Original Article

Structural and Functional Changes of Hippocampus in Long Life Experienced Taxi Driver

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Purpose : The objective of this study was to investigate the differences of hippocampal volume and shape as well as the functional change between long life experienced taxi drivers and controls of Korean population.

Materials and Methods: Three-dimensional T1-weighted images and blood oxygen level dependent functional MRI(fMRI) were obtained from 8 subjects, consisting of 4 experienced (20–30 years) taxi drivers and 4 age-matched controls. The hippocampal volume and shape were analyzed with three-dimensional T1-weighted images. In addition, neuronal activities of brain were analyzed using a blood oxygen level dependent fMRI between the two groups.

Results: The hippocampal volume showed no statistically significant difference between the two groups ($p > 0.05$). The left hippocampi of the taxi drivers were slightly elongated with larger head and tail portions than those of the controls ($p < 0.05$, uncorrected). For the functional MRI, fusiform gyrus was specifically activated in taxi drivers, compared with the control group.

Conclusion: The structural and functional changes of taxi driver's hippocampus indicate the functional differentiation as a result of occupational dependence on spatial navigation. In other words, the continuous usage of spatial navigation performance may diminish degeneration of hippocampus and the related brain regions.

Index words : Hippocampus · Behavior · Magnetic resonance imaging (MRI) · Orientation

INTRODUCTION

Magnetic resonance imaging (MRI) has the advantage of acquiring both structural and functional images simultaneously. Voxel-based morphometry (VBM) which is a voxel-based comparison between groups can be used to investigate gray matter integrity in certain diseases (1). Shape analysis is a recently developed method for the statistical evaluation of morphometric changes of brain subregions with a three-dimensional (3D) T1-weighted image (T1WI). Shape analysis of hippocampus allows statistical assessment of the subregional anatomy of morphologically changed areas with 3D modeling of the hippocampus so that contracted or expanded subregions of the hippocampus can be identified (2). The functional MRI (fMRI) commonly uses blood oxygen level dependent (BOLD) signal changes to visualize brain activity during certain tasks (3). An increase in neural activity results in an increase in oxygen consumption to meet metabolic demands (4–7).

Hippocampus has been the main subject of many studies on human memory functions. The structural or

functional changes in the hippocampus in relation to long-term navigation have been investigated by some scientists (8). For example, Maguire et al. (9) investigated the taxi drivers who drove around London, England, and analyzed the relationship between hippocampus and navigation ability using VBM. The result of their study showed structural changes in the hippocampi of the taxi drivers who did not use a navigation system while driving. In addition, Spiers and Maguire (10) studied the taxi drivers who drove around London and had an average 18 years experience. They found significantly increased activity in the hippocampus on functional MRI when subjects planned routes between start and destination points compared with that in the non-experienced drivers. In another fMRI study, the hippocampus was also significantly active when subjects, who had lived in London for on average 16 years, engaged in mental navigation (11).

However, there was no study that investigated VBM, shape analysis, and BOLD functional changes together in the taxi driver group compared with a normal control group. The aims of this study were to compare: 1) changes in hippocampal volumes using automatic segmentations of the hippocampi, 2) alterations of the hippocampal shapes using shape analysis, and 3) functional changes in the temporal lobes using BOLD fMRI, between the two groups. Therefore, we attempted to analyze the differences in hippocampal shape and volume using 3D T1WI and the different neural activities using BOLD fMRI between the very well experienced taxi drivers and control subjects from Korean population.

MATERIALS AND METHODS

Subjects

Data was reported from 4 male subjects who had 20–30 experience as taxi drivers and did not use a navigation tool or used only for a few years while driving and 4 male age-matched healthy control subjects who used a navigation system while driving in the same area of Pusan, South Korea (Table 1). The mean age in the control group was 50 years (range, 49~53 years) and that in the taxi driver group was 51 years (range, 46~59 years). There were no female subjects in this study. Subjects, both the controls and taxi drivers, were recruited through the project program of Korean Broadcasting System investigating the process of human memory restoration.

Roadmap navigation fMRI paradigm

For BOLD fMRI, we had a session of block design. There were four blocks for stimulations and four blocks for baseline controls. Fifteen dynamics were obtained in each 45-second block. There were a total 120 dynamics. During the activation period, there were four problems showing roadmaps to find a final destination by imagining real driving on the road. In each problem, there was a starting point, a stop by point and a final destination point (Fig. 1A). The overall picture, including the starting point, stop by point and final destination point was shown for the first 3 seconds. After that, the enlarged picture of the starting point was shown for 12 seconds, that of the stop by point was shown for the next 15 seconds and that of the final destination point was shown for the last 15 seconds in continuation. Each subject was

Table 1. Demographic Characteristics of Taxi Drivers and Control Subjects

Subject	Age (years)	Occupation	Educational level	Driving experience (years)	Years of use of navigation system (years)	Alcohol consumption per month (bottles)	Cigarette consumption per day (packs)
Control 1	49	Local officer	College graduate	27	3	2	None
Control 2	49	Local officer	College graduate	15	3	none	None
Control 3	53	Local officer	High school graduate	20	3	none	None
Control 4	52	Local officer	College graduate	30	2~3	1	0.2
Driver 1	59	Local taxi driver	High school graduate	20	2	0.5	None
Driver 2	49	Local taxi driver	High school graduate	23	None	1	1
Driver 3	46	Local taxi driver	High school graduate	20	None	none	1
Driver 4	50	Local taxi driver	High school graduate	21	1	none	0.14

asked to navigate from the starting point to the final destination point using the pre-decided stop by point. During the baseline period, the four different crossroads were shown (Fig. 1B).

Image acquisitions

The experiment was performed using a 3T MRI system with a dedicated 8-channel head coil (Achieva, Philips Medical Systems, Best, Netherlands). The

Fig. 1. A sample of road maps (A) and control maps (B) that was used during the functional MRI task. The four different question pictures were shown during the stimulation period.

A. An example of road map

(a). An overall picture showing the starting point (red), stop by point (green) and the final destination point (blue).

(b). A close-up image showing the starting point (red).

(c). A close-up image showing the stop by point (green).

(d). A close-up image showing the final destination point (blue).

B. The control maps. The four different crossroad pictures were shown during the baseline period.

subjects lied down supine in the scanner supported by an immobilized head cushion. In order to investigate the hippocampal shape and volume, a three-dimensional T1-weighted (3D T1W) sagittal sequence was run for 5 min with the following parameters: repetition time (TR) = 9.9 ms, echo time (TE) = 4.6 ms, flip angle = 8°, field of view (FOV) = 240 × 240 mm, slice thickness = 1 mm, matrix size = 240 × 240, and resolution = 1 × 1 × 1 mm. In addition, we obtained anatomical images by using a two-dimensional T2-weighted (2D T2W) and fluid-attenuated inversion recovery (FLAIR) transverse sequences for detecting the structural abnormalities. Imaging parameters for the 2D T2W images were as follows: TR= 3000 ms, TE= 80 ms, flip angle= 90°, FOV= 230 × 230 mm, slice thickness= 4.5 mm, matrix size= 256 × 256, and resolution= 0.9 × 0.9 × 4.50 mm. Imaging parameters for the FLAIR images were as follows: TR= 11000 ms, TE= 125 ms, inversion time (TI)= 2800 ms, FOV= 230 × 230 mm, slice thickness= 4.5 mm, and matrix size= 256 × 256.

To investigate the functional differences between the two groups, the BOLD fMRI data were acquired using a gradient-echo echo-planar imaging (EPI) sequence using the fMRI paradigm mentioned in the previous paragraph. The corresponding imaging parameters were as follows: TR= 3000 ms, TE= 35 ms, flip angle= 90°, FOV= 230 × 230 mm, slice thickness= 4.5 mm without gaps between slices, number of slices= 30, the acquired image matrix size= 64 × 64, and resolution= 3.6 × 3.6 × 4.5 mm. These procedures were carefully explained and also provided in writing to all subjects before entering the scanner to make sure they fully understood the experimental procedure. The total scan time for each subject was about 25 min.

Hippocampal volume and shape analyses
Automatic hippocampal segmentation

The 3D T1WI image in native space was registered to the Montreal Neurological Institute (MNI) template using non-linear registration. The tissue classification into the gray matter, white matter and cerebrospinal fluid (CSF) was performed on the registered 3D T1WI image. After that, the hippocampus in individual brain was segmented using automatically defined hippocampus on the MNI brain template (12). To exclude false positive results, the segmentation results on the white matter or CSF were masked out using gray matter

tissue probability map (12). We specifically used the threshold value of 0.3 to define the gray matter regions on the probability map. The isolated pixels and small gaps in the segmented region were removed using Gaussian kernel smoothing with a kernel size of 1.5 voxels. Finally, each hippocampus segmentation result in common space was transformed into the native space using the transformation made in the previous normalization step. After the hippocampal volumes were measured for each subject, mean hippocampal volume was normalized to each intracranial volume to minimize the individual variation. The exact Wilcoxon rank-sum test was used to examine the group differences in hippocampal volumes. The level of significance was p = 0.05.

Hippocampal shape modeling

For hippocampal shape modeling, the in-house software was used. Details have been described in the previous publication (13). The main steps were as follows: The region of interest (ROI) was automatically delineated using the center of mass of hippocampal volume. A 3D hippocampal model was generated through the deformation of the initial shape model (14). The deformation process was carried out based on an objective function, which was composed with different terms such as a stretch, self-proximity, and inter-surface proximity. In order to normalize the hippocampal surface model of every subject, each model was translated and rotated so as to match the centroid and long axis of the model with that in the model of the randomly selected subject. Before this normalization, the selected surface model was smoothed using the Gaussian kernel smoothing with 7 mm full width at half maximum (FWHM). Using these generated individual 3D hippocampal shape models, the local shape differences were investigated using the previously developed methods (13). The distance was mapped as a feature on the initial shape model with the same spatial domain. Each vertex of the initial shape contained the distance from the hippocampus. The surfaces of the single objects were parameterized, providing a point-to-point correspondence between the homologous surface points. In individual 3D shape models, distance from each vertex to the center of mass was measured. The total distance (from each vertex to the center of mass) of hippocampus in each subject was normalized by the subject's ICV value.

Then, to increase the signal-to-noise ratio, diffusion Gaussian smoothing was applied to the distance in individual shape models (14). The results of voxel-based shape analysis were presented at p = 0.05 without correcting for multiple comparisons. After the mean shape distances were obtained for each subject, the exact Wilcoxon rank-sum test was used to examine the group differences in hippocampal shapes, which were the mean distances from each vertex to the center of hippocampus. The level of significance was p = 0.05.

Roadmap navigation fMRI data analysis
Data Preprocessing

For reaching maximum signal equilibrium in the functional data, the first three images were rejected. Further steps were performed using statistical parametric mapping version 8 (SPM8, http://www.fil.ion. ucl.ac.uk, the Wellcome Trust Centre for Neuroimaging) as follows: (15). To correct for head movements, the functional images were realigned to the first image and an average image of the functional images (mean EPI) was generated, followed by the slice-timing procedure. The next step was the co-registration of 3D T1WI images and the mean EPI and all the EPI images. After that, the 3D T1WI dataset of each subject was spatially normalized into the MNI template (16). The thereby estimated transformation was applied to the functional images, which were re-sampled to a cubic voxel size of 2 mm. Finally, the normalized functional images were smoothed with a Gaussian kernel of $8 \times 8 \times 10$ mm FWHM.

For the individual level analysis, the effect of the activation task at each voxel was estimated using a general linear model. A typical delayed boxcar model convolved with a hemodynamic response function was used. Voxel values for stimulation versus baseline yielded a statistical parametric map of the t statistic. An activation or deactivation contrast image for each subject was created for the group analysis.

Statistical analyses (2nd level analyses)

To investigate within-group activation in the second level analysis, one-sample t-test was performed for each group using the result of the individual level analysis. The voxel-wise significance threshold of p = 0.01 was used for correcting for multiple comparisons by the false discovery rate (FDR) method. Only clusters with more than 10 voxels were included. For anatomical localization, transformations of voxel coordinates from the MNI to Talairach space were performed, as described by Brett (www.mrc-cbu.cam.ac.uk/ Imaging/Common/ mnispace.shtml), and, afterwards, the regions were anatomically charac-terized by the use of the Talairach atlas Imaging (17) and the Talairach Daemon (http://ric.uthscsa.edu/resources) software.

RESULTS

Hippocampal volume and shape analyses

The results of hippocampal volume are listed in Table 2. The mean ± SD hippocampal volume normalized to the intracranial volume (ICV) value in the taxi driver group was 0.198 ± 0.005 and 0.198 ± 0.009 for the right and left hippocampus, respectively. The mean ± SD hippocampal volume normalized to

Table 2. Comparisons of Hippocampal Volumes between the Taxi Driver (D) Group and the Control (C) Group

Right hippocampal volume (corrected)				Left hippocampal volume (corrected)			
Control group		Taxi driver group		Control group		Taxi driver group	
C1	0.219	D1	0.199	C1	0.215	D1	0.203
C2	0.195	D2	0.192	C2	0.21	D2	0.186
C3	0.212	D3	0.205	C3	0.195	D3	0.197
C4	0.207	D4	0.197	C4	0.177	D4	0.207
Mean	0.209 ± 0.01	Mean	0.198 ± 0.005	Mean	0.199 ± 0.017	Mean	0.198 ± 0.009

Note.— Rt, right; Lt, left
Mean ± SD in the subjects
Corrected volume: the normalized mean hippocampal volume with intracranial volume
There was no statistically significant difference in the hippocampal volume between the two groups (p value > 0.101 for the right side, p value > 0.609 for the left side).
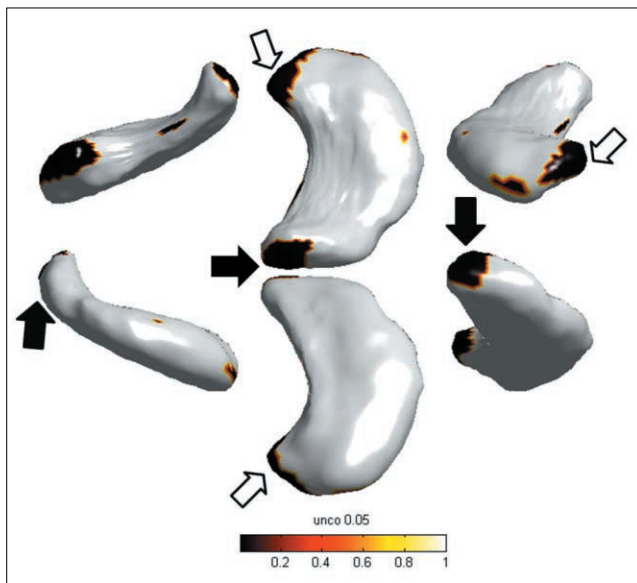
Fig. 2. The morphometric analysis with reconstructed hippocampal structures using spherical harmonic descriptors. The left hippocampus of taxi driver group is shown in this figure with slightly elongated mean distances from center of the mass to each vertex and larger head (open arrows) and tail (thick black arrows) portions. The comparison of mean distance value between the two group was recorded as color spectrum (uncorrected p < 0.05). Areas that have statistically significant differences in hippocampal shape between the taxi driver group and the control, are shown here as black colored region-head and tail portions of hippocampus.

the ICV value in the control group was 0.208 ± 0.010 and 0.199 ± 0.016 for the right and left hippocampus, respectively. There were no statistically significant differences in the hippocampal volumes for both sides between the two groups ($p > 0.05$).

The result of the VBM shape analysis of the left hippocampus is shown in Fig. 2. The head and tail portions of the left hippocampus in the taxi driver group were slightly but statistically significantly larger than those of the left hippocampus in the control group ($p < 0.05$, uncorrected). There was no significant difference in the right hippocampal shape between the taxi driver group and the control group ($p = 0.2$). Table 3 lists the total distances and the corrected distances, which was normalized by the subjects's ICV value, of hippocampi in the taxi driver and control groups. The normalized mean $\pm$ SD distance of the left hippocampus was 12.945 ± 0.198 and 12.891 ± 0.523 in the taxi driver and control groups, respectively. The mean $\pm$ SD length of the left hippocampus in the taxi driver group was significantly longer than that of the left hippocampus in the control group ($p < 0.05$, uncorrected). There was no significant difference in the mean length of the right hippocampus between the taxi driver group and the control group.

Table 3. The Mean Length (distance) of Hippocampi in the Taxi Driver (D) Group and the Control (C) Group

Subject	ICV*	Distance**		Normalized distance[¶]	
		Right side	Left side	Right side	Left side
C1	1470990	3230	3165	12.212	12.195
C2	1608150	3140	3371	12.519	12.895
C3	1542261	3272	3008	12.169	13.018
C4	1685368	3496	2987	12.363	13.457
mean $\pm$ sd[§]				12.316 ± 0.159	12.891 ± 0.523
D1	1562383	3118	3175	12.216	13.090
D2	1611243	3099	2992	12.159	12.884
D3	1580794	3235	3109	12.286	13.115
D4	1466725	2886	3037	12.195	12.692
mean $\pm$ sd				12.214 ± 0.054	12.945 ± 0.198

Note.— * ICV; intracranial volume (number of voxels)
** Distance (mm) = the sum of distances of hippocampus as measured from each vertex to the center of the mass.
[¶]Normalized distance = the normalized distance of hippocampal shape by using the individual ICV and then multiply by 10000.
[§] Mean $\pm$ SD in the subjects
The mean length of hippocampus in the taxi driver group was slightly longer than that in the control group for the left side (uncorrected p < 0.05), but not for the right side (uncorrected p = 0.2).

Roadmap navigation fMRI

During the activation period, the activated brain regions on BOLD fMRI are shown in Fig 3 and are listed in Table 4. The temporal lobe and the limbic lobe were more activated in the taxi driver group than in the control group. Especially a significant activation in the fusiform gyrus was noted in the taxi driver group (Fig. 3A). The control group showed more

Table 4. The Activated Brain Regions During the Activation Period in the Control (A) Group and in the Taxi Driver (B) Group on Functional MRI Obtained with One Sample t-test (p=0.05) and Correcting for Multiple Comparisons with the False Discovery Rate (FDR) Method

A. Activated brain region (Control group)			Brodmann area	Talairach Coordinate			Z-score
				X	Y	Z	
Frontal Lobe	Right	Middle Frontal Gyrus, WM		24.59	34.26	38.57	6.65
				33.95	31.36	29.44	5.98
		Sub-gyral, WM		18.64	−21.66	52.99	4.5
		Paracentral Lobule, WM		11.14	−33.32	57.16	2.77
	Left	Middle Frontal Gyrus, WM		−27.46	9.09	47.92	6.17
Sub-lobar	Left	Extra-nuclear, WM		−19.85	−53.37	13.3	2.82

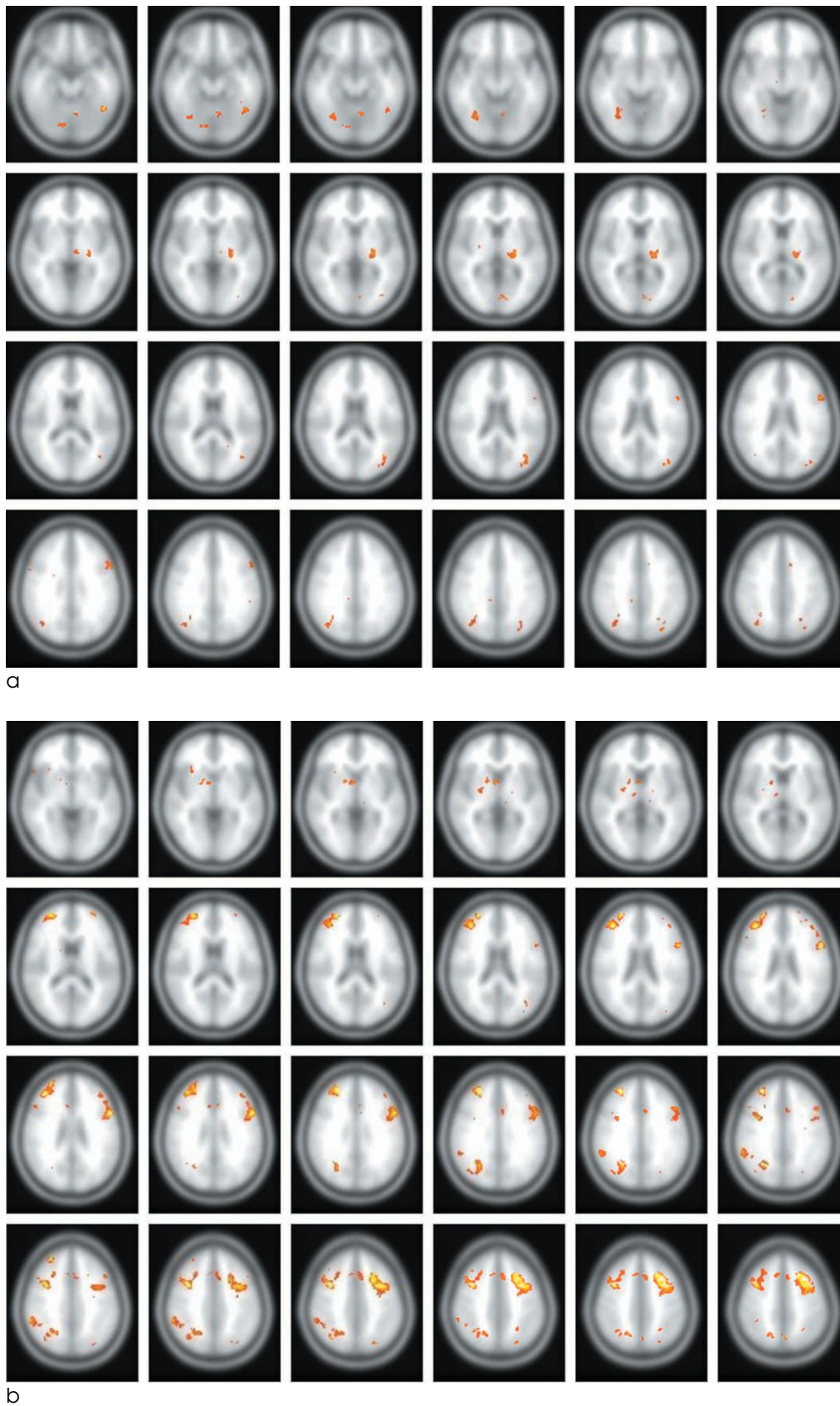| B. Activated brain region (Taxi driver group)			Brodmann area	Talairach Coordinate			Z-score
				X	Y	Z	
Limbic Lobe	Right	Posterior Cingulate, WM		9.78	−55.21	11.82	2.87
		Posterior Cingulate, GM	30	9.76	−64.53	10.94	2.52
	Left	Parahippocampal Gyrus, GM		−22.99	−7.19	−16.61	3.35
Frontal Lobe	Right	Middle Frontal Gyrus		24.14	−3.75	61.99	4.44
		Middle Frontal Gyrus, WM		26.42	35.94	40.56	3.58
				30.2	40.17	35.62	3.32
				35.58	24.19	45.01	3.13
				46.71	17.03	40.91	3.37
		Paracentral Lobule,WM		12.98	−35.19	57.02	3.56
		Postcentral Gyrus, GM	4	42.8	−17.36	46.6	3.79
	Left	Medial Frontal Gyrus,WM		−10.95	−4.91	55.88	4.81
		Medial Frontal Gyrus,GM	32	−8.93	9.17	46.43	4.73
		Precentral Gyrus, GM	6	−40.46	−7.61	46.11	4.68
Parietal Lobe	Right	Precuneus, WM		29.65	−47.97	52.48	4.83
	Left	Postcentral Gyrus, WM		−35.09	−32.73	52.83	3.75
Sub–lobar	Right	Insula, GM	13	39.62	−24.51	4.43	2.77
	Left	Extra–nuclear, WM		−32.29	1.65	−10.53	2.77
				−37.85	7.1	−8.3	2.58
				−28.79	23.94	11.46	3.33
Temporal Lobe	Right	Superior Temporal Gyrus, GM	41	41.38	−30.63	9.28	2.84
	Left	Middle Temporal Gyrus,		−38.25	−48.85	6.21	3.19
		Fusiform Gyrus, WM		−41.65	−48.43	−17.23	4.93

Fig. 3. Activated brain regions in the functional MRI study of the taxi driver group (a) and the control group (b) are shown.
a. The taxi drivers show neuronal activation mainly in the temporal lobe and fusiform gyrus.
b. The controls show neuronal activation mainly in the frontal and parietal lobes.

activation in the frontal lobe (Fig. 3B).

DISCUSSION

We were interested in investigating the very well experienced taxi drivers because it is likely that they may have used the temporal lobe functions more frequently than the other drivers who often used a navigation system. This study can be meaningful due to the application of both hippocampal shape and volume in the structural analysis and BOLD functional MRI in the functional analysis for examining the spatial memory tasks, relationship between spatial memory and the temporal areas, and environment-induced changes in the related brain regions.

The first major finding of this study was that there was a significant difference in the left hippocampal shape between the taxi driver group and the control group. The head and tail portions of the left hippocampus were larger in the taxi driver group, and the total distance of the left hippocampus was slightly longer in the taxi driver group than that in the control group. The result of our hippocampal shape analysis can be meaningful in the view of demonstrating the structural changes in the hippocampus of the taxi drivers. To the best of our knowledge, there has been no other study investigating the hippocampal shape among taxi drivers by using shape analysis.

Previous fMRI studies demonstrated that the head of hippocampus usually contributes to several tasks such as; verbal memory(18), associative memory, working memory which is important for executive function and the control of prefrontal lobe function (19). The anterior hippocampal region may be more involved in combination with the posterior hippocampus during the encoding of new environmental layouts (9). On the other hand, the tail of hippocampus is responsible for the spatial memory and so it can help to recognize the locational and directional information and to find the familiar places (9). The tail portion of hippocampus is also responsible for the context memory which is required for recalling specific information. For example, if a person forgot where he put the car keys, he would be considered to lack hippocampal functioning related to this area. The posterior hippocampus seems to be preferentially involved when previously learned spatial information is used. In this regard,

posterior hippocampus (tail portion) is more responsible for the occupational dependence on spatial memory among taxi drivers especially on remote spatial memory than anterior hippocampus(head portion)(9). In case of damage to the tail portion of hippocampus, one can be more vulnerable to retrograde amnesia than anterograde amnesia. Concerning to our study result, it might be possible to infer that not only the portion of a hippocampus but also left or right sideness would be related to the human spatial memory function. The right hippocampus plays more important role in spatial navigation and recall of spatial memory according to the previously published reports(20), which shows a discrepancy with our result. Also, left hippocampus has been considered to be more responsible for the mood or emotional memory(21). In this regard, our study result that showing the significant difference of left hippocampal shape in the taxi driver group needs further examination with larger study sample to be validated.

Examination of the structural changes in the hippocampus on VBM in several previous studies (9) demonstrated that the gray matter volume of the posterior hippocampus was greater in the taxi driver group compared with the non-taxi driver control group. Also, the number of years of navigation experience correlated with the hippocampal gray matter volume which demonstrates that the posterior hippocampal gray matter volume increases with more navigation experience. Therefore, the structural differences in the human hippocampus reflect the use of the spatial representation acquired, and not innate navigational expertise (22). However, several studies reported that the anterior hippocampal gray matter volume decreased as navigation experience increased in taxi drivers (9).

The second major finding of this study was that the fusiform gyrus area showed activation in the taxi driver group but not in the control group. Previous studies showed that fusiform regions should be thought to be critical in encoding face traits and identity (5). The activation of fusiform gyrus among taxi drivers on the functional MRI can be responsible for their occupational dependency and functional differentiation within this specific area.

The fusiform gyrus area is also responsible for the analysis of color information, cognitive function about

words or numbers, declarative memory or semantic memory (23), and for the ability to recognize the specific spatial information (24). Functional neuroimaging studies of topographical memory showed results similar to those in our study (10, 23). It is relatively well established that a posterior parahippocampal-anterior lingual or fusiform sector of the medial occipitotemporal cortex is preferentially responsive to spatially contained layouts (25).

In the study investigating the navigation ability of a licensed London taxi driver, Maguire et al. (26) found that the hippocampus is not required for general orientation in the city, detailed topographical knowledge of landmarks and their spatial relationships, or even for active navigation along some routes, but it is necessary for facilitating navigation in places learned long ago. Surprisingly, the hippocampal areas showed no significant activation in any groups of our study. Previous studies showed hippocampal activation during generating the initial vector to specified goals (27), during updating the most efficient route (28), and during goal-specified route planning (10). In this study, the subjects performed a simulated navigation process with the provided maps instead of real navigation around the specific place. This difference in the study design could contribute to the negative functional activation of hippocampus in our study. The frontal and parietal lobes were more activated in the control group than in the taxi driver group. A previous study also showed activation of the prefrontal cortex (10), retrosplenial cortex (29), posterior parietal cortex (30) and medial temporal cortex (28) during goal-directed route planning.

There were several limitations to this study. First of all, the sample size was too small with only 4 subjects in each group. More studies with a larger sample size would be needed in order to validate this result. Secondly, the hippocampal volume and shape analyses may not be accurate because automatic segmentations of hippocampus may not be perfect, especially in the head and tail portions of hippocampus. Thirdly, the control group and the taxi driver group did not match exactly in the context of navigation ability. The educational level and occupation were not properly controlled during the selection of control subjects. Further studies would be necessary to investigate the navigation ability of taxi driver groups in a local area such as a group of taxi drivers who did not use a navigation system, a group of taxi drivers who used some navigation systems, and a group of controls who used some navigation systems. Finally, the 'time factor' was not considered in this study so we could not determine when the structural and functional changes related to navigation process started in the hippocampus. We propose a further study with stratification according to the years of driving experience.

CONCLUSION

The hippocampus in the taxi drivers was more elongated with slightly larger head and tail portions and increased neural activities in the fusiform gyrus. This means that occupational dependence on spatial navigation could lead to functional differentiation within the hippocampus and the related regions as an environment-related plasticity of the brain. In other words, the continuous usage of spatial navigation performance might reduce hippocampal degeneration.

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오랜 운전경험을 가진 택시운전기사들의 해마의 구조와 기능적 변화에 대한 MRI연구

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목적: 본 연구에서는 숙달된 택시운전기사들을 대상으로 내비게이션 시스템을 이용하여 운전하는 한국인 대조군에 비교하여 해마의 부피와 모양 그리고 기능적 변화를 알아보고자 하였다.

대상과 방법: 총 8명의 대상군(4명의 숙달된 택시운전기사들과 4명의 같은 나이대 일반인 대조군)에 대해 삼차원 T1강조영상과   류   소 수준에 따른 기능성 자기공명영상을 촬영하였다. 해마의 용적과 모양, 기능성 자기공명영상 자료를 분석하여 두 군간에 신경 활성도 차이를 비교하였다.

결과: 해마의 용적은 두 군간에 통계적으로 유의한 차이를 보이지 않았다(p 〉 0.05). 해마의 모양을 보면, 택시운전기사군의 왼쪽 해마가 대조군에 비해 전체 길이가 약간 길고 머리와 꼬리부분이 약간 더 컸다(p 〈 0.05, uncorrected). 기능성 자기공명영상에서는 택시운전기사군에서 대조군에 비해 방추상회가 특히 활성화되어 있었다.

결론: 택시운전기사군의 해마가 보이는 이러한 구조적, 기능적 변화는 그들의 직업과 관련하여 공간적 탐색능력을 지속적으로 사용하면서 해마와 관련 뇌영역이 기능적으로 분화했음을 나타내는 소견으로 추측할 수 있겠다.

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