right inferior parietal lobule, right frontal sub-gyral, bilateral middle frontal gyrus, right inferior frontal gyrus, right parietal sub-gyral, right superior frontal gyrus, and left parietal supramarginal gyrus. The temporal area contains right temporal fusiform gyrus, right superior temporal gyrus, right middle temporal gyrus, and right temporal sub-gyral. The occipital area comprises right occipital fusiform gyrus and left middle occipital gyrus. As the driving speed difference increased, the total number of

Table 1

The MNI coordinates, t-scores, and number of voxels in the activated areas by the subtraction method (70-50 km/h, 90-50 km/h, and 110-50 km/h) (corrected $p < 0.05$)

Speed difference	Number of voxels	t-score	MNI coordinates x, y, z (mm)	Side	Region	Brodman area
70 km/h-50 km/h	26	6.25	48 -60 -12	R	Temporal Fusiform Gyrus	
	98	5.49	57 -60 24	R	Superior Temporal Gyrus	39
		5.25	48 -66 39	R	Inferior Parietal Lobule	39
90 km/h-50 km/h	191	5.35	33 6 24	R	Frontal Sub-Gyral	
		5.16	42 33 18	R	Middle Frontal Gyrus	
		4.94	51 24 21	R	Inferior Frontal Gyrus	45
	38	5.13	36 -45 30	R	Parietal Sub-Gyral	
	21	4.66	39 -72 24	R	Middle Temporal Gyrus	
	27	4.55	-39 12 39	L	Middle Frontal Gyrus	
110 km/h-50 km/h	227	6.25	42 -69 -12	R	Occipital Fusiform Gyrus	
	243	5.97	45 -48 -6	R	Temporal Sub-Gyral	
	232	5.86	54 -33 33	R	Inferior Parietal Lobule	
	95	5.99	42 36 30	R	Superior Frontal Gyrus	9
	51	5.49	30 21 24	R	Frontal Sub-Gyral	
	10	5.1	-27 24 6	R	Middle Frontal Gyrus	6, 8
	6	4.51	-51 -45 36	R	Inferior Frontal Gyrus	
	18	4.44	48 15 18	R	Inferior Frontal Gyrus	
	119	6.43	-36 9 51	L	Middle Frontal Gyrus	9, 46
	28	4.68	-51 15 33	L	Middle Occipital Gyrus	18
	11	4.62	-33 -93 3	L	Parietal Supramarginal Gyrus	
58	5.23	18 -51 -39	RC	Cerebellar Tonsil		

Note: R: right cerebral; L: left cerebral; RC: right cerebellar.

activated voxels also increased. According to the area-based analysis using one-way ANOVA, the number of activated voxels increased in the fronto-parietal area as the driving speed difference increased ($p = .002$). The number of activated voxels also increased in temporal ($p = .013$), occipital ($p = .007$), and cerebellar tonsil areas ($p = .033$) with an increasing driving speed difference. Interestingly, the 110 km/h-50 km/h trial showed an abrupt increase in the number of activated voxels in temporal, occipital, and cerebellar tonsil areas when compared to the 90 km/h-50 km/h and 70 km/h-50 km/h trials (Figure 1(c)). Bonferroni post-analysis verification revealed that the number of activated voxels in the 110 km/h-50 km/h trial compared to the 70 km/h-50 km/h trial increased with statistical significance in the fronto-parietal area ($p = .002$), temporal area ($p = .052$), occipital area ($p = .018$), and cerebellar tonsil ($p = .050$).

4. Discussion

An fMRI study was performed for the analysis of neuronal activation areas as well as the number of activate voxels induced by the passive perception of various driving speeds (70, 90, and 110 km/h) in comparison to a reference speed of 50 km/h.

fMRI studies on the change of neuronal activations relevant to visual cognition and spatial attention during driving have been performed [17-21]. Brain areas as primary visual (V1) region, motion-sensitive visual regions (V5/ area middle temporal: MT), and parietal cortex (Brodmann area 7) were

reported as the main areas relating to visual cognition [17, 19], and the areas relevant to a high-order visual cognition were known to be cingulate, cerebellum, and occipital and parietal cortex areas [3]. On the other hand, it was reported that the areas relating to visual attention were occipital, inferior-temporal, and parahippocampal cortices, thalamus, and cerebellum [18, 21], and areas such as frontal and parietal cortical regions were related to spatial attention (or vigilance) [5]. Another fMRI study using a video game for car driving reported that the cognition of slow and high driving speeds not only activated such brain areas as occipital fusiform, cerebellum, middle and superior occipital lobes, inferior temporal lobe, and superior parietal lobe, which are related to a high-order visual cognition, but also activated the vigilance-related areas such as medial, inferior, middle, superior frontal lobes, and precuneus (parietal area) [3].

The results of our study on the passive perception of various driving speeds are consistent with the previous studies in that the areas related to visual cognition and spatial attention that were activated included the temporal, occipital, parietal, and frontal areas, as well as the cerebellum. As shown in Table 1 and Figure 1(b), it was especially observed in this study that the temporal and parietal areas were mainly activated when the difference in driving speed was small (e.g., 70 km/h in comparison to 50 km/h). On the other hand, in the case of the cognition of a large driving speed difference (e.g., 90 km/h or 110 km/h compared to 50 km/h) neural activations occurred, especially in the frontal areas related to spatial attention or vigilance as well as the areas relevant to visual cognition [3, 18, 21, 22].

According to the previous studies done by Calhoun, et al. (2002) and Horikawa, et al. (2005), while the total number of voxels in all activation areas was larger in the driving condition than the rest condition, there was little difference in the total number of activated voxels between the cases of a low driving speed (110-140 km/h) and a high driving speed (160-224 km/h). In addition, the number of activated voxels increased at the high driving speed condition than the low driving speed condition in the areas such as medial, inferior, middle, superior frontal lobes, and precuneus, which are related to spatial attention (or vigilance), and these areas were regarded to be mainly involved in the cognition of the driving speed difference. However, occipital lobe and cerebellar areas related to a high-order visual cognition were reported as being irrelevant to the cognition of a driving speed because there was little difference in the number of activated voxels between the slow and fast driving conditions in spite of the occurrence of neuronal activations in both cases [3].

According to this study, as the driving speed difference increased, the number of activated voxels also tended to increase, which was not consistent with the previous studies. Furthermore, the brain area related to visual cognition seemed to be relevant to the passive perception of the driving speed difference because the neuronal activation appeared to be considerably increased in temporal area, occipital area, and cerebellum as well as fronto-parietal areas in the case of the 110 km/h driving condition in comparison to 50 km/h. Orban and Orban, et al. reported that the discrimination of the speed of a randomly moving dot (70 stimuli/min and 35 stimuli/min) induced the neuronal activations in the areas such as superior temporal gyrus, lingual gyrus, and cuneus in occipital lobe. This result shows that the visual cognition areas are relevant to the cognition of the speed difference of a moving dot. Despite a different stimulation scheme, it can be inferred from these previous studies [20, 22, 23] and the present study that the areas of spatial attention (or vigilance) as well as visual cognition are related to the passive perception of driving speed difference. In the previous studies [3, 5-7], the neuronal activation patterns were induced in a single driving condition compared to a rest condition using a video game and applied only two driving speed (low and high speed). Unlike the previous studies, our study was performed with a realistic simulation scheme as a visual stimulus using a driving video recorded in a real driving situation on the road with various driving speeds. For such reasons, between our results and the previous studies were exhibited the discrepancy. Walter, et al. [24]

reported that neuronal activations in brain areas such as MT and MST were reduced in the case of active driving (subjects steered the car themselves) when compared to the case of passive driving (a person outside the scanner was steering the car), which implies a difference between active driving and passive driving in terms of neuronal activation. Further studies will be thus required for the analysis of the difference of neuronal activations between active driving and passive driving.

Few studies have been performed for the analysis of the change of the number of voxels activated in each brain area due to the cognition of a various driving speed difference. According to our study, as the driving speed difference increased, the number of activated voxels also increased in the area related to spatial attention or vigilance such as a fronto-parietal area as well as the areas related to visual cognition such as temporal area, occipital area, and cerebellum. However, while the number of activated voxels in the area related to spatial attention or vigilance tended to increase in a linear manner, it did not in the areas related to visual cognition (i.e., it abruptly increased in the cognition of some driving speed differences, such as 110 km/h compared to 50 km/h). This result implies that each brain area might be involved in the passive perception of the driving speed difference at a different level, which needs to be verified in a future study by increasing the number of subjects, offering a more various driving speed, and analyzing brain areas more in detail. A further study on functional connectivity using covariant analysis will also be desirable for a better understanding of the passive perception of the driving speed difference in brain areas.

Driving is very popular in daily life and it requires a complicated cognitive process. However, few fMRI studies have been performed so far because it is restricted in practice to deliver a simulated driving condition as real as possible in a MR environment. In this study, although the analysis of motor function was not made which is most important in driving, the change of neuronal activations was investigated due to the cognition of a various driving speed difference using a driving video recorded in a real driving situation on the road. It can be concluded that this study provides some basic data for elucidating the brain-function mechanism relating to a driving task based on a realistic visual stimulation.

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