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N450 as a candidate neural marker for interference control deficits in children with learning disabilities

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ABSTRACT

A deficit in the ability to suppress irrelevant or interfering stimuli may account for a variety of dysfunctional behaviors in children with learning disabilities (LD). However, neural correlates underlying this deficit in interference control in the LD are still unknown. In this study, we recruited a group of children with LD (age: 10.78 ± 0.52) along with an age-matched control group (age: 10.74 ± 0.86) and asked them to perform a numerical Stroop task. During the task, we used electroencephalogram (EEG) to record their event-related potentials (ERPs). We further evaluated performance of these children on a battery of tests, including the Academic Adaptability Test (AAT), an adapted Chinese version of Pupil Rating Scale (PRS), and Raven's Standard Progressive Matrices (SPM). Children's scores on recent math and Chinese exams were also obtained. Results showed that: 1) children with LD had worse performance in the incongruent condition of the numerical Stroop task suggesting that children with LD had interference control deficits but not basic numerical cognition; 2) children with LD had larger N450 effects on the frontal and posterior sites, but did not show any difference in early ERP components, suggesting that the behavioral difference was related with interference control rather than early visual perception processing; and 3) N450 effects were correlated with accuracy in the numerical Stroop task, performance in Raven's SPM, as well as school math performance. These results suggest that N450 can serve as a potential electrophysiology marker for identifying and potentially, providing targeted intervention for children with LD.

1. Introduction

Interference control is the cognitive process that helps people focus on the current task without being interfered by irrelevant information, which can either be an external stimulus or an internal representation (Burgess and Braver, 2010). Deficit in interference control often leads to compromised working memory capacity (Borella et al., 2010; Maehler and Schuchardt, 2009; van der Sluis et al., 2004), which in turn contributes to learning disabilities (LD) (De Weerdt et al., 2013).

The relation between LD and deficit in interference control has been studied in a large number of studies using Stroop tasks (e.g. Carretti et al., 2009; Franco-de-Lima et al., 2012; Johnson et al., 2010; van Mourik et al., 2005; Wang et al., 2012). In the original Stroop task (Stroop, 1935), subjects are shown names of colors printed in different colors, and required to ignore the word and solely report its color. The task becomes difficult when the color name does not agree with its printed color, because subjects have to inhibit the dominant response of reading the word. Therefore, the task is often used to evaluate one's ability in interference control. Based on this idea, many variants of the original Stroop task have been developed, which generally showed that children with LD had worse performance.

However, one question remains largely unknown, brain mechanisms of the underperformance of children with LD in Stroop tasks. One promising method to investigate the brain mechanism is to look at the scalp recorded event-related brain potentials (ERPs). ERPs are the electrical activities locked to a specific task event or response. They offer a high temporal resolution (in the range of milliseconds) of neural processes underlying behavioral performance (Banaschewski and Brandeis, 2007). This method has been used in prior efforts to understand the brain mechanisms of LD. For example, Robichon, Besson, and Habib (2002) compared the cued-recall performance of adult with dyslexia and that of a control group in a semantic congruity task. They also recorded subjects' ERPs using electroencephalography (EEG)

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during the task, and found that the dyslexic group showed lager N400 in both congruous and incongruous sentence ending conditions, suggesting dyslexic subjects' impaired ability to integrate word meanings in a sentence.

EEG data can also help to understand the electrophysiological mechanisms of performance in a Stroop task. Two electrophysiological markers have been obtained by averaging stimulus-locked segments of EEG data for the conflict trails of a Stroop task. The conflict related negativity (N450), typically occurring at around 400 ms after the onset of a target stimulus, reflects the conflict-monitoring activity of the anterior cingulate cortex (Szucs and Soltesz, 2012; Tillman and Wiens, 2011); the sustained positivity (SP) appears as a sustained parietal positivity beginning approximately 500 ms after stimuli onset, and it is more positive following correct incongruent trials than congruent trails, suggesting its relation to conflict resolution (Larson et al., 2009; Zurron et al., 2009). In brief, the ERP components N450 and SP are reliable indicators for inhibition ability (Markela-Lerenc et al., 2009; McNeely et al., 2008).

In the current study, we attempted to use ERPs to pinpoint the impaired cognitive abilities in the Stroop task and explore potential neural markers of interference control deficit in children with LD. We hypothesize that 1) children with LD will show worse behavioral performance in a numerical Stroop task, and 2) their ERP components (N450 and SP) in the incongruent trials will show different patterns compared to the control group.

2. Methods

2.1. Participants

Twenty-three children (13 boys) with LD and 23 normal children (12 boys) were recruited from a public elementary school in Beijing. They were in 5th (n = 26, age: 10.38 ± 0.57 years) or 6th grade (n = 20, age: 11.25 ± 0.55 years). All children were placed in a standard curriculum offered by the school. Before participation, they were screened for left-handedness, color-blindness, and previous psychiatric and neurological diseases or emotional disorders. All participants had normal vision, hearing, and emotional status. Written informed consents were obtained from parents after the procedures fully explained. The ethical committee of Beijing Normal University approved the study.

In order to screen children with LD, we adopted a combined method based on the aptitude–achievement discrepancy model (Proctor and Prevatt, 2003). The selection procedures for the LD group were as follows. 1) Students took an Academic Adaptability Test (AAT; Zhou, 1991) and their scores were transformed to level scores. Only those who fell below Level II were considered for inclusion. 2) The head teachers of these students filled out an adapted Chinese version of Pupil Rating Scale (PRS) (Myklebust, 1981; Salvesen and Undheim, 1994) in order to characterize the students' academic difficulty. Only the students who received scores less than 65 were considered for inclusion. 3) The scores that these students received on the latest academic exams were transformed into Z scores. Only students whose math and language (Chinese) scores were below the 25th percentile were considered for inclusion. 4) Students also took the Raven's Standard Progressive Matrices (SPM) as a measurement of their IQ (Raven, 2000). Their scores were transformed into standard scores and only those who were above the 50th percentile were included. 5) Only healthy students, who had no problems in vision, hearing, motor skills, emotion, social and cultural adjustment, etc., were included.

All participants in the control group met the following criteria: 1) scored above the 25th percentile in both the most recent language and math exams; 2) showed above-medium performance in AAT; 3) had normal IQ, as measured by SPM; 4) showed academic performance consistent with teachers' rating and had no problems with vision, hearing, motor skills, mental status, or social and cultural adjustment; and 5) matched the age and grade-level of the LD group (Table 1).

2.2. Stimuli and task

Participants performed a numerical Stroop task as used in Soltész et al. (2011a,b). Their EEG was recorded when performing the Stroop task. Task stimuli were single-digit number pairs with one being three larger than the other (1–4, 2–5, 3–6, 4–7, 5–8, and 6–9). The numbers were white in color, presented on a black background. Depending on the condition, the numbers were presented either with a large or a small font size. The large font was 200 points, about 4.8 cm high with a visual angle of 3.93°; the small font was 140 points, about 3.4 cm high with a visual angle of 2.78°. Both sizes were presented with Arial font.

There were three conditions: congruent, incongruent and neutral. In the congruent condition, the larger valued number was presented with the large font. In the incongruent condition, the larger valued number was presented with the small font. In the neutral condition, the two numbers were presented with the same size, with half of the trials using the large font and the other half using the small font.

2.3. Procedure

E-prime software 1.1 (Psychology Software Tools, Inc.) was used to control the whole experimental procedure by presenting stimulus trials, recording response times and coordinating with the EEG recording system. Stimuli were presented in white color against a black background. The experiment took place in a dimly lit room, and the screen was placed 70–100 cm in front of the participant.

Each trial began with a fixation "+" for 200 ms, followed by a blank screen lasting randomly from 800–1200 ms. After the blank screen, subjects saw two numbers on the screen and they were asked to respond to the larger valued number by pressing the corresponding key on a keyboard. They were asked to respond as quickly as possible without sacrificing accuracy. If they did not respond within 5 s, the numbers would disappear and their response would be coded as missing. If subjects gave a correct response, the next trial would began after 1000 ms. If the response was wrong, they next trial began after 2000 ms. Children were not explicitly told about this manipulation.

Trials for the three conditions were mixed together and randomly presented, except that trials for the same condition did not repeat more than three times in a row, and that trials that required the same response key did not repeat more than four consecutive trials. There were a total of 216 trials, with 72 for each condition. Fig. 1 provides a summary of the procedures.

2.4. EEG data recording and analysis

EEG recording was performed with the ESI-64 system (NEUROSCAN) with reference on the left mastoid. All electrodes were placed according to the 10–20 system. The vertical electrooculogram (VEOG) was recorded

Table 1
Descriptive and diagnostic measures of children with learning disabilities and control group (M ± SD).

	IQ		Adaptability		Academic	PRS
	SPM	AAT	Math	Chinese	Verbal	Nonverbal
LDs (n = 23)	37.45 (6.32)	42.30 (8.54)	69.59 (13.81)	72.08 (11.41)	20.91 (4.76)	38.36 (7.71)
Controls (n = 23)	48.13 (4.45)	55.26 (8.16)	94.65 (4.10)	90.54 (3.46)	34.86 (2.61)	54.86 (7.43)