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Short communication

Atypical temporal activation pattern and central-right brain compensation during semantic judgment task in children with early left brain damage

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ABSTRACT

In this study we investigated the event-related potentials (ERPs) during the semantic judgment task (deciding if the two Chinese characters were semantically related or unrelated) to identify the timing of neural activation in children with early left brain damage (ELBD). The results demonstrated that compared with the controls, children with ELBD had (1) competitive accuracy and reaction time in the semantic judgment task, (2) weak operation of the N400, (3) stronger, earlier and later compensational positivities (referred to the enhanced P200, P250, and P600 amplitudes) in the central and right region of the brain to successfully engage in semantic judgment. Our preliminary findings indicate that temporally postlesional reorganization is in accordance with the proposed right-hemispheric organization of speech after early left-sided brain lesion. During semantic processing, the orthography has a greater effect on the children with ELBD, and a later semantic reanalysis (P600) is required due to the less efficient N400 at the former stage for semantic integration.

1. Introduction

Some research studies have provided convergent evidence of good compensation of language development following early brain injury (Liégeois et al., 2004; Staudt, 2007). According to the "Kennard Principle", the developing human brain possesses greater potential for functional compensation than a mature brain (Kolb & Whishaw, 1989). In a brain imaging study using fMRI, Staudt et al. (2002) provided neural evidence of right-hemispheric organization of language. They used the silent word generation task, which started with a letter of the first word given by the examiner. The participants (five young adults with congenital right hemipareses due to unilateral left periventricular brain lesions) were asked to continue chaining words silently according to the rule that the following word should start with the last letter of the previous word (example: dog–garden–neighbor–road). The fMRI topography showed that in the word chaining task, homotopic areas in the contralesional hemisphere of the subjects with left-hemispheric brain lesions were activated. Furthermore, the voxel-wise comparison exhibited insignificant group difference. Liégeois et al. (2004) used fMRI to test language lateralization during the covert verb generation task in ten children and adolescents who had suffered from early left hemisphere lesion. Consistent with Staudt et al. (2002) report, they also found fMRI activation in the region homologous to Broca's area in the right hemisphere among these subjects. The relocating phenomenon of right hemisphere activation may explain the spared language functions after left-side brain lesion. Furthermore, the success should depend on the timing and the severity of impairment (Rasmussen & Milner, 1977).

Neuroimaging techniques revealed that the language zones of patients with early left brain damage (ELBD) were developing in the contra-lesional hemisphere, particularly in areas homotopic to the original language zones in the left hemisphere of healthy subjects (Liégeois et al., 2004; Staudt et al., 2002). Children who suffered from left periventricular lesions (Staudt et al., 2002), left hemispherectomy (Liégeois, Connelly, Baldeweg, & Vargha-Khadem, 2008; Mariotti, Iuvone, Torrioli, & Silveri, 1998; Molinaro, Duñabeitia, Marìn-Gutièrrez, & Carreiras, 2010), or extensive left-hemispheric brain damage (Muter, Taylor, & Vargha-Khadem, 1997) often recovered their language functions to the same degree as their age-matched peers. Even though the deficit occurred, the brain develops multiple neural pathways to overcome the situation. Moreover, the phenomenon of postlesional reorganization is found not only in the language system but also in motor and somatosensory systems (Staudt, 2010). From Müller et al.

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(1998) study using PET to examine the domain-specific differences in reorganization from nine subjects with unilateral left hemisphere lesions, the greater potential for homotopic interhemisphric reorganization was suggested predominantly in the language than in the motor domain. Although the evidence of topographical reorganization has been reported, no study has used the event-related potential (ERP) method to investigate the language functions in children with early brain damage. Previous studies have suggested ERP as a powerful tool that can reveal semantic processing with high temporal resolution. With an interest in the relationships between cerebral plasticity and behavioral development, we tested the ERP waveform elicited by a semantic judgment task in children with early left brain damage (ELBD) and normal developed children. The primary purpose of this study was to investigate the cortical mechanism for semantic process in children with ELBD. More specifically, we looked at whether or not the temporal brain dynamics were reorganized among this special population.

2. Results

2.1. Clinical examinations and behavioral results

By the Modified Ashworth Scale (MAS), the children with ELBD (n = 4) exhibited significant spasticity in the hemiparetic limb (scores minimal 0.63 at fingers and maximal 2.25 at elbow joint, all p values < .05). However, children with ELBD and the control group showed equal performance for motor control and strength, and sensory status of their dominant hand (right hand for the control and left hand for the ELBD group). The sensorimotor efficiency from differential dominant hand between ELBD and control groups was therefore excluded. For more detail about the individual performance of motor control and strength, and sensory status, please see Table 1. As for the cognitive function, the ELBD and control group demonstrated the percentile of 42 ± 25.12 and 48.5 ± 28.07 for the Test of Nonverbal Intelligence ($Z = -0.60$, $p = .55$) (Wu, 2000), and the percentile of 64 ± 26.08 and 59.88 ± 29.24 for the Grade Chinese character reading test ($Z \fallingdotseq 0.00$, $p \fallingdotseq 1.00$) (Huang, 2001), respectively. Generally, in addition to the spasticity, we considered sufficient cognition and dominant hand function in completing the semantic judgment task from all the recruited children.

High percentile accuracy of 97.08 ± 3.70 for ELBD, 96.67 ± 3.88 for controls in the Semantic Related (SR) condition ($Z = -0.17$, $p = .86$), and 98.75 ± 1.60 for ELBD, 97.5 ± 4.18 for controls in the Semantic Unrelated (SU) condition ($Z = -0.09$, $p = .92$) were found. Similar reaction times were also reported in both groups (1043.40 ± 163.02 ms for ELBD, 1144.45 ± 330.56 ms for controls in the SR condition, $Z = 0$, $p = 1$; 1090.83 ± 200.98 ms for ELBD, 1142.72 ± 525.03 ms for controls in the SU condition, $Z = -0.17$, $p = .87$). No significant group or condition differences were found for the accuracy and reaction time.

2.2. ERP results

Fig. 1 showed the grand average waveforms for the ELBD and the control group in the SR (Fig. 1A) and the SU (Fig. 1B) conditions. After ERP analysis, seven visible components were screened, including P1 (from 100 to 140 ms) and N170 (from 150 to 250 ms) at the parietal-occipital region, N1 (from 80 to 150 ms), P200 (from 170 to 230 ms), P250 (from 230 to 320 ms), and N400 (from 300 to 450 ms) and late positivity P600 (from 450 to 700 ms) with a broad scalp distribution. First of all, none of the electrodes showed any group difference at the P1, N170, and N1 components (all $p > .05$). Subsequently in the SR condition, enhanced positivity P200 at C4 electrode ($Z = -2.038$, $p = .048$) as well as P250 at PZ and OZ electrodes ($Z = -2.038$, $p = .048$ at both electrodes) were observed in the ELBD group, whereas the control group showed larger negative N400 amplitude at central CZ electrode ($Z = -2.208$, $p = .028$). While in the SU condition, stronger P600 neural activity was found in the ELBD group at P4 electrode ($Z = -2.208$, $p = .028$) (Fig. 1). None of the rest of the electrodes for each component of interest in each condition demonstrated any significant group differences. The mean amplitudes of each electrode of the ERP components that reached group significance in each condition were illustrated in Table 2. Meanwhile, because of the small sample size, we displayed the scatter-plots of those electrodes showed significant group differences to provide an overview of our data distribution. The presentation was also more in line with the idea of using the nonparametric Mann-Whitney U test (Fig. 2).

3. Discussion

This study investigates the language function of semantic process in children with ELBD by using the ERP method to reveal the temporal brain dynamics. We suggest that despite comparable behavioral performances (indexed by accuracy and reaction time), distinctive time serial neural activities of enhanced P2, P250, and P600 was found in ELBD compared to the controls during semantic process. Another contribution of the present study is that we further confirm the functions of

Table 1
Individual performance of the clinical examinations for motor control and strength, and sensory.

Case ID	Age (years)	Handedness quotient (0–100)	Motor control and strength			Sensory		
			Fine motor (number)	Voluntary movement (number)	Grip power (lb)	Proprioception-shoulder	Proprioception-elbow	Touch/pressure (cm)
ELBD group								
1	15.00	Left(10)	12:3	13:8	9.73: 2.00	4.5: 4.0	2.5: 5.5	2.83: 3.06
2	12.67	Left(0)	12:6	13:6	4.29: 1.17	1.5: 3.5	2.0: 2.5	2.91: 2.91
3	11.25	Left(0)	12:0	13:5	6.20: 0.17	4.0: 9.5	5.5: 9.0	2.83: 2.99
4	11.16	Left(0)	12:5	13:6	6.70: 1.80	4.5: 3.0	2.0: 5.5	2.83: 2.91
Control group								
1	16.17	Right(1 0 0)	12:12	13:13	9.50: 7.83	1.5: 3:0	2.0: 6.5	2.60: 2.67
2	12.75	Right(1 0 0)	12:12	13:13	6.30: 5.30	5.0: 4.5	3.5: 3.5	2.83: 2.83
3	11.67	Right(90)	12:12	13:13	8.17: 6.83	4.5: 6.5	1.5: 2.5	2.83: 2.83
4	12.33	Right(1 0 0)	12:12	13:13	14.0: 10.7	1.5: 3.0	4.0: 2.0	2.83: 2.83
5	12.17	Right(90)	12:12	13:13	7.10: 6.10	4.0: 4.5	3.0: 2.0	2.83: 2.91
6	11.33	Right(1 0 0)	12:12	13:13	8.37: 6.77	3.0: 7.0	2.5: 6.5	3.14: 3.14
7	10.00	Right(1 0 0)	12:12	13:13	5.83: 4.70	2.5: 1.0	4.5: 2.5	2.83: 2.83
8	9.92	Right(85)	12:12	13:13	4.83: 4.70	2.5: 1.5	1.5: 1.5	3.06: 2.91

Notes: Values for Motor control and strength, and Sensory sections are the performances of the preferred hand: the non-preferred hand. The Handedness quotient denotes the laterality quotient of Edinburgh handedness inventory, 100 indexes the right handedness.