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Effect of visual experience on structural organization of the human brain: A voxel based morphometric study using DARTEL

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ABSTRACT

Objective: To investigate structural reorganization in the brain with differential visual experience using Voxel-Based Morphometry with Diffeomorphic Anatomic Registration Through Exponentiated Lie algebra algorithm (DARTEL) approach.
Materials and methods: High resolution structural MR images were taken in fifteen normal sighted healthy controls, thirteen totally blind subjects and six partial blind subjects. The analysis was carried out using SPM8 software on MATLAB 7.6.0 platform.
Results: VBM study revealed gray matter volume atrophy in the cerebellum and left inferior parietal cortex in total blind subjects and in left inferior parietal cortex, right caudate nucleus, and left primary visual cortex in partial blind subjects as compared to controls. White matter volume loss was found in calcarine gyrus in total blind subjects and Thlamus-somatosensory region in partially blind subjects as compared to controls. Besides, an increase in Gray Matter volume was also found in left middle occipital and middle frontal gyrus and right entorhinal cortex, and an increase in White Matter volume was found in superior frontal gyrus, left middle temporal gyrus and right Heschl's gyrus in totally blind subjects as compared to controls. Comparison between total and partial blind subjects revealed a greater Gray Matter volume in left cerebellum of partial blinds and left Brodmann area 18 of total blind subjects.
Conclusion: Results suggest that, loss of vision at an early age can induce significant structural reorganization on account of the loss of visual input. These plastic changes are different in early onset of total blindness as compared to partial blindness.

1. Introduction

Voxel-Based Morphometry (VBM), introduced by Ashburner and Friston offers rapid unbiased assessment of the whole brain [1]. This automated technique examines differences in local composition of tissue on a voxel-by-voxel basis after global differences in anatomy have been discounted. VBM has been used to characterize structural brain differences in a variety of disease conditions including Down's syndrome, autism, schizophrenia, epilepsy, Alzheimer's disease, Parkinsonism, type II diabetes mellitus [2], etc. VBM studies have also investigated the impact of learning and practice on brain structure of the healthy subjects [3]. These morphological studies clearly give evidence of morphological plasticity of the brain. Moreover, the morphology and the function seem to be inter-related. Morphological studies on diseased conditions have shown that altered function is often associated with brain atrophy in the related areas [2]. On the other hand, training or acquisition of new skills often results in an increase in gray matter volume in the relevant regions [3].

Neuroimaging studies have demonstrated that the visual cortex of both the early and late blind subjects exhibits significant cross-modal functional plasticity [4]. However, fewer studies have dealt with structural plasticity associated with blindness using automated techniques like Voxel or Tensor Based Morphometry [4–8]. As the disuse related and compensatory mechanisms, both govern the structural plasticity in the brain, we hypothesized that the morphological changes would be different in totally blind subjects who had no vision left in them, as compared to the morphological changes in partial blind subjects who had partial vision left. In the present study we attempted to detect gray matter changes in the brain, with the extent of sightedness a person has, using Voxel Based Morphometry technique applied to three groups consisting of totally blind subjects, partially blind subjects and controls. To improve inter-subject registration of the MRI images, we applied Diffeomorphic Anatomic Registration Through Exponentiated Lie algebra algorithm (DARTEL) [9], which has been found to optimize the sensitivity of such analyses [10] by using

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Table 1
Clinical characteristics of the blind subjects.

Subject ID[a]	Age (years)	Onset of blindness	Cause of blindness	Light sense
T_1	21	Birth	Congenital cataract	None
T_2	23	3.0	Poor medical aid after conjunctivitis	None
T_3	23	5.0 years	Eye infection	None
T_4	25	Birth	Optic nerve atrophy	Bright light
T_5	24	Birth	Glaucoma	None
T_6	21	4.0 years	Post iridocyclitis	None
T_7	20	Birth	Congenital cataract	Bright light
T_8	23	Birth	Post iridocyclitis	Bright light
T_9	25	6.0 years	Poor medication when affected with smallpox	None
T_{10}	21	6.0 years	Ophthalmitis	Bright light
T_{11}	23	Birth	Congenital cataract	None
T_{12}	20	Birth	Optic nerve atrophy	Bright light
T_{13}	24	4.0 years	Ophthalmitis	None
P_1	21	5.0 years	Congenital cataract	Yes
P_2	20	Birth	Optic nerve atrophy	Yes
P_3	23	Birth	Congenital cataract	Yes
P_4	27	Birth	Congenital cataract	Yes
P_5	20	5.0 years	Congenital cataract	Yes
P_6	25	Birth	Post iridocyclitis	Yes

[a] T – total blind subjects; P – partial blind subjects.

the Levenberg–Marquardt strategy as compared to standard VBM. The current study on one hand explores the morphological changes using DARTEL, which to the best of our knowledge has never been applied in blind subjects, as compared to previous studies using other methods viz. optimized VBM [5], fast fluid registration [6], analysis of cortical thickness and surface area [8], etc. Secondly, it also compares the morphological changes in early total and partial blinds.

2. Materials and methods

2.1. Subjects

Fifteen normal sighted right handed healthy males (21–27 years old, mean age ± SD = 23.61 ± 2.10 years, group 1), thirteen right handed early totally blind males (20–25 years old, mean age ± SD = 22.42 ± 1.78 years, group 2) and six right handed early partial blind males (20–25 years old, mean age ± SD = 22.86 ± 2.67 years, group 3) participated in the study. No statistically significant age difference was found between the three groups ($p < 0.134$ for groups 1 and 2; $p < 0.222$ for groups 1 and 3; $p < 0.974$ for groups 2 and 3). All the subjects chosen for the study were Indian natives and none of them had any clinical evidences of stroke, head injury, cardiovascular diseases, history of drug dependence, psychiatric disorder or cognitive impairment nor did they have any cortical infarctions on the T_2-weighted MR images. The reported onset of total or partial blindness for all the subjects ranged from birth to 6 years of age (Table 1). In ophthalmologic examinations, five of the totally blind subjects were found to be sensitive only to strong sunlight that too only from one of their eyes. The maximum distance to which partial blind subjects could perform finger counting ranged from 'close to face' to 2 m. Both the partially blind and totally blind subjects were students, undergoing either graduate or post graduate courses in various subjects of Arts (Political Science, History, Hindi, Programming, Sanskrit, Education, English or Buddhist Study). Further, all subjects gave their consent to participate in the study.

Table 2
Normalized gray matter volume (nGM), normalized white matter volume (nWM), normalized cerebrospinal fluid volume (nCSF) and total intracranial volume (TIV) for the three groups (mean ± SD).

	TIV (ml)*	nGM*	nWM*	nCSF*
Controls	1445.77 ± 112.68	0.45 ± 0.01	0.34 ± 0.01	0.21 ± 0.01
Total blinds	1403.66 ± 84.62	0.45 ± 0.01	0.33 ± 0.01	0.22 ± 0.01
Partial blinds	1358.68 ± 0.09	0.46 ± 0.01	0.33 ± 0.01	0.21 ± 0.01

* TIV, nGM, nWM and nCSF showed no significant difference between the three groups ($p > 0.05$).

2.2. Scanning protocol

The MRI scans were acquired using 1.5 Tesla whole-body MRI system (Siemens Magnetom Vision, Erlangen, Germany) with a circularly polarized head coil and 25 mT/m actively shielded gradient system. T_1 weighted 3D Magnetization Prepared Rapid Acquisition Gradient Echo (MPRAGE) sequence with 160 slices (1 mm slice thickness) covering the whole brain was performed in

Table 3
Regions of GM volume changes.

Hemisphere	Localization of peak voxels	MNI coordinates			Z value (peak voxel)	Cluster size (no. of voxels)
Controls minus Total blinds*						
L	Lobule VIIIa (Hem), Cerebellum	−27	−58	−63	4.26	4836
R	Lobule VIIa Crus II (Hem), Cerebellum	47	−65	−57	3.98	2898
L	IPC (PF), Inferior Parietal Lobule	−57	−39	43	3.37	369
Controls minus Partial blinds#						
L	IPC (PFm), Middle Temporal Gyrus	−62	−54	19	3.58	473
R	Caudate Nucleus	12	15	16	3.67	319
L	BA 17, Cuneus	−12	−79	16	3.75	302
L	BA 17	−21	−64	0	3.95	235
Partial blinds minus Total blinds@						
L	Lobule VIIIa (Hem)	−24	−66	−60	3.49	460
L	Lobule VIIa Crus II (Hem)	−42	−49	−51	3.48	301
Total blinds minus Controls$						
L	Middle Occipital Gyrus (hOC5 (V5))	−42	−79	1	4.36	1034
L	BA 6, Middle Frontal Gyrus	−50	51	6	4.32	451
R	Hippocampus (EC)	20	3	−35	3.28	157
Total blinds minus Partial blinds!						
L	BA 18	−5	−81	28	3.66	354

MNI: Montreal Neurological Institute; BA: Brodmann area.
* Small Volume Correction (FWE corrected), $p < 0.012$.
# Small Volume Correction (FWE corrected), $p < 0.011$.
@ Small Volume Correction (FWE corrected), $p < 0.002$.
$ Small Volume Correction (FWE corrected), $p < 0.01$.
! Small Volume Correction (FWE corrected), $p < 0.01$.