Research in Developmental Disabilities 36 (2015) 142–149

Contents lists available at ScienceDirect

Research in Developmental Disabilities

Digital memory encoding in Chinese dyscalculia: An event-related potential study

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ARTICLE INFO

Article history:
Received 4 August 2014
Accepted 22 September 2014
Available online 22 October 2014

Keywords:
Digital
Dm effect
Dyscalculia

ABSTRACT

This study reports the neurophysiological and behavioral correlates of digital memory encoding features in Chinese individuals with and without dyscalculia. Eighteen children with dyscalculia (ages 11.5–13.5) and 18 matched controls were tested, and their event-related potentials (ERPs) were digitally recorded simultaneously with behavioral measures. The results showed that both groups had a significant Dm effect, and this effect was greater in the control group. In the 300–400-ms, 400–500-ms, and 600–700-ms processing stages, both groups showed significant differences of digital memory encoding in the frontal, central, and parietal regions. In the 500–600-ms period, the Dm effect in the control group was significantly greater than that in the dyscalculia group only in the parietal region. These results suggest that individuals with dyscalculia exhibit impaired digital memory encoding and deficits in psychological resource allocation.

1. Introduction

Developmental dyscalculia is a specific learning disability that affects arithmetic skill acquisition despite normal intelligence, in the absence of neurological injuries. Epidemiological studies have shown that dyscalculia affects 3.5%–6.5% of school-age children (Mejias, Grégoire, & Noël, 2012; von Aster & Shalev, 2007) and often persists into adolescence. Despite the high prevalence rates of developmental dyscalculia, our current knowledge about the neurocognitive and developmental characteristics of this learning disability remains limited. Moreover, most major theories about numerical cognition are derived from adult studies and consequently, many developmental studies are based on adult calculation models that may not be applicable to the developing brain.

Higher cognitive activities, such as learning, memory, thinking, and problem solving, require a temporary storage mechanism, and individual differences in storage capacity are thought to directly affect academic performance. Numerous studies have reported that subjects with dyscalculia, who have difficulty understanding and manipulating numbers, have deficits in memory, attention, and processing speed, and several models have been proposed to explain this phenomenon. The four main theoretical hypotheses are: the special processing theory, the theory of general processing, voice storage capacity assumptions, and the general assumption that these different conditions related to memory deficits are calculation disorders. Currently, calculation-impaired memory deficit studies focus on aspects of working memory and short-term memory (Maehler & Schuchardt, 2009; Swanson, Kehler, & Jerman, 2010; Wang, Zhao, Liu, Lv, & Shen, 2008).

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http://dx.doi.org/10.1016/j.ridd.2014.09.020
0891-4222/

Swanson and Sachse-Lee (2001) investigated verbal working memory, visual–spatial working memory, and phonological processing disorder issues affecting the calculation of application problems and found that verbal working memory, visual–spatial working memory, and problem solving ability were important for working memory tasks related to knowledge extraction and long-term memory storage. Wang et al. (2008) reported various types of learning and short-term memory deficits in children with working memory deficits. Their results suggested that working memory and problem-solving accuracy are important for extracting knowledge from long-term memory. Dyscalculia defects exist in two forms; the first is characterized by difficulty extracting arithmetic knowledge from long-term memory, but the underlying neural mechanisms are poorly understood. The second type of extracting defect occurs when the memory retrieval process is affected by interference. Geary (2004) found that when children see the topics presented, the topic activates relevant information in working memory and inhibits irrelevant information from entering the working memory. Subjects with dyscalculia cannot inhibit the activation of irrelevant information, which reduces the working memory capacity, leading to problem-solving errors. Thus, deficits in memory impairment calculation seem to be due to defective extraction abilities. However, memory can be divided into three separate, but interacting processes: coding, storage, and retrieval. Coding refers to the initial information processing and produces a memory trace. Extraction refers to the repeated activation of previously coded information. Numerous studies have reported that encoding and extraction rely on different neural mechanisms, supporting the hypothesis that they are two separate phenomena (Duarte, Ranganath, Winward, Hayward, & Knight, 2004; Elger et al., 1997; Greenham & Stelmack, 2003; Guo, Voss, & Paller, 2005; Kujala & Naatanen, 2001; Mangina, 2004). To date, it is unclear whether calculating disability coding defects exist in the early stages of processing.

Event-related potentials (ERPs) can be measured to provide information about the neural mechanisms of memory-encoding methods in different stages of processing, and these measurements can be compared to subsequent memory test scores. Sanquist, Rohrbaugh, Syndulko, and Lindsley (1980) found that the recognition of words that had been previously presented was associated with a greater late positive component (LPC), and they termed this difference the called memory effect. Paller, Kutas, and Mayes (1987) and Paller, McCarthy, and Wood (1988) reported similar results, and they termed this phenomenon the Dm effect or "memory difference." Wang et al. (2011) used Chinese characters to explore how children with dyslexia encode and retrieve memory; they found that these children exhibited insufficient encoding and retrieval phases. In summary, although the memory characteristics of children with learning disabilities have been researched, the different types of learning disabilities and their cognitive processing characteristics remain to be elucidated.

In this study, we employed an ERP paradigm to investigate the memory encoding Dm effect and the neural mechanisms of dyscalculia in children. It is expected that if the memory deficits of dyscalculia only affect the late-stage retrieval phase, then the dyscalculia and control groups should exhibit similar Dm effects. If dyscalculia memory defects affect the early coding stage of processing, then there should be differences in the Dm effect between the two groups. Our results clarify the neural mechanisms of learning difficulties in children and provide a basis for future Dm effect research with various materials and different groups of subjects.

2. Methods

2.1. Participants

A total of 40 preadolescents who were screened from several primary schools in Kaifeng, China were tested; 20 were normal controls, and 20 had dyslexia. The age range of all preadolescent participants was 11.5–13.5 years (mean age 12.5). According to the International Classification of Diseases (ICD-10, 2009), none of the participants had a history of neurological, emotional, or psychiatric disorders or were medicated for attention deficit hyperactivity disorder (ADHD). All the participants were right-handed and had normal hearing and normal or corrected-to-normal vision. All participants were determined to have normal intelligence, with an overall intelligent quotient (IQ) score of 85 or above, and had received sufficient learning opportunities, but had math scores lower than 51% of those of their fellow students in the same grade. The parents of all participants provided their informed consent, thus permitting their children to participate in the experiment. The children were accompanied by their parents to the ERP laboratory. After the experiment, participants were paid for their participation (Table 2).

2.2. Materials

Each group of digits for learning comprised 40 Arabic numerals of similar length and four target numbers (e.g., five, two), and each recognition group included 80 numbers of similar length, including 40 new and 40 old digits.

2.3. Procedures

The experiment employed the "learning–recognition" research paradigm (Wang et al., 2011), and the experimental sequence included three stages.

(1) Learning stage: central numbers were presented for the participants to study, and during the test task, participants were asked to use a key pad to provide a response when they saw a capital number (such as four). The thumb was used to press