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Cognitive precursors of word reading versus arithmetic competencies in young Chinese children

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ABSTRACT

Word reading and arithmetic calculation are foundational to higher level reading (e.g., text comprehension) and mathematics (e.g., fraction), respectively. The present study aims to examine the similarities and differences in the cognitive precursors of word reading and arithmetic competencies in young Chinese children. A total of 75 Hong Kong Chinese children were tested first in the fall (T1) and then in the spring (T2) of their third kindergarten years. Competencies in Chinese word reading, including both single- and double-character word reading, and arithmetic calculation, including nonsymbolic arithmetic, arithmetic word problems, and written arithmetic, were assessed at both T1 and T2. Phonological awareness, orthographic awareness, rapid automatized naming (RAN), spatial perception, and spatial visualization were assessed at T1. The results showed that phonological awareness predicted later competencies in word reading and symbolic arithmetic, specifically arithmetic word problems and written arithmetic. RAN was predictive of later competencies in word reading and nonsymbolic arithmetic. Orthographic awareness was associated with later competencies in word reading but not arithmetic. Visual-spatial skills predicted later competencies in arithmetic word problems but not word reading. The findings suggest that similarities and differences both exist in the cognitive underpinnings of Chinese word reading and arithmetic competencies at a young age.

Young children acquire a substantial amount of reading and mathematical competencies during their early years. Because these competencies are strongly predictive of later academic achievement (Duncan et al., 2007; for a study of Chinese children, see Wong et al., 2012), it is crucial to identify factors associated with early reading and mathematical competencies. Over the past decades, a sizeable body of research has been accumulated on the cognitive precursors of reading competence. Much fewer studies have examined the cognitive factors that underlie mathematical competence. This condition is especially true in the context of Chinese societies: the knowledge obtained on the sources of Chinese children's individual differences in learning mathematics (e.g., Geary, Fan, & Bow-Thomas, 1992; Ho & Fuson, 1998) has been much less than that in learning to read (e.g., McBride, 2016).

The nature and learning of mathematics differ from those of reading. Yet empirical evidence suggests that there is a modest connection between reading and mathematics skills (e.g., Davis et al., 2014) and that the co-occurrence of reading and mathematics learning difficulties is common (e.g., Mazzocco & Grimm, 2013). It is likely that some cognitive processes are different between reading and mathematics, whereas others are shared. However, the knowledge about whether cognitive precursors of reading versus mathematical competencies are more alike or different is considerably limited. Recent research has shown that comorbidity of reading and mathematics learning difficulties is related to more severe impairment in both academic and social functioning than difficulty in one domain (e.g., Willcutt et al., 2013). To facilitate identification of and interventions for children with comorbid learning difficulties versus those with difficulty in one domain, it is essential to identify which cognitive precursors are associated with competencies across both domains and which are unique to each domain. In the present study, we examined the similarities and differences in the cognitive precursors of Chinese word reading and arithmetic competencies in a longitudinal sample of young Hong Kong Chinese children. We focused on word reading and arithmetic (addition and subtraction), because they are foundational to higher level reading (e.g., text comprehension; Snow, 2002) and mathematics (e.g., fraction; Vukovic, Fuchs, Geary, Jordan, Gersten, & Siegler, 2014), respectively.

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1. Word reading and arithmetic: forms and development in the early years

Reading development depends upon the language, the script, and the literacy environment. Ehri and McCormick (1998) distinguished five phases that describe how children develop their word reading ability in alphabetic languages. In the first phase, called the *logographic* or *pre-alphabetic* stage, children recognize words by attending to contextual clues or particular visual features of the word itself. As children gain an understanding of the sound-symbol correspondence that defines an alphabetic language, they enter the second phase, referred to as the *cipher* or *partial-alphabetic* stage, in which they read words by using a limited amount of information about the word such as first letters. In the *full-alphabetic* stage, children read words by using a variety of slow, laborious decoding strategies (e.g., analogy). As children begin to utilize common sequences of letters (e.g., *-ed*, *-ing*) in their decoding efforts, they move next into the *consolidated-alphabetic* stage. In the final phase, the *automatic* stage, children can read words rapidly and effortlessly.

In contrast to English in which the unit of a word is clear, there is some ambiguity in defining the unit of a word in Chinese. Generally speaking, Chinese is a morpho-syllabic language in which each character corresponds to one morpheme and one syllable. Chinese words can consist of one or more characters. Although a single character, in most cases, can stand alone to convey meanings, the majority of Chinese words are compound words consisting of two or more characters: over 65% are two-character (e.g., ""汽车" [automobile]), and about 10% are three-character (e.g., ""自行车" [bicycle]; Sun, Sun, Huang, Li, & Xing, 1996). Phases of Chinese word reading development have not been investigated systematically. However, Ho and Bryant (1997) found that Chinese children begin in the logographic stage and then progress to the cipher stage to read characters by using strategies such as analogy and the principle of grapheme–phoneme correspondence. In the kindergarten period from ages 3–6, Chinese children progress gradually from learning single-character words (e.g., ""车"" [vehicle]) to double-character words. Wang and McBride (2016) documented that young Chinese children scored higher on a double-character word reading task (e.g., ""汽车"") than on a single-character one consisting of the same characters (e.g., ""汽"[steam], ""车""), suggesting some difference in young children's learning of single- and double-character words. Part of the reason may be that double-character words, as compared to single-character ones, involve easier access of contextual clues and tap more readily into children's vocabulary knowledge to construct a word with known characters. In Hong Kong, traditional kindergartens typically start to teach children to read Chinese characters in the second semester of their first kindergarten year, when they are approximately 3.5 years old. Most Hong Kong children learn Chinese in the form of traditional script with Cantonese, which is their native language, as the medium of instruction (Hong Kong Education Department, 1996).

Children's development of arithmetic knowledge, studied predominately in Euro-American settings, originates from their early experience with concrete objects (Gelman & Gallistel, 1978; Ginsburg, 1977; Resnick, 1992). For example, when playing with a collection of candies, young children realize that adding two candies to a collection of four makes a collection of six and that taking away two candies makes a collection of two. Later on, they learn about numerical and arithmetic symbols, including verbal (e.g., two) and written (e.g., 2) symbols, and connect them with the objects (e.g., two candies) they represent (Ginsburg, 1977). In other words, to perform the addition or subtraction of two numbers, children must align the verbal or written number symbols with the number of objects in a set, and connect the arithmetic operator to the operation of adding one set to the other or taking away one set. This sequence of development underscores three common forms of arithmetic calculation that represent number in different modes, namely nonsymbolic arithmetic that represents numbers in sets of objects (e.g., the operation of adding two real candies to a collection of four), arithmetic word problems that represent numbers in verbal codes (e.g., "Ivy has four candies. Her sister gives her two more candies. How many candies does Ivy have now?"), and written arithmetic that represents numbers in a visual format (e.g., 4 + 2 = ?). So far little work has examined the developmental progression of arithmetic in Chinese. However, it is widely observed that Chinese children have higher arithmetic competence than their Euro-American peers from an early age (Geary et al., 1992; Ho & Fuson, 1998).

The developmental sequences of Chinese word reading and arithmetic highlight the similarity and difference between the two domains in the learning process. At least one similarity and one difference can be identified. The similarity is that both domains require young children to learn written symbols by connecting them with verbal symbols and/or concrete objects. Eventually children must acquire the ability to perform translations among objects and verbal and written symbols and to achieve a flexible integration among visual, phonological, and semantic representations of words and numerals. On the other hand, one difference between the two domains is that arithmetic calculation requires young children to grasp the ability to perform operations and transformations among objects and symbols, whereas Chinese word reading does not require operations or transformations. Notably, some structural features of English language, such as the change of tense, singular versus plural forms, and transformations from verbs to nouns, may drive children to perform operations and transformations when they read English words. These features, however, are not shared by Chinese language.

It seems that the cognitive processes underlying Chinese word reading can be both similar to and different from those underlying arithmetic calculation. Unfortunately, no attempt has been made to examine these processes. In societies using an alphabetic script, a small handful of studies have examined the similarities and differences in the cognitive underpinnings of word reading and arithmetic calculation, and these studies have focused on primary school children (Fuchs, Geary, Fuchs, Compton, & Hamlett, 2016; Geary, 2011; Hecht, Torgesen, Wagner, & Rashotte, 2001; Koponen, Aunola, Ahonen, & Nurmi, 2007; Koponen, Salmi, Eklund, & Aro, 2013). In the present study, we measured a variety of cognitive skills, including meta-linguistic, RAN, and visual-spatial skills, in young Chinese children and examined whether these skills are associated similarly or differentially with their word reading and arithmetic competencies. In the literature, these cognitive skills are referred to as "domain-general" functions that are often regarded as important for learning across domains. We focused on these skills, instead of domain-specific skills that are important for only one domain (e.g., number skills for arithmetic; Geary, 2011), because we wanted to clarify whether the contributions of "domain-general" cognitive skills to reading versus mathematical competencies are really alike or not.

2. Relations of meta-linguistic skills to word reading and arithmetic competencies

Meta-linguistic skills involve the awareness and manipulation of the structural elements (e.g., phonology, orthography) of spoken and written language. It has long been found that language impairment often places children at risk for reading and arithmetic difficulties (Ho, Chan, Tsang, & Lee, 2002; Koponen, Mononen, Räsänen, & Ahonen, 2006). The finding suggests that meta-linguistic skills may contribute to the development of word reading and arithmetic competencies.

In the literature, the meta-linguistic skill that has been linked most commonly to both reading and arithmetic competencies is phonological awareness, or the ability to detect and manipulate meaningful segments of a spoken language (Simmons & Singleton, 2008; Wagner & Torgesen, 1987). Phonological awareness has a causal impact on learning to read many alphabetic writing systems (Wagner & Torgesen, 1987), because it helps children to understand the alphabetic principle that the letters