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Developmental dyscalculia and low numeracy in Chinese children

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ABSTRACT

Children struggle with mathematics for different reasons. Developmental dyscalculia and low numeracy – two kinds of mathematical difficulties – may have their roots, respectively, in poor understanding of exact non-symbolic numerosities and of symbolic numerals. This study was the first to explore whether Chinese children, despite cultural and linguistic factors supporting their mathematical learning, also showed such mathematical difficulties and whether such difficulties have measurable impact on children's early school mathematical performance. First-graders, classified as dyscalculia, low numeracy, or normal achievement, were compared for their performance in various school mathematical tasks requiring a grasp of non-symbolic numerosities (i.e., non-symbolic tasks) or an understanding of symbolic numerals (i.e., symbolic tasks). Children with dyscalculia showed poorer performance than their peers in non-symbolic tasks but not symbolic ones, whereas those with low numeracy showed poorer performance in symbolic tasks but not non-symbolic ones. As hypothesized, these findings suggested that dyscalculia and low numeracy were distinct deficits and caused by deficits in non-symbolic and symbolic processing, respectively. These findings went beyond prior research that only documented generally low mathematical achievements for these two groups of children. Moreover, these deficits appeared to be persistent and could not be remedied simply through day-to-day school mathematical learning. The present findings highlighted the importance of tailoring early learning support for children with these distinct deficits, and pointed to future directions for the screening of such mathematical difficulties among Chinese children.

1. Introduction

Mathematics literacy is important for survival in modern society. Everyday tasks such as paying bills or budgeting for daily expenses all have to do with numbers. Most children first learn numeracy at preschool, but some already fall behind their peers in mathematics by first grade. Previous studies (Butterworth, 2005a; Shalev, 2007) have estimated that 6–7% of children suffer from developmental dyscalculia (DD), a learning difficulty in mathematics characterized by problems in acquiring and remembering arithmetical facts (Geary & Hoard, 2001; Jordan, Hanich, & Kaplan, 2003; Shalev & Gross-Tsur, 2001) as well as executing calculation procedures (Geary, 1993).

One account for developmental dyscalculia focuses on a specific deficit in basic numerical processing (Landerl, Bevan, & Butterworth, 2004). According to this account, namely the number module theory (Butterworth, 1999, 2005a), children are

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born with a specific core numerical capacity for representing and processing numerical information, which is governed by specialized neural network dissociable from non-numerical capacities such as language (Cohen, Dehaene, Cochon, Lehericy, & Naccache, 2000) and working memory (Butterworth, Cipolotti, & Warrington, 1996). With such innate numerical capacity, even infants can discriminate small numerosities (Starkey & Cooper, 1980; Starkey, Spelke, & Gelman, 1990; Wynn, 1992, 1995). This capacity is derived from a "number module" constructing concepts of exact numerosities of sets, which lays the foundation for arithmetic development (e.g., Butterworth & Reigosa-Crespo, 2007; Butterworth, 2005b). A deficit in this core numerical capacity underlies developmental dyscalculia, according to the "defective number module hypothesis" (Butterworth, 2005a).

Due to an inability to represent exact numerosities, children with developmental dyscalculia tend to be slow and inefficient in even very basic numerical tasks, such as recognizing and comparing the numerosities of object sets (Butterworth, 2005a; Iuculano, Tang, Hall, & Butterworth, 2008; Landerl et al., 2004). Yet, they can still perform well in non-numerical academic subjects and have normal or even superior intelligence (Butterworth, 2005a; Landerl et al., 2004). *Dyscalculia Screener* (Butterworth, 2003) is a standardized software with an English norm for screening dyscalculic children. Children who are classified as dyscalculic should perform substantially below average in at least one of the two tasks tapping basic numerical processing, namely recognizing the numerosities of displays of dots (i.e., dot enumeration task) and comparing the numerosities of numbers (i.e., number comparison task).

However, not all of the children who struggle with mathematics are dyscalculic. Some of them have intact concept of exact numerosities, but poor understanding of symbolic numerals. These children are hypothesized to have low numeracy, a mathematical difficulty caused by problem in relating symbols to the concept of numerosities (Iuculano et al., 2008). Unlike dyscalculic children, they perform at normal level in non-symbolic tasks such as comparing the numerosities of objects (Rousselle & Noël, 2007). Yet, they fail when the tasks involve numerical symbols (i.e., symbolic tasks), such as adding numerals (Rousselle & Noël, 2007). On the *Dyscalculia Screener* (Butterworth, 2003), children with low numeracy should perform within normal range on the two tasks tapping basic numerical processing, but show significantly impaired performance in the (symbolic) addition task (Iuculano et al., 2008).

While prior research has only documented generally poor mathematical performance for children with dyscalculia or low numeracy, it remains unclear if, and how, these two supposedly distinct deficits may impact on children's mathematical learning and achievement differently. In this study, we examined how the underlying deficits in developmental dyscalculia and low numeracy would differentially affect children's performance in various numerical tasks during their early formal mathematical learning in the elementary school. Our findings can enhance teachers' and parents' awareness and understanding of these children's difficulties in acquiring school mathematics, thereby facilitating early screening for appropriate learning support. The tasks adopted in this study were designed to assess various targeted numerical skills in the first grade (Hong Kong Curriculum Development Council, 2000), such as reciting count names, place-value concept, and simple addition. These tasks were further categorized as symbolic, involving numerical symbols, or non-symbolic, involving pictorial objects instead of numerals. If developmental dyscalculia is indeed caused by a deficit in processing exact non-symbolic numerosities whereas low numeracy is caused by a deficit in symbolic numerical processing, children with dyscalculia should show impaired performance in non-symbolic tasks but not symbolic ones, while children with low numeracy should have impaired performance in symbolic tasks but not non-symbolic ones. To see whether the underlying deficits persist over time or can be compensated by day-to-day school learning, we traced the children's numerical performance across the two semesters in the first grade.

This study is also the first to explore developmental dyscalculia and low numeracy among Chinese children. To date, the findings and theories on mathematical difficulties are primarily based on studies with Western children. Fundamental questions remain open. First, how robust are these findings and theories across cultures and languages? Consider Chinese children as a case in point: academic achievements in general, and mathematical skills in particular, are highly valued in the Chinese culture. Children are taught to count and add and subtract with the Arabic number system from an early age, with massive practices integrated in daily routines and play (Huntsinger, Jose, Liaw, & Ching, 1997; Zhou et al., 2006). Indeed, informal numerical abilities are more developed in 4- to 5-year-old Chinese as well as other East Asian (Japanese and Korean) children than their counterparts in the U.S. (Starkey & Klein, 2008).

Moreover, the number naming system in Chinese is highly regular and transparent (e.g., the count name for "11" in Chinese literally means "ten-one," unlike *eleven* in English). In terms of information processing, all single-digit numbers in Chinese are labeled with single syllables with simple phonological structure (i.e., consonant-vowel or consonant-vowel-consonant), whereas the name for "7" in English has two syllables, and the names for "3" and "6" in English have tricky consonant clusters (i.e., the amalgam of the "th" and "r" sounds in *three* and the amalgam of "k" and "s" sounds for *six*.) Indeed, Chinese preschool children's counting abilities are much more precocious than those of their English-speaking counterparts (Miller & Stigler, 1987; Miller, Smith, Zhu, & Zhang, 1995). Such cultural difference occurs even at age 3 and increases during childhood (Miller, Kelly, & Zhou, 2005). With cultural emphasis and a user-friendly number naming system on their side, are dyscalculia and low numeracy problems for Chinese children? If yes, how might such difficulties be manifested in their mathematical learning and tasks performance?

There is a growing concern over how theories and research findings from Western cultures can be applied to Chinese children in order to understand and accommodate their difficulties in mathematical learning. Our findings would bridge the gap between East and West in the study of dyscalculia and low numeracy, and provide implications for the direction of future investigation into mathematical difficulties among Chinese children.