Neuroanatomical Evidence of Dyslexia (II): A Review of Functional Imaging Studies

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Functional Imaging Studies

Morphological studies do not tell us which parts of the brain are activated during a certain cognitive task. There are ways to examine the brain activities while a subject is engaging in a task. A cognitive task requires activation of particular neural systems. The neural activities are reflected by changes in brain metabolic activity (e. g., changes in cerebral blood flow or changes in cerebral utilization of metabolic substrates, such as glucose). Subjects inhale or are injected radio-active substance and brain metabolic activities are measured by positron emission tomography (PET) while they are engaging in a task and resting. The brain regions in which difference of activity levels between resting and task-engaging period is found are interpreted to be associated with the cognitive task. Since different tasks activate different regions of the brain, results are reviewed according to the task type.

Phonological Tasks

There are two studies which employed the same phoneme detection task (Hagman, Wood, Buchsbaum, Tallal, Flowers, Katz, 1992 ; Wood, Flowers, Buchsbaum, & Tallal, 1991). Hagman, et al. found that dyslexic adults had higher metabolic rates in medial temporal regions. Wood, et al. did not report the difference of the activation level, but reported different correlation pattern between normal and dyslexic subjects. The task accuracy was related to lower left superior temporal activation in normals, while it was related to greater left temporal activation in dyslexics.

The task used in these studies are relatively easy for normal subjects and they were assumed to have performed without much effort. However, this task is not so easy for dyslexics. Thus, the higer activation level in dyslexics is interpreted that the task required more activation for dyslexic subjects (Wood, et al., 1991).

Verbal Task

This is the second part of a series of review articles. The texts related to Tables 1 to 4 are shown is the first part of this review article appeared in the previous issue of this journal. Table titles for Table 2 and 3 in the first article are not correct and should be replaced by the following title : Table 1 Summary of the Characteristics of Subjects (Continued).

Three different kinds of tasks were employed in the studies reviewed here. Rumsey, et al. (1992) used rhyme detection task that requires phonological awareness, a core deficit in dyslexia. Dyslexic subjects showed less activation in the left temporoparietal regions near the angular gyrus. The activation of this area is related with verbal intelligence score (VIQ). These results in conjunction with structural abnormality of the left Planum Temporale (PT) found in morphological studies support the hypothesis that individuals with dyslexia have both structural and functional deficit in the temporoparietal language region.

They also found that dyslexic group showed greater activation in the left anterior temporal and the right temporal region. This is interpreted as compensatory activities for the malfunctioning left temporoparietal region. The anterior temporal region was also activated only in dyslexic group during non-verbal task, which suggests that this activation is abnormal. Actually, the greater activation in the area is related to lower VIQ in dyslexic subjects.

Flowers, Wood, and Naylor (1991) employed spelling task in which they asked subjects to count the number of letters for presented words. Subjects with normal reading ability during their childhood showed more activation in the left temporal region (Wernicke's region) than poor childhood readers did, while poor childhood readers showed greater activation in the left temporoparietal region than normal childhood readers did.

These results seem contradictory with the Rumsey, et al.'s (1992) results. However, the sites measured in Flowers et al.'s study are different from those in Rumsey's. Considering the limited localizability of regional cerebral blood flow (rCBF) study compared with magnetic resonance imaging (MRI) study, the two temporoparietal sites may not overlap completely between the two studies. Another interpretation is that the task difference is responsible for the different activation pattern. If that were true, the impairment in the temporoparietal region in dyslexics should be task specific, that is, selective dysfunction to phonological tasks. If this is the case, it is more natural to assume the abnormal connectivity of neural network rather than abnormality of one specific structure. Since the abnormality of the left temporoparietal activation during phonological task is only reported in one study, we need more evidence to make a conclusion about the abnormality.

In another study by Gross-Glenn, Durara, and Barker (1991), subjects were asked to read aloud words presented one at a time. Group difference was found in prefrontal cortex (more rightward asymmetry in control group) and lingual lobule (more activation and rightward asymmetry in dyslexic group, and leftward asymmetry in control group). The right prefrontal cortex play an important role in directing sustained focal attention, and rightward asymmetry was found in another PET scan study involving visual discrimination task (Kushner, et al, 1988, cited in Gross-Glenn, et al., 1991). The lack of group difference in language regions may have stemmed from the nature of the task. The authors reported that the subjects engaged in the reading activities for only about 25% of the experimental session, and the task is quite easy for normals. The brain activities presented in the study, therefore, may not reflect actual reading process.

The various group differences found in word level tasks were not found in the syntax task (Rumsey, et al., 1994a). Although their dyslexic group showed reduced blood flow in the left parietal region during the rest period, syntax task (judging whether the paired sentences have the same meaning) did not yield different activation patterns across groups. This result suggests that the deficits in dyslexia are limited to very specific aspect of reading (e. g., phonological decoding), but no difference from normals in linguistic ability in general.

Non-verbal Tasks

Dyslexic group shows different activation patterns to non-verbal tasks. As mentioned in the previous section, more activation was observed in the left anterior temporal region in dyslexic group for auditory attention task (Rumsey, et al., 1992). Rumsey, et al. (1994b) also presented the data that showed dyslexic group had less activation in the right middle temporal and the right frontal regions during an auditory memory task.

The activation pattern in the control group is consistent with a previous study (Mazziotta, 1982 ; cited in Rumsey, et al., 1994b). These right frontal, temporal activation is assumed to be associated with non-verbal temporal (e. g., serial) processing. The lack of activation in the right hemisphere in dyslexic group suggests that the functional deficit in dyslexia is not limited to linguistic, or left hemisphere dysfunction, but they have more general, bilateral dysfunction. This hypothesis is contradictory to the specificity of the deficit in dyslexia.

Summary of the Functional Imaging Studies

Most of the studies summarized here provided some differences between normal and dyslexic groups. However, the areas in which group difference was found varied across studies. Task difference is a reason for the variability, and it is reasonable to expect different regions to be activated to a different task. These results suggest that the functional abnormality is not limited to a specific region in dyslexia, but spread out all over the cortex. This is not consistent with the fact that dyslexic individuals have deficits only in reading.

One explanation of this inconsistency is that reading is a highly complex cognitive activity and not localized in a single structure of the brain. If we assume the dyslexia is a manifestation of the deficits in the connectivity of neural network, the variability in the findings are reasonable. Deficits in any parts of the network can yield dyslexia. This model also can explain the inconsistent results in morphological studies. Abnormal asymmetry pattern or size of structures may stem from abnormal neural network. This causal relationship can be opposite direction, that is, a lesion in a specific structure caused abnormal neural connectivity. Still another possibility is a third factor produced both abnormal structures and neural networks. There is no way to test this causality. At this point we can only conclude that the patterns of the abnormalities vary across individuals with dyslexia.

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Table 1 MRI Results of Hemispheric Asymmetry

	Technique	Linguistic measure	Section to be analyzed	Measured area of hemispher	Hemispheric asymmetry
Durara, et al. 1991	MRI (1.0 or 1.5 T Super Conducting Whole-body Scanner, Siemens Magnetron)	Severety score for dyslexics: Average score of the difference on standardized scores of IQ and three reading measures	Horisontal section parallel to the inferior orbitomeatal plane at the level of the foramen of Monro	Lines perpendicular to the midline of the transverse section devide the section into 6 areas. The lines were drawn at 20% and 40% from the midpoint of the midline.	Middle part of posterior half: dyslexia L < R, normal L = R The right side of the most posterior 10% correlates positively with severelity score (r = .58) in dyslexics
Hynd et al. 1990	MRI (0.6-T Technicare Scanner, Health Images)	--	Axial slice transversing PT	ROI measurements for the width and area of the left and right anterior and posterior regions	Anterior region: Dyslexics L = R, Normals L < R, Right Anterior region: Dyslxics < Normals.

Note. The abbrebiations used in Tables 1 to 4 stand for following terms:
ADD: Attention Deficit Disorder without Hyper activity, ADHD: Attention Deficit Disorder with Hyper activity, AEP: Auditory Evoked Potential, AHQ: Annett Handedness Questionnaire, BAS-WRT: British Ability Scale Word Reading Test, CC: Corpus Callosum, CNV: COntingent Negative Variation, CPT: Continuous Performance Task, DSM-III-R: Diagnostic and Statistical Manual of Mental Disorders, Revised Third Edition , EHI: Edinburgh Handedness Inventory, ERP: Event Related Potential, FSIQ: Full Scale IQ, GFW-RS: Goldman-Fristoe-Woodcock Reading of Symbols (non-words) (mean=50, SD=10), GORT: Gray Oral Reading Tes LAC: Lindamood Auditory Conceptualization Test, MGN: Medial Geniculate Necleus, MR: Mental Retardation, MRI: Magnetic Resonace Imaging, NPRE: Nonsen Passage Reading Error, NPRT: Nonsense Passage Reading Time, NR: Not Reported, OHI: Oldfield Handedness Inventory, PINV: Post Imperative Negative Variatio PIQ: Performance IQ, PNES: Physical and Neurological Examination for Subtle signs, PT: Planum Temporale, RD: reading dificulties, reading disabilities, ROI: Region of Interest, VEP: Visual Evoked Potential, VIQ: Verbal IQ, WAIS: Wechsler Adult Intelligence Scale, WISC: Wechsler Intelligence Scale for Children, WJI Woodcock-Johnson Letter-Word Identification, WJP: Woodcock-Johnson Passage Comprehension, WJR: Woodcock-Johnson Reading Cluster, WJW: Woodcock-Johnson Word Attack, WRAT-M: Wide Range Achievement Test Revised, Math, WRAT-R: Wide Range Achievement Test Revised, Reading, WRAT-S: Wide Rar Achievement Test Revised, Spelling, WRAT: Wide Range Achievement Test, WRMT-PC: Woodcook Reading Mastery Test-Revised, Passage Comprehension, WRMT-T: Woodcook Reading Mastery Test-Revised, T, WRMT-WA: Woodcook Reading Mastery Test-Revised, Word Attack

Table 2 MRI Results of Planum Temporale

	Technique	Linguistic measure	Section to be analyzed	Definition and measurement of PT	Dylexics	Normals
Hynd et al. 1990	MRI (0.6-T Technicare Scanner, Health Images)	--	PT: Extreme lateral 7.5 mm sagittal slices; Other measures: Axial slice transversing PT	NR	L > R: 1, L ≤ R: 9	L > R: 7, L ≤ R: 3 Left PT: Dyslexics < Normals, Right PT: Dyslexics = Normals
Larsen et al. 1992	MRI (1.5 T Superconducting Magnet, Gyroscan Philips)	Use non-word reading to classify dylexics into phonological and orthographic dysfunction	10mm thick midsagittal section		R=L: 13, L>R: 6	R=L: 5, L>R: 12
Larsen, et al. 1990	MRI (1.5 T Supreconducting Magnet, Gyroscan Philips)	Phonological decoding (non-word reading), orthographic decoding (brief exposure of a word)	3 mm thick T1 weighted coronal slices	Anterior border: ridge of Heschl's gyrus; Posterior boader: most caudal slice showing the Sylvian fissure; Lateral margin and length: outer boader of the fissure. Size of the reconstructed area and the length of the outer boader of the PT	L > R: 6, L = R: 13 Twelve of 13 dyslexics who showed symmetry PT had phonological deficit.	L > R: 12, L = R: 5 Two of 3 normal subjects who showed phonological deficiency had symmetrical PT
Leonard et al. 1993	MRI (Seimens 1 T Magnetom, Seimens)		1 to 1.17 mm thick 3-D Flash Sagittal sequences (13 subjects); 6-minutes Turbo-flash sequence (the others)	Anterior border: the most anterior Hescl's sulcus; Posterior termination of the temporal bank of PT: bifurcation into a posterior ascending and descending ramus. Interhemispheric and intra-hemispheric coefficient of asymmetry were calculated	PT-T: L > R, PT-P: L < R; More anomalies (multiple Heschl's gyri) found	PT-T: L > R, PT-P: L < R
Schultz, et al. 1994	MRI (1.5 T General Electric Signa imager)		5 mm coronal slices in an obliquity that was perpendicular to the hippocampus	Anterior: The rostral-most slice not including the insula of Reil; Posterior: The termination of the ascending branch of the sylvian fissure	L > R: 76%	L > R: 71%

Table 3 MRI Results of Temporal Lobe and Insular Region

	Technique	Linguistic measure	Area Measured	Result
Hynd et al. 1990	MRI (0.6-T Technicare Scanner, Health Images)	--	Length of the insular region	Insular region (both L & R): Dyslexics < Normals
Kushch, et al. 1993	MRI (Superconducting Whole-body Scanner , Siemens Magnetron)		Entire horizontal superior surface of the temporal lobe. The area was divided into anterior and posterior region and laterality indices were calculated for anterior, posterior, and total surface areas.	Normals: L > R, Dyslexics: L = R Laterality Index: Normal showed greater leftward asymmetry on the posterior half than dislexics, but no difference on the anterior half. Significant positive correlation (r=.69) between laterality (leftward) and WJP in dyslexics.
Schultz, et al. 1994	MRI (1.5 T General Electric Signa imager)		(a) Temporal lobe (posterior boader: the last slice in which the ascending ramus is visible; anterior boader: the last slice which contains the uncinate fasciculus) surface, (b) volume, (c) temporal lobe volume	When age influence was controled, no measure showed group difference at p < .05 level.

Table 4 MRI Results of Corpus Callosum

	Technique	Linguistic measure	Section to be analyzed	Measured area of CC	CC Result
Durara, et al. 1991	MRI (1.0 or 1.5 T super conducting whole-body scanner, Siemens Magnetron)	Severety score for dyslexics: Average score of the differences on standardized scores of IQ and three reading measures	7.5 mm thick T1-weighted midsagittal section	CC was divided into fifths along a line joining the most anterior and posterior points. The areas of total area, anterior fifth (genu), and posterior fifth (splenium) were expressed as a percentage of the midsagittal brain area.	Total CC: female dyslexics > male dyslexics, normal female Genu: female dyslexics > male dyslexics Splenium: female dyslexics > male dyslexics, normal female, normal male. Correlations between severelity score and CC areas are not significant.
Hynd et al. 1995	MRI (0.6-T scanner, Health Images)	--	7.5 mm midsagittal section that best visualized the CC	Areas of CC that was divided into five areas by radial lines. Genu: most anterior 20% Splenium: most posterior 20%	Genu: Dyslexics < Normals, Other areas: Dyslexics = Normals; Significant correlation between reading score and areas of genu (r =.398) and splenium (r =.354).
Njiokiktjien, et al. 1993	MRI		7.5 mm midsagittal section,	Relative CC surface area expressed in percentage of midsagittal cortical surface area	No difference among three LD groups; statistical information about difference between LD groups and control was not reported; (A) compared with control group: undersized CC in 11% and larger CC in 16%; children with familial dysphasia had a larger CC
Larsen et al. 1992	MRI (1.5 T superconducting magnet (Gyroscan Philips)	Use non-word reading to classify dylexics into phonological and orthographic dysfunction	10 mm thick midsagittal section	Total Area. Percentage of the area of splenium that is defined as the area within the posterior 20% of the maximal anterior-posterior length of the CC	Normals = Dyslexics

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