PSYCHOLOGY & NEUROSCIENCE

Psychology & Neuroscience, 2014, 7, 4, 583-591
DOI: 10.3922/j.psns.2014.4.18

Understanding and processing numbers among Chinese children

Winnie Wai Lan Chan

The University of Hong Kong, Pokfulam, Hong Kong, China

Abstract

Chinese children learn mathematics using a user-friendly, regular number naming system. Such a number naming system has been suggested to facilitate Chinese children's mathematical development. Recent studies investigated how Chinese children, with such a language advantage, understand and process Arabic numerals. These studies consistently indicate that Chinese children become able to process numerals proficiently and automatically and make sense of the place-value Arabic number system in the first grade, and children who fail to do so are apt to encounter difficulties in later mathematical learning. Moreover, recent findings show that Chinese children with mathematical difficulties have deficits in number-fact retrieval and the place-value concept. These studies prompted the first steps to explore Chinese children's number processing and understanding. Yet, further studies are needed to provide a complete picture of how Chinese children process and understand numerals using a user-friendly number naming system. **Keywords:** numbers, mathematics, Chinese.

Received 18 December 2013; received in revised form 06 October 2014; accepted 07 October 2014. Available online 16 December 2014.

Introduction

Learning numbers is a foundational step in acquiring mathematical knowledge. Chinese children use the same Arabic numeral system as their English-speaking counterparts. Yet, their number naming system is more regular and transparent than the English one. In particular, the structure of Chinese number words maps clearly onto the place-value features of the Arabic numeral system (i.e., each digit in a number carries a place value, which is a power of 10, depending on its position). For example, in Chinese, the number "11" is lexicalized as "shi^2 yi^1," which literally means "ten one" (i.e., the place values of the two digits, respectively). In English, it is lexicalized as "eleven," without clear mapping onto "ten" and "one." Moreover, the phonological structure of Chinese number names is much simpler than that of the English ones. In Chinese, all single-digit numbers have single syllables with a simple phonological pattern (i.e., consonant-vowel or consonant-vowel-consonant), whereas in English, the name for "7" contains two syllables, and the names for "3" and "6" contain consonant clusters (e.g., the blend of the "th" and "r" sounds in "three" and the blend of "k" and "s" sounds in "six"). With a user-friendly number naming system on their side, Chinese children are ahead of their English counterparts in mathematical development (Miller, Kelly, & Zhou, 2005; Miller, Smith, Zhu, & Zhang, 1995; Miller & Stigler, 1987). How do Chinese children with such language advantage process and understand the Arabic numeral system?

In the following sections, we focus on the abilities of Chinese children to deal with numbers compared with their English-speaking peers. Numbers are representations of magnitudes. First, in the *Numerical Processing* section below, we shall see how well Chinese children can access the magnitudes of numbers. The Arabic numeral system actually has regularities in representing magnitudes. Next, in the *Number Knowledge* section, we shall see how well Chinese children understand some of these regularities. In particular, we examine children's knowledge of the teen quantities and linear representations of numerical magnitudes. Such knowledge contributes to the conceptualization of the structure of Arabic numerals, which is called the place-value concept. In the *Place-Value Concept* section, we shall look at how Chinese children develop their conception of the place-value numeral system. Finally, in the *Mathematical Difficulties* section, we shall examine whether Chinese children are safeguarded by their number naming system against basic numerical deficits, the underlying causes of mathematical difficulties among English-speaking children.

Numerical processing

All calculations start with the process of activating the magnitude of numbers. If such a process occurs

Winnie Wai Lan Chan, The University of Hong Kong - Department of Psychology. Correspondence regarding this article should be directed to: Winnie Wai Lan Chan, The University of Hong Kong - Department of Psychology – Pokfulam Hong Kong SAR - China. E-mail: wlwinnie@hku.hk

automatically without conscious monitoring, then spare cognitive resources can be devoted to retrieving and executing complex mathematical procedures, thereby enhancing arithmetic performance. Western children begin to process single-digit numbers automatically in their early to middle elementary grades (ranging from the end of the first grade to the third grade; see Berch, Foley, Hill, & Ryan, 1999; Girelli, Lucangeli, & Butterworth, 2000; Rubinsten, Henik, Berger, & Shahar-Shalev, 2002). Are Chinese children ahead of their Western counterparts in developing automaticity in processing single-digit numbers?

A study by Zhou, Chen, Chen, Jiang, Zhang, and Dong (2007) examined whether Chinese kindergarteners can process single-digit numbers automatically. The authors used a number-Stroop task in which two numbers were shown in different physical sizes (e.g., 5 9), and the children had to decide which number was physically larger. In fact, the numerical magnitude was irrelevant to the task (i.e., physical size comparison). Yet, if numerical magnitude was activated anyway, then it would affect task performance. The task had three kinds of trials: congruent, incongruent, and neutral. In the congruent trials, the physically larger number was also numerically larger (e.g., 5 9). In the incongruent trials, the physically larger number was actually numerically smaller (e.g., 5 9). In the neutral trials, the two numbers were numerically identical (e.g., 5 5). If numerical magnitude was activated automatically, even though it was irrelevant to the task at hand, then it would facilitate the physical size comparison when the numerical magnitude was consistent with the physical magnitude in the congruent trials, but it would interfere with the physical size comparison when the numerical magnitude was inconsistent with the physical magnitude in the incongruent trials. This was called the congruity effect. The numerical magnitude would neither facilitate nor interfere with the physical size comparison in the neutral trials. Indeed, the authors found that Chinese kindergarteners were slower and less accurate in the incongruent trials compared with the congruent and neutral trials, suggesting that the numerical magnitude was processed automatically.

Why do Chinese children develop automaticity in number processing much earlier than their Western counterparts? Automaticity develops through overlearning. One possible explanation is that Chinese children have greater exposure to numbers in their daily lives because days of the week and months are named by numbers in Chinese (e.g., *xingqi-yi* or "weekday one" for Monday; *xingqi-er* or "weekday two" for Tuesday; *yi-yue* or "one month" for January; *er-yue* or "two month" for February; Kelly, Miller, Fang, & Feng, 1999). Another possible reason is that Chinese kindergarteners have already received informal numerical training at home well before formal schooling. Chinese parents also encourage mathematics-related activities more than Western parents (Huntsinger, Jose, Liaw, & Ching, 1997). With such linguistic and cultural advantages, are Chinese children ahead of their Western counterparts in developing automaticity in two-digit number processing as well?

Western studies have adopted a two-digit version of the number-Stroop task to demonstrate the automatic processing of two-digit numbers (Ganor-Stern, Tzelgov, & Ellenbogen, 2007; Mussolin & Noël, 2007, 2008). In each trial, two two-digit numbers are shown in different physical sizes (e.g., 25 48), and the participants have to decide which number is larger in physical size while ignoring the numerical magnitude. As with the single-digit version, the two-digit version contains congruent trials (i.e., the physically larger number is also numerically larger; e.g., 25 48) and incongruent trials (i.e., the physically larger number is numerically smaller; e.g., 25 48). The automatic processing of two-digit numbers would be demonstrated by a congruity effect in which physical size comparisons in the congruent trials are faster and more accurate than in incongruent trials. Using this task, Western studies have found a congruity effect among adults (Ganor-Stern et al., 2007) but not among children (e.g., third graders in Belgium; Mussolin & Noël, 2007, 2008). Yet, some researchers have challenged the validity of using the task among children. Schwarz and Ischebeck (2003) suggested that children might indeed process numerical magnitudes automatically, but such a process might be too slow among children to interact with the physical size comparison, thus failing to demonstrate a congruity effect. Chan, Au, and Tang (2011) also indicated that it is doubtful whether children can actually pay attention throughout the entire task, which contains over 700 trials. Hence, the current findings on the automaticity of two-digit number processing among Western children remain inconclusive.

In a recent study, an improved task (i.e., the dot-number Stroop task) was used to demonstrate the automatic processing of two-digit numbers among Chinese children (Chan et al., 2011). In each trial, two two-digit numbers with some dots inside were presented, and the children had to decide which number's dots were larger (Figure 1). If the numerical magnitude is activated automatically, then the dot-size comparison would be sped up in the congruent trials (i.e., the larger number containing the larger dots) and slowed down in the incongruent trials (i.e., the larger number containing the smaller dots; i.e., the congruity effect). Because the physical dimension in the dot-number Stroop task (i.e., the physical size of the dots embedded in the numbers) is less salient than that in the two-digit version of the number-Stroop task (i.e., physical size of the numbers), the former takes longer to process, thus giving automatic number processing a chance in the race against physical size processing. Indeed, Chinese adults respond more slowly in the dot-number Stroop task compared with the two-digit version of the number-Stroop task (Chan et al., 2011). The dot-number Stroop task is also more child-friendly because it contains only 48 trials.

In the study by Chan et al. (2011), the dot-number Stroop task was administered to 390 Chinese children

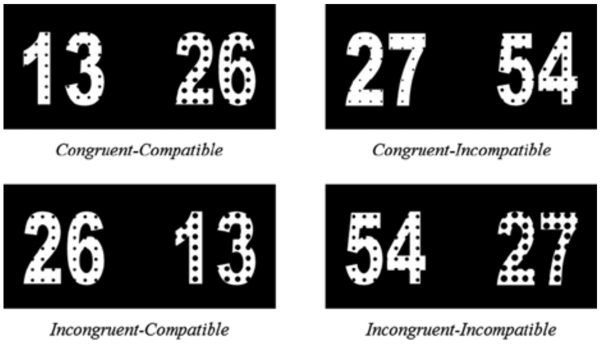

Figure 1. Examples of stimuli in the dot-number Stroop task. Adapted from "Exploring the developmental changes in automatic two-digit number processing" by W. W. L. Chan, T. K. Au, and J. Tang, 2011, *Journal of Experimental Child Psychology*, *109*, p. 267. Copyright 2011 by Elsevier Inc.

from the first to fifth grades to reveal any automatic processing of two-digit numbers. The results showed a congruity effect among children from all grades, suggesting that Chinese children can already process two-digit numbers automatically early in elementary school (age 6-7).

How do Chinese children process a two-digit number that carries multiple magnitudes, namely, the magnitudes of the decade digit, the unit digit, and the integration of the two (i.e., whole-number magnitude)? Western studies have differentiated three ways of two-digit number processing, depending on which kinds of magnitudes are activated. In holistic processing, the whole-number magnitude is activated (Brysbaert, 1995; Dehaene, Dupoux, & Mehler, 1990; Reynvoet & Brysbaert, 1999). In decomposed processing, both the decade and unit digits are activated (Nuerk, Weger, & Willmes, 2001, 2004b; Ratinckx, Brysbaert, & Fias, 2005). There are two subtypes of decomposed processing, namely, decomposed sequential processing, in which the decade digit is activated first (Nuerk, Kaufmann, Zoppoth, & Willmes, 2004a) and decomposed parallel processing in which both digits are activated simultaneously (Nuerk et al., 2004a).

In the dot-number Stroop task, the congruity effect (i.e., the dot-size comparison is faster when the larger dots are inside the larger number in congruent trials but slower when the larger dots are inside the smaller number in incongruent trials) can be explained by holistic processing or decomposed sequential processing because the larger/smaller number always has the larger/smaller decade digit (e.g., 26 and 48). Hence, the congruity effect *per se* is insufficient to determine how children actually process two-digit numbers.

In the dot-number Stroop task, the manipulation of the unit-decade compatibility of the number pairs enables differentiating between decomposed sequential processing and decomposed parallel processing. In a unit-decade compatible pair (e.g., 26 and 48), one of the numbers carries both the larger decade and unit digits than the other number. In the unit-decade incompatible pair (e.g., 28 and 46), one of the numbers carries the larger decade digit, whereas the other number carries the larger unit digit. Depending on which subtype of decomposed processing occurs, the congruity effect would be moderated by the unit-decade compatibility of the number pairs in a different way.

If decomposed sequential processing occurs (i.e., the decade digit is activated first), then the decade digits in the unit-decade incompatible pairs (which are numerically farther apart because of the matching of the absolute difference between the paired numbers) would be activated faster than those in the unit-decade compatible pairs because of a distance effect (i.e., the larger the numerical distance between two numerals, the faster the numerical processing; Moyer & Landauer, 1967). Hence, the decade digits in the unit-decade incompatible pairs would facilitate or interfere with physical size processing more than those in the unit-decade compatible pairs, leading to a larger congruity effect in the unit-decade incompatible pairs. If decomposed parallel processing occurs (i.e., both digits are activated simultaneously), then the decade and unit digits in the unit-decade compatible pairs (i.e., the larger decade and unit digits are held by a single paired number) would facilitate or interfere with the physical size comparison more than those in the unit-decade incompatible pairs (i.e., the larger decade and unit digits are held by different paired numbers), leading to a larger congruity effect in the unit-decade compatible pairs. In summary, the unit-decade incompatible pairs will show a larger congruity effect than the unit-decade compatible pairs if decomposed sequential processing occurs, but a smaller congruity effect would occur if decomposed parallel processing occurs.

In the study by Chan et al. (2011), the Chinese elementary school children demonstrated a congruity effect in the dot-number Stroop task, which was moderated by the unit-decade compatibility of the number pairs. In particular, the unit-decade compatible pairs showed the larger congruity effect than the unit-decade incompatible pairs, indicating decomposed parallel processing. A two-step cluster analysis was also conducted to uncover individual differences in processing two-digit numbers among the children. Two clusters of children were formed. The majority of the children in Cluster 1 were in the lower grade levels, and those in Cluster 2 were in the higher grade levels. The children in Cluster 2 showed a larger congruity effect in the unit-decade compatible pairs than in the unit-decade incompatible pairs, indicating decomposed parallel processing. However, the children in Cluster 1 showed similar congruity effects for both unit-decade compatible and incompatible pairs. Such a pattern of performance suggests a transition from sequential to parallel processing, a trend that is also observed in intentional number processing (Nuerk et al., 2004a).

These results suggest that Chinese children as young as first graders can already process two-digit number automatically, and they appear to do so in a decomposed way. At first (likely in kindergarten), the digits are activated one by one, starting with the decade digit; later, both digits can be activated simultaneously. Children's automatic processing of individual digits likely suggests their recognition of the decompositional structure of the Arabic numeral system. The developmental shift from sequential to parallel processing may involve children's accumulation of experience in manipulating both digits in calculations.

The developmental story for the automatic processing of two-digit numbers (including the age of onset and type of processing) among Western children is less clear because the task that is used (i.e., the two-digit version of the number-Stroop task) appears to be inadequate in uncovering children's automatic number processing (Chan et al., 2011; Schwarz & Ischebeck, 2003). Future studies should explore the Western children's automatic processing of two-digit numbers using the dot-number Stroop task in order to gain a clearer picture of any developmental gap in such numerical processing between Western and Chinese children.

Number knowledge

In the previous section we saw that Chinese elementary school children are able to process individual digits in a two-digit number automatically. Such a capacity likely has to do with the awareness of the digital structure of numbers, which is one of the regularities that governs the Arabic numeral system. Automatic processes are essentially mechanical and learned through practice. How well do Chinese children actually *know* the regularities in the Arabic numeral system? In this section, we discuss whether Chinese children are more advanced than their Western peers in two kinds of number knowledge, one having to do with the teen quantities and the other having to do with the linear representations of numerical magnitudes.

A teen quantity (i.e., from 11 to 19 or generally 1x) is composed of a quantity of 10 plus a quantity of x. This is called embedded-ten cardinal understanding, which is facilitated by the regular Chinese number words (e.g., 11 and 16 are spoken as "ten-one" and "ten-six," respectively; Ho & Fuson, 1998). English number words, however, are less regular and obfuscate the tens and ones (e.g., eleven for "11"; sixteen for "16"). Indeed, 5-year-old Chinese children show embedded-ten cardinal understanding, but their English-speaking peers do not (Ho & Fuson, 1998). This is observed in the hidden-object addition task in which the 5-year-old Chinese children can sum up 10 and x items quickly and accurately without any counting, whereas they have to count to sum 4 and x items. This is probably because these children understand the embedded-ten cardinality, which helps them easily combine 10 and x items. By contrast, the 5-year-old English-speaking children have to fall back to counting to sum up 10 and x items, suggesting an absence of embedded-ten cardinal understanding. At the age of 4, both Chinese- and English-speaking children have to count to sum 10 and x, suggesting that embedded-ten cardinal understanding is universally absent among children before 5.

Similar to the teen quantities, any larger two-digit quantity is composed of a quantity of decades and a quantity of ones. In general, each decade is a new cycle in our numeral system (i.e., 10, 20, 30…). Within each decade cycle, the numerical magnitudes increase incrementally by one (e.g., 21, 22, 23…). Such numerical organization can be conceptually represented by a number line in which numerals are evenly spaced and arranged in order of magnitude.

Children with a better understanding of numerical organization are more accurate in estimating the position of a number on a number line. A typical number-line estimation task requires children to locate the position of a number on a number line, with 0 at one end, 100 at the other, and nothing in between (Siegler & Opfer, 2003). In a cross-cultural study on number-line estimation (Siegler & Mu, 2008), Chinese kindergarteners' estimates were considerably more accurate than American kindergarteners' estimates, with mean percentages of absolute errors of 15% and 22%, respectively. If the estimation was perfect, then the best-fitting linear function would account for 100% variance in the number-line estimates and have a slope of 1.00. The study found that the Chinese kindergarteners' median estimates were better fit by a linear function (R^2 = .95 for linear function; R^2 = .86 for logarithmic function), whereas the American kindergarteners' median estimates were better fit by a logarithmic function (R^2 = .72 for linear function; R^2 = .90 for logarithmic function). For the best-fitting linear functions, the slope for the Chinese kindergarteners (.53) was also closer to 1 compared with American kindergarteners (.39). These findings suggest that Chinese children already possess a better understanding of the numerical organization in their kindergarten years compared with their American peers.

The authors also noted that number-line estimation was not routinely practiced among Chinese children in their daily lives, although Chinese parents tended to provide more informal training in counting and arithmetic at home well before formal schooling. Hence, the authors suggested that practice in counting and arithmetic might improve Chinese children's understanding of numerical magnitude, thereby resulting in superior number-line estimation. Consider the early counting strategy (i.e., finger counting) as an example. It provides kinesthetic (number of fingers put up), visual (number of fingers shown), verbal (numbers counted aloud), and temporal (time required to reach the sum) cues for the development of a sense of numerical magnitudes (Siegler & Mu, 2008). Chinese children with more experience and practice in counting and arithmetic excel in their early understanding of numerical organization compared with their American counterparts.

The place-value concept

The number knowledge mentioned above contributes to the place-value concept (i.e., understanding the positional values and interrelationships of digits in a number). Such a concept is essential to early mathematical learning (Collet, 2003; Dehaene & Cohen, 1997; Fuson et al., 1997b) and has to do with how numbers are conceptualized (Chan, Au, & Tang, 2014). In this section, we discuss how well Chinese children understand the place-value concept, reflected by their conception of numbers.

The well-known UDSSI model (Fuson, Smith, & Lo Cicero, 1997; Fuson et al., 1997b) describes a developmental sequence of the conception of two-digit numbers among Western children. The model was named after five major concepts: Unitary multi-digit, Decade and ones, Sequence-tens and ones, Separate-tens and ones, and Integrated sequence-separate-tens. Old concepts may co-exist with newly evolved concepts and be used in certain situations. Each concept would cause a child to count in a specific way. Starting with the unitary multi-digit concept, children see a number as an undivided entity and thus count items by ones without grouping (e.g., 1, 2, 3,…, 35). They then become able to understand that a number can be separated into meaningful parts (i.e., a sense of partitioning). Initially, they separate a number into decade and unit (e.g., 30 and 5 for 35). This is the decade and ones concept, which is facilitated by language systems with separate decade names, such as twenty and thirty in English. Later, they develop the sequence-tens and ones concept in which they regard a number as a composition of groups of tens and thus tend to count items by tens (e.g., 10, 20, 30, 31, 32,…, 35). In the next stage, they can see a number as a composition of groups of tens and of ones (i.e., the separate-tens and ones concept) and thus count the two groups separately (e.g., 1, 2, 3 tens and 1, 2,…, 5 ones for 35). Such a concept is difficult for children using the Western number naming systems without clear mapping onto the base-ten Arabic number structure. When children become sophisticated in the sequence-tens and ones concept and the separate-tens and ones concept, they can readily shift back and forth between the two concepts, depending on the situation (i.e., the integrated sequence-separate-tens concept).

A recent research project (Chan et al., 2014) developed the Strategic Counting task to elicit children's counting strategies to provide insights into their conceptual structures of two- and three-digit numbers. In the task, pictures of small squares, bars (each containing 10 small squares), and large squares (each containing 10 bars) are shown, and children have to count the total number of small squares in each picture (Figure 2). The squares and bars are specially arranged so that children have to apply their place-value knowledge (e.g., grouping in tens and carrying over) to count effectively. The task contains 10 items that involve two- and three-digit quantities. In traditional place-value tasks, similar base-ten stimuli may also be adopted to elicit children's counting. Yet, the typical arrangement of those stimuli allows children to easily map onto the base-ten number structure without genuine place-value understanding (e.g., given two bars on the left and five small squares on the right, children can mechanically map the quantities "two" and "five" onto the left and right sides of a number, respectively, to yield the total number 25). In the Strategic Counting task, however, such a mechanical-mapping strategy is no longer useful.

In a series of three studies, Chan et al. (2014) used the Strategic Counting task to assess Chinese children's conception of numbers and predict early difficulties with the place-value concept and later low mathematics achievement. In Study 1, 72 Chinese kindergarteners and 60 first graders completed the Strategic Counting task and a battery of numerical tasks on simple counting, number representation, place-value understanding, and arithmetic. Children's counting strategies were recorded and categorized for each item. A two-step cluster analysis was conducted on the frequencies of the strategies that were adopted by the children. Three clusters of children were formed (Clusters 1, 2, and 3), with higher proportions of first graders in the upper clusters. Hence, the developmental trend appeared to go from Cluster 1 to Cluster 2 to Cluster 3. The three clusters of children showed different patterns of counting strategies, reflecting different underlying conceptions of numbers. Children in Cluster 1 tended to count by ones more often than their peers (i.e., the unitary multi-digit concept). Children in Cluster 2 tended to count by tens more frequently (i.e., the sequence-tens and ones concept). Children in Cluster 3 tended to count the groups of ones, tens, and hundreds separately (i.e., the separate-tens and ones concept).

Such findings suggest a developmental story that Chinese children start to construct number meaning in their kindergarten years and continue to do so in first grade, and they start with the unitary multi-digit concept, go through the sequence-tens and ones concept, and subsequently reach the separate-tens and ones concept. Such a developmental sequence is generally consistent with the one suggested for Western children using a less regular number naming system compared with Chinese, except that the decade and ones concept is not evident among Chinese children because their language system does not have separate decade words. The separate-tens and ones concept, however, is likely facilitated by the Chinese number words, with clear mapping onto the place values of the digits. Note that there is still a lack of systematic, empirical studies on the development of number concepts among Western children. The well-known UDSSI model for Western children (Fuson et al., 1997a, b) was actually based on the researchers' informal observations only. Future studies should more systematically compare the development of number concepts between Chinese and Western children. Further analysis in Study 1 showed that children in Cluster 3 performed the best on the battery of numerical tasks, suggesting that children with a more sophisticated

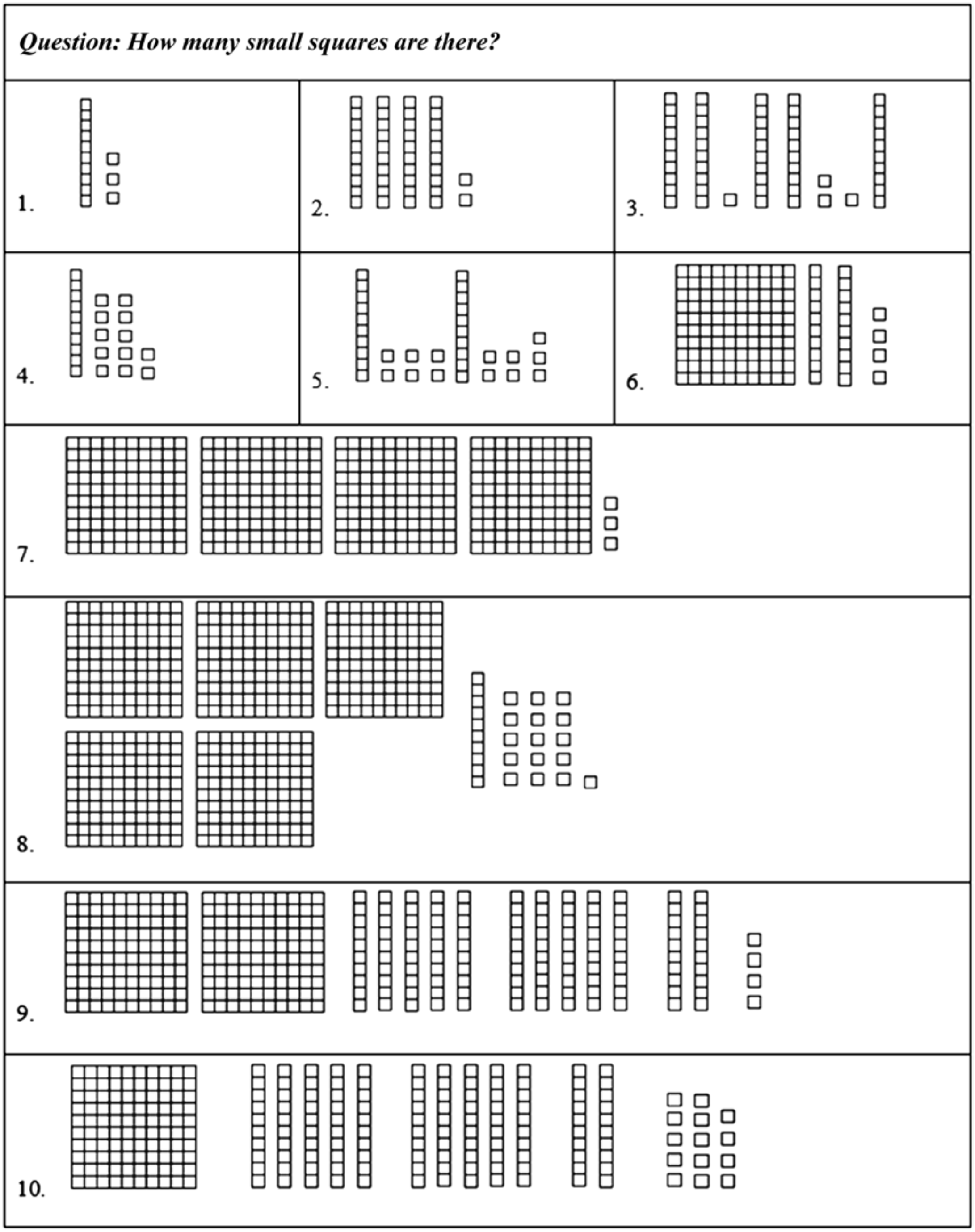

Figure 2. Items in the Strategic Counting task. Adapted from "Strategic counting: a novel assessment of place-value understanding" by W. W. L. Chan, T. K. Au, and J. Tang, 2014, *Learning and Instruction*, *29*, p. 93. Copyright 2013 by Elsevier Ltd.

understanding of the place-value structure of numbers (reflected by more advanced counting strategies) have better mathematical knowledge and skills. Hence, the place-value concept appears to play a role in early mathematical learning.

In Studies 2 and 3, the authors further examined the importance of place-value understanding in Chinese children's mathematical development. In Study 2, 582 first graders completed the Strategic Counting task and the battery of numerical tasks at the end of the first semester and a standardized mathematical achievement test with a local norm (LAMK; Hong Kong Education Bureau, 2008) at the end of the second semester. The results showed that the children's accuracy on the Strategic Counting task was the single strongest predictor of their mathematical achievement one semester later among various numerical tasks, including reciting the count sequence, reading Arabic and Chinese numbers aloud, adding numerals, adding objects, grouping objects in tens, and representing numerals with base-ten blocks (Total $R^2 = .34$). Moreover, the authors used item analysis to streamline the Strategic Counting task from

10 items to five items only for easy administration in daily classroom sessions.

In Study 3, the authors examined how children's performance on the brief version of the Strategic Counting task related to their later mathematical outcome and whether such performance was useful for screening potential low-mathematics achievers. One hundred ninety-three first graders completed the brief version of the Strategic Counting task four times (i.e., at the end of each semester in the first and second grades). They also completed the battery of numerical tasks at the first time point and the LAMK at the end of the fourth time point. The results showed that the brief version of the Strategic Counting task was the single strongest predictor of children's mathematical achievement 18 months later among various numerical tasks (i.e., transcoding numbers from Arabic to Chinese and *vice versa*, in addition to the numerical measures in Study 2), as well as working memory tasks and Chinese word reading (Total R^2 = .61). The Strategic Counting task contributed an additional unique variance of 2% beyond the cluster of both general and traditional numerical measures, suggesting that the Strategic Counting task taps unique mathematical knowledge (i.e., place-value knowledge) apart from assessing some overlapping skills with other measures (e.g., counting and working memory).

Growth curve modeling was also performed to examine the developmental trajectories of place-value understanding among the Chinese children, who were divided into three groups based on their year-end mathematical achievement in the second grade: high-math (at or above the 75th percentile), average-math (between the 25th and 75th percentiles), and low-math (at or below the 25th percentile). The results showed that children in the low-math group had persistently subpar performance on the brief version of the Strategic Counting task since the end of first semester in the first grade, suggesting that children who turn out to be low-mathematics achievers in the second grade have early difficulties with the place-value concept. This again highlights the strong association between place-value understanding and mathematical achievement. Discriminant analysis confirmed that the brief version of the Strategic Counting task was useful in distinguishing low-mathematics achievers in the second grade from their peers. Based on receiver-operating-characteristic curve analysis, two cutoff scores were established. The first cutoff score was applicable at the end of the first semester in the first grade for initial screening for low-math achievers at the end of the second grade (sensitivity = 95%, i.e., 95% of low-math achievers were correctly identified; specificity = 59%, i.e., 59% of on-track math achievers were correctly identified). The second cutoff score was applicable at the end of the second semester in the first grade for follow-up screening (sensitivity = 87%; specificity = 66%).

The studies by Chan et al. (2014) were the first to examine how Chinese children conceptualize the place-value number system and how such conceptualizations affect their later mathematical achievement. Based on children's counting strategies on the Strategic Counting task, the authors uncovered a developmental trend of number concepts that goes from a holistic view (numbers as undivided entities) to a decomposed view (numbers as a composition of groups of powers of tens), highlighting an increase in knowledge of the place-value structure of the Arabic numeral system. Children who fall behind this developmental schedule are at risk of becoming low-mathematics achievers. The Strategic Counting task appears to be a potentially useful screening tool for early difficulties in the place-value concept. In the next section, we explore whether a deficit in basic numerical capacities (e.g., the place-value concept) leads to mathematical difficulties among Chinese children.

Mathematical difficulties

Previous studies with Western children suggested that deficits that underlie mathematical difficulties can be both domain-specific (i.e., related to numbers) and domain-general (i.e., not related to numbers). Domain-specific deficits include difficulties executing arithmetic procedures (Geary, 1996), retrieving number facts from long-term memory (Geary, 2004), understanding the place-value concept (Hanich, Jordan, Kaplan, & Dick, 2001), and developing number sense (e.g., counting, recognizing number patterns, comparing numerical magnitudes, making estimations, and transforming numbers; Gersten, Jordan, & Flojo, 2005; Jordan, Kaplan, Locuniak, & Ramineni, 2007). Domain-general deficits include poor working memory (Geary, Hoard, Byrd-Craven, & DeSoto, 2004) and slow processing speed (Ostad, 2000). Are these cognitive deficits universal across different languages and cultures and thus applicable to Chinese children with mathematical difficulties?

In fact, mathematical difficulties have been rarely examined among Chinese children. One exception is a recent study by Chan and Ho (2010). In the study, three groups of children (aged 7-11 years; one group with mathematical difficulties, one group with both mathematical and literacy difficulties, and a control group) were compared for their domain-specific (i.e., arithmetic procedural skills, number-fact retrieval, place-value concept, and number sense) and domain-general (i.e., working memory and processing speed) performance. Note that there are no standardized diagnostic criteria for mathematical difficulties among Chinese children. In the study by Chan and Ho (2010), children with mathematical difficulties were those who had normal intelligence (IQ ≥ 85) but subpar performance on the Hong Kong Arithmetic Test on Mathematics (Hong Kong Education Department, 2000) and the Arithmetic subtest (scores below the bottom 25th or 20th percentile). Children with literacy difficulties were those whose Literacy composite score on the standardized Hong Kong Test of Specific Learning Difficulties in Reading and Writing (HKT-SpLD; Ho, Chan, Tsang, & Lee, 2000) was at least one standard deviation below the age mean.

The results from the study showed that children with both mathematical and literacy difficulties performed the worst on both domain-specific and domain-general measures, whereas children with mathematical difficulties only performed worse than the children in the control group in the domain-specific measures and verbal working memory. Using stepwise discriminant analyses, the authors found that among all of the measures, number-fact retrieval and the place-value concept were significant factors that differentiated children with and without mathematical difficulties. The importance of place-value understanding in Chinese children's mathematical development was also well-documented in the study by Chan et al. (2014; see *Place-Value Concept* section). Such findings suggest that Chinese children with mathematical difficulties exhibit deficits in domain-specific capacities/skills, especially in number-fact retrieval and the place-value concept, with important implications for the future development of standardized assessment tools for mathematical difficulties among Chinese children. These findings also imply that although Chinese children use a user-friendly number naming system, they are not safeguarded against numerical deficits, suggesting that these domain-specific deficits likely have roots in very basic number capacities, regardless of language.

Conclusions

Although prior studies found language advantages among Chinese children over their Western counterparts in mathematical development, little is known about whether such an advantage actually exists in very basic number processing and the understanding of numbers. Most studies on number processing and understanding in children have focused on Western populations, and only very few studies have examined specifically Chinese children. Recent studies prompted the first steps to explore Chinese children's automatic numerical processing, number knowledge, conception of numbers, and mathematical difficulties. Importantly, these studies suggest that Chinese children at age 6-7 years (i.e., first graders) develop automaticity in number processing and sophisticated number concepts, providing the foundation for more advanced mathematical learning in the upper grades. Indeed, children who fail to develop such an understanding or capacity at this stage turn out to be low-mathematics achievers. As with their Western counterparts, Chinese children may also have deficits in number-fact retrieval and the place-value concept, suggesting that the user-friendly Chinese number naming system cannot completely compensate for such deficits. Further cross-cultural studies are needed to clarify whether language actually affects Chinese children's understanding and processing of numbers.

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