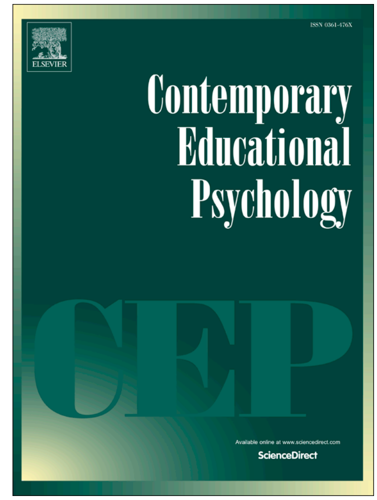

Mathematics anxiety and working memory: Longitudinal associations with mathematical performance in Chinese children

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Mathematics anxiety and working memory: Longitudinal associations with mathematical performance in Chinese children

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Abstract

The link between mathematics anxiety and mathematical performance in young children remains inconclusive. The present study examined the longitudinal associations between mathematics anxiety and mathematical performance (calculation and story problem solving) in 246 Chinese children followed from second to third grade. Multiple regression analyses showed that mathematics anxiety made independent contributions to mathematical performance beyond non-verbal intelligence, working memory, number skills, general and test anxieties. However, mathematics anxiety does not affect all children and all kinds of mathematical performance equally. Mathematics anxiety has a more pronounced impact on mathematical problems that require more processing resources, as opposed to simple arithmetic problems and straightforward story problems and children who are higher in working memory are more vulnerable to its deleterious impacts.

Keywords: Mathematics anxiety; working memory; children

Mathematics anxiety and working memory: Longitudinal associations with mathematical performance in Chinese children

In recent years, there has been significant psychological interest in mathematics anxiety and its impact on mathematical performance (Carey, Hill, Devine, & Szucs, 2016; Dowker, Sarkar, & Looi, 2016). Mathematics anxiety refers to the 'feelings of tension and anxiety that interfere with the manipulation of numbers and the solving of mathematical problems in a wide variety of ordinary life and academic situations' (Richardson & Suinn, 1972, p. 551). To date, research has focused predominantly on adolescents and adults to test whether mathematics anxiety hampers individuals' performance in mathematical tasks. It has been shown that mathematics anxiety is negatively associated with mathematical performance in adults (e.g., Ashcraft & Kirk, 2001; Beilock & Carr, 2005; Beilock, Rydell, & McConnell, 2007; Brodish & Devine, 2009; Cadinu, Maass, Rosabianca, & Kiesner, 2005; Dew, Galassi, & Galassi, 1983; Ganley & Vasilyeva, 2011; Ma, 1999; Miller & Bichsel, 2004). Relatively scarce attention has been paid to the role of mathematics anxiety in children's mathematical performance and the evidence is inconsistent. Some studies have shown that mathematics anxiety makes independent and negative contributions to variations in calculation and story problem solving (e.g., Vukovic, Kieffer, Bailey, & Harari, 2013), whereas some evidence suggests that the negative influence of mathematics anxiety occurs in children with higher level of working memory only (e.g., Ramirez, Gunderson, Levine, & Beilock, 2013; Ramirez, Chang, Maloney, Levine, & Beilock, 2016). The present study, conducted with a group of Chinese children for the first time, investigated (1) whether mathematics anxiety of children at the age of 7 would predict their performance in calculation and story problem solving one year later, and (2) whether there is an interactive effect between mathematics anxiety and working memory on children's mathematical performance.

Mathematics Anxiety and Mathematical Performance

People with mathematics anxiety experience difficulties in tasks that demand basic numerical skills (e.g., Maloney, Ansari, & Fugelsang, 2011; Núñez-Peña & Suárez-Pellicioni, 2014) and complex problem solving (e.g., Beilock & Carr, 2005; Wu, Barth, Amin, Malcarne & Menon, 2012). In his meta-analytic review of research on mathematics anxiety, Hembree (1990) showed that mathematics anxiety was consistently associated with poor performance on mathematical achievement tests. For example, in adolescents, self-reported scores on mathematics anxiety were negatively associated with term grades, final exam grades and tests of mathematics aptitude. Mathematics anxiety was negatively correlated with the scores on all the mathematics subtests (including mathematics concepts, applications, and computations) and the total score of the Stanford Achievement Test (SAT) (Richardson & Suinn, 1972; Suinn, Taylors & Edwards, 1988; Wigfield & Meece, 1988). Later research has also demonstrated the detrimental consequences of mathematics anxiety on mathematical achievements in upper elementary grades. Chiu and Henry (1990), for example, showed that in fifth, sixth, and eighth graders, mathematics anxiety had negative associations with semester grades in mathematics. Ma (1999) found that the severity of mathematics anxiety in children tended to increase over time. Among the 122 studies that Hembree reviewed, most of them (115 studies) involved participants who were late adolescents, university students, and adults, whereas none of these studies included children below the fifth grade. Given that childhood is a period that is important for the learning of mathematics, we need more research to examine whether and how mathematics anxiety affects younger children's performance and progress in mathematics learning.

Recent evidence suggests that children may experience mathematics anxiety as early as first and second grades. Thomas and Dowker (2000) devised the 'Math Anxiety Questionnaire' (MAQ) and investigated the connection between mathematics anxiety and mathematical performance in children between the ages of six and nine. They found that although mathematics anxiety was present in this age group, it was not significantly linked to the calculation ability of the children participants. Krinzinger, Kaufmann, and Willmes (2009) employed a German version of the MAQ to study the longitudinal relation of mathematics anxiety to calculation ability in children followed from first through third grade. They asked the children to solve a series of single-digit addition and subtraction problems orally as quickly as possible within a minute. Consistent with the finding obtained by Thomas and Dowker, they did not observe a significant association between mathematics anxiety and calculation ability. However, Krinzinger and colleagues speculated that their nonsignificant findings might reflect a methodological limitation in their measure of mathematics anxiety. For example, the children were asked to infer emotional reactions from pictures, such as candies versus wasps, and relaxed faces versus worried faces. They suggested that this kind of response format might have been too difficult for children, so they recommended a more direct measure of mathematics anxiety in children.

Following the suggestion of Krinzinger et al. (2009), Harari, Vukovic, and Pailey (2013) created a 12-item scale that measured mathematics anxiety in which children answered more direct questions about mathematics anxiety instead of inferring levels of anxiety from pictures. They found that mathematics anxiety of first graders was significantly associated with calculation ability and early number skills, such as identifying number patterns, counting-on backward, and skip counting. However, in another study, Wu and colleagues (2012) showed a more complex picture regarding the relation between mathematics anxiety and mathematical performance. They found that mathematical achievement, as measured with the WIAT-II Math Composite score, were negatively associated with mathematics anxiety, but not with trait anxiety, in second and third graders. They also showed that mathematics anxiety was strongly correlated with children's performance in mathematical reasoning, which included complex verbal problem solving. However, unlike the study by Harari and colleagues, there was only a weak correlation between mathematics anxiety and numerical operations, which assessed basic computational skills. It appears that the influence of mathematics anxiety on children's mathematical performance depends on the type or level of difficulty of mathematical problems.

Importance of Working Memory in Mathematics Learning

To interpret the differential influence of mathematics anxiety on different types of mathematical tasks, Wu and colleagues (2012) refer to the role of working memory in the relation between mathematics anxiety and mathematical performance. Some researchers suggest that mathematics anxiety impairs mathematical performance by taxing processing resources including working memory (Ashcraft, 2002; Ashcraft & Kirk, 2001; Hembree, 1990; Lyons & Beilock, 2012; Park, Ramirez, & Beilock, 2014). Working memory has been defined as "a brain system that provides temporary storage and manipulation of the information necessary for …complex cognitive tasks" (Baddeley, 1992, p.556). It seems uncontroversial that learning and using mathematics must draw on some general cognitive resources. For example, to solve the following problem, 'David had 8 books. Then Peter gave him 3 more books. How many books does David have now?', we need to (1) pay attention to the information, (2) select, remember, and reason about the relevant parts of this information, and (3) execute arithmetic operations that help us answer the problem. Likewise, when children solve a calculation or an applied problem, they must keep in mind the information in the problem and the steps to execute the solution, while monitoring what they have done and what remains to be done. 'Working memory' is the term that researchers use to denote the ability to keep track of information and operate on it simultaneously, which is expected to influence how well individuals retain information in mind and think mathematically.

The contributions of working memory to mathematics learning in children has been demonstrated in cross-sectional (e.g., Andersson, 2007; Berg, 2008; Geary, 2011; Swanson &

Jerman, 2006), longitudinal (e.g., Alloway & Alloway, 2010; Bull, Espy, & Wiebe, 2008; Ching & Nunes, 2016; Hecht, Torgesen, Wagner, & Rashotte, 2001; LeFevre et al., 2013; Monette, Bigras, Guay, 2011; Passolunghi, Vercelloni, & Schadee, 2007; Swanson, 2011; Welsh, Nix, Blair, Bierman, & Nelson, 2010), experimental studies (e.g., Imbo & Vandierendonck, 2007; McKenzie, Bull, & Gray, 2003), and training studies (e.g., Holmes, Gathercole, & Dunning, 2009, Kroesbergen, van't Noordende & Kolkman, 2014). However, the connection between working memory and children's mathematical achievement is complicated (Raghubar, Barnes, & Hecht, 2010) and seems to be moderated by other factors including the age of children and the kind of mathematical tasks administered. Some studies, for instance, suggest that individual differences in visuospatial sketchpad are the best predictor of mathematical achievement in preschool children (McKenzie, Bull & Gray, 2003; Rasmussen & Bisanz, 2005; Simmons, Chris & Horne, 2008). From primary school onwards, as children become increasingly reliant on verbal rehearsal to retain materials in memory (Hitch, Halliday, Schaafstal & Schraagen, 1988), phonological loop emerges to be the best predictor of children's mathematical performance during this period (Rasmussen & Bisanz, 2005). In comparison to visuospatial sketchpad and phonological loop, evidence concerning the strong connection between the central executive component of working memory and children's performance in mathematics has been more consistent (e.g., Ching & Nunes, 2016; Cowan & Powell, 2014; Gathercole & Pickering, 2000; Holmes & Adams, 2006; Keeler & Swanson, 2001; Lee, Ng, Ng, & Lim, 2004; Lehto, 1995; Noel, Seron, & Trovarelli, 2004; Swanson & Beebe-Frankenberger, 2004; Wilson & Swanson, 2001).

Influence of Task Demands: The Role of Working Memory

The influence of mathematics anxiety on children's mathematical performance may depend on the types or difficulties of mathematical problems, which is related to the cognitive resources that the problems demand. Wu and colleagues (2012) argued that their measures of numerical operations did not assess complicated mathematical concepts, and at the same time the children participants completed the task using paper-and-pencil without any time pressure, therefore they did not tax children's working memory resources so much that affected their performance. By contrast, the measures of mathematical reasoning required the children to listen to a problem that was read out loud by an experimenter. To answer the problem correctly, the children needed to execute several procedures in mind, such as retaining and manipulating relevant information before deciding which operation to perform. This kind of tasks, compared with the numerical operation task, requires the children to use a higher level of working memory resources. Therefore, working memory demands of different mathematical tasks may be one plausible explanation for the finding that the effects of mathematics anxiety was stronger on mathematical reasoning than on numerical operations in their study.

This interpretation is consistent with an earlier study (Ashcraft & Kirk, 2001) that examined the relation of mathematics anxiety to working memory. The researchers divided a group of college students into two groups based on their dispositional mathematics anxiety level: High mathematics anxiety and low mathematics anxiety groups. The students were asked to perform two-column addition problems that required a carry operation, which placed a load on working memory. While performing the calculation, the students had to do a letter memory task that required them to maintain either two-letter strings or six-letter strings in memory. Ashcraft and Kirk found that when under the two-letter load, the students high in mathematics anxiety performed similar with those low in mathematics anxiety on the calculation tasks. However, when under the six-letter load, the students high in mathematics anxiety produced significantly more errors in calculation than those low in mathematics anxiety. In subsequent work, Ashcraft and Krause (2007) replicated this finding by showing that performance on mathematical tasks that demanded a higher working memory load was more affected by mathematics anxiety. These findings suggest that mathematics anxiety exerts its influence on individuals' mathematical performance particularly in highly demanding test situations because anxieties compromise working memory resources.

Influence of Individual Differences in Working Memory Capacity

In addition to using different types of tasks that place different loads on working memory, research that examined the role of working memory in the relation between mathematics anxiety and mathematical performance has also considered working memory an individual difference variable. There are competing hypotheses regarding who (high-mathematics anxiety versus low-mathematics anxiety individuals) is more vulnerable to performance deficits as a result of working memory disruption. One view postulates that the higher the working memory capacity, the more cognitive resources a person can use to deal with anxiety-related thoughts as well as solving the mathematical problem at hand. The evidence that support this account has been obtained predominantly from studies conducted on adults. For example, Miller and Bichsel (2004) showed that for adults who are high in mathematics anxiety, those with a higher working memory capacity obtained higher scores on calculation tasks and applied problem solving compared to those with lower working memory capacity.

Another view posits that people with higher working memory capacity are more susceptible to performance decline because of working memory disruption (Beilock & Carr, 2005; Beilock & DeCaro, 2007; Ramirez, Gunderson, Levine, & Beilock, 2013). This hypothesis has received increasing empirical support in recent scholarship. In one study, Beilock and Carr (2005) asked high and low-working memory adults to perform a series of mathematical problems under a low-pressure condition and then under a high-pressure condition, which was designed to place the participants under a higher state of anxiety. They found that in the absence of pressure, the participants with high working memory performed significantly better than those with low working memory. However, when under high pressure, the participants with high working memory performed similarly with those with low working memory. These effects were only observed in more difficult problems that demanded more processing resources. In a recent study, Ramirez, Gunderson, Levine, and Beilock (2013) replicated this finding in a group of first and second-grade children. They found that mathematics anxiety was negatively associated with mathematical achievement only for children who were higher in working memory. There was no relation between mathematics anxiety and mathematical performance for children with lower working memory scores.

Ramirez and colleagues (2013, 2016) argued that individuals with higher working memory are more likely to rely on problem-solving strategies that load working memory heavily. Thus, when working memory capacity is co-opted by mathematics anxiety, the efficiency of using these strategies are likely compromised. In contrast, mathematics anxiety does not detrimentally affect individuals with low working memory, presumably because they do not rely on problem-solving strategies that demand high working memory resources in the first place. This hypothesis is supported by recent evidence (Ramirez et al., 2016) that showed that children with higher working memory capacity avoided using advanced problem-solving strategies when they were high in mathematics anxiety, which impaired their mathematical performance.

However, Vukovic, Kieffer, Bailey, and Harari (2013) did not replicate the interaction effect of mathematics anxiety and working memory on any kind of mathematical outcome (i.e. computation, mathematical applications, and geometry) in their cross-sectional analyses on a group of second graders. They only replicated the interaction effect in their longitudinal analyses on children's performance on mathematical applications. For the children with higher working memory, there was a significant negative association between second-grade mathematics anxiety and third-grade performance on mathematical applications, even after controlling for the effects of general reading achievement and early numeracy skills. They also found that the association remained significant after the autoregressive effect of second-grade mathematical applications was accounted for. By contrast, there was no effect of second-grade mathematics anxiety on third-grade performance on mathematical applications for children with lower working memory. Vukovic and colleagues (2013) suggest that mathematics anxiety has a "learning effect" (p. 8) but not a "performance effect" on children. They argued that, in real-time, mathematics anxiety may impair mathematical performance of children with high and low working memory equally. However, mathematics anxiety seems to be a greater obstacle to learning mathematical applications (but not basic arithmetic problems) for children with higher working memory over time (learning effect), whereas mathematic anxiety does not block the learning of children with lower working memory. They suggest that while mathematics anxiety affects both kinds of mathematical tasks, the anxiety for basic arithmetic tasks does not last long presumably because children can easily identify and then correct any errors. Children can also use backup strategies to solve these problems readily and the effects of anxiety will subside once the problem is solved. By contrast, they argued that the effects of anxiety induced by mathematical applications linger because children cannot obtain clear cues to wrong answers or rely on backup strategies to solve these problems easily. Hence, the anxiety persists over time and presents further barriers to learning for these problems, especially for children with higher working memory. By contrast, the mathematical performance of children with low working memory remains comparatively unaffected (still low) by mathematics anxiety.

Mathematics Learning in Chinese Children: Does Mathematics Anxiety Matter Much?

Regarding the link between mathematics anxiety and mathematical performance, research has been done mostly with children in the United States and European countries. It remains unclear to what extent mathematics anxiety matters for Chinese children. Cross-cultural comparisons have demonstrated that the mathematical performance of East Asian children is on average better than that of their non-Asian counterparts. Chinese children, for example, outperformed their Western peers in object and abstract counting as well as in concrete and mental addition and subtraction (Ginsburg, Choi, Lopez, Netly, & Chi, 1997; Huntsinger, Jose, Liaw, & Ching, 1997; Miller, Smith, Zhu, & Zhang, 1995). It would be interesting to examine whether and how mathematics anxiety influences mathematics learning in Chinese children. Language differences may impact children's understanding of the number structure, counting, and numerical representation, which in turn influences the strengths and relations among factors in relation to mathematics learning.

The structure of the numerical sequence in different languages may determine the emergence of counting abilities and the cognitive representation of numbers. In Chinese, for example, the relation between the words for numbers in different denominations is transparent. The word for the number '14' is the equivalent of 'ten-four'. So once a person knows the Chinese words for 4, 2, and 10, he/she can figure out the words for 14, 40, 42, and 24 readily. This is not always true for English-speaking people. When the Chinese say the equivalent of 'ten-two' for 12, English-speaking people say 'twelve'. The Chinese words for 20 and 30 are the equivalent of 'two-ten' and 'three-ten', the English words for these numbers are 'twenty' and 'thirty'. The base structure of the number system is only partially reflected in European languages (e.g., English and Finnish). If we understand the logic of a numeration system, we can generate numbers that we have not heard before. The different ways of naming numbers may be one of the reasons that Chinese-speaking children make fewer mistakes in saying the numbers to 19 and learn the numerical sequence between 109 and 2000 earlier than English-speaking children in the United States (e.g., Fuson & Kwon, 1992). In Finland, sixty-three percent of the 7-year-old children could say number words accurately from 1 to 50 (Kinnunen, Lehtinen, & Vauras, 1994), whereas almost 100% of the 6-year-old Chinese-speaking children could say from 1 to 100 (Yang et al., 1985).

In another study, Miller and Stigler (1987) compared the way in which 4- to 6-year-old Taiwanese and American children counted and demonstrated striking differences. They found that the Taiwanese children performed much better than the American children in abstract counting (i.e. producing numerical sequences in correct orders). The American children were especially weak at counting the teens. When the children counted objects, there was no difference between the two groups of children in terms of their success in counting each object once. However, the Taiwanese children again performed significantly better than their American peers in producing the right number words in the correct order. Miller, Smith, and Zhang (1995) conducted a longitudinal study to examine the counting skills between 2- to 4-year-old children in China and the United States. They found that the 2-year-old children in both countries had difficulty in reciting a list of 10 items. However, their performance started to diverge around 3 and 4 years. By the age of 4, the Chinese children could recite number names up to 100, while only a few children from the United States could do so.

The number words in a regular system may also make additive composition rather explicit. Additive composition of number refers to a property of numbers that any number 'n' can be broken down into two others that are smaller than it and that these two numbers add up exactly to 'n'. Understanding a base system involves the awareness that 14 can be decomposed into one ten plus four ones. In a regular numeration system, the words used with 'ten' and 'four' highlight this particular way of decomposing this number, which may contribute to the relatively early mastery of the concept of additive composition in children who use a more regular numeration system. Miura (1987) investigated the potential influence of East Asian languages on numerical representations among Japanese- and English-speaking first graders who resided in the United States. The children were first introduced some base-ten blocks. There were two types of blocks – small cubes that represented a unit of one ('one' blocks), and three-dimensional rectangles that represented a unit of ten ('ten' blocks). The children were asked to show a set of five two-digit numbers with the blocks. Miura found that Japanese-speaking children tended to represent the two-digit numbers as a combination of the ten and one blocks (e.g., they used one 'ten' block and three 'one' blocks to represent '13'). In contrast, English-speaking children seldom chose to use 'ten' blocks to represent the two-digit numbers. Instead, they used 'one' blocks only (e.g., they used thirteen 'one' blocks for '13'). Miura found that around 75% of the Japanese-speaking children used correct combinations of ten and one blocks for all five two-digit numbers, whereas only around 50% English-speaking children did so. This study provided some early evidence that the number naming system may affect how children represent numbers.

Follow-up studies by Miura and colleagues demonstrated evidence remarkably similar to Miller's (1987) initial findings. For example, first graders who speak East Asian languages (Chinese, Korean, and Japanese) tended to use combinations of 'ten' blocks and 'one' blocks to represent two-digit numbers (Miura, Kim, Chang, & Okamoto, 1988), whereas those who speak European languages (English, French, and Swedish) tended to use 'one' blocks only (Miura, Okamoto, Kim, Chang, Steere, & Fayol, 1994). All East Asian children in their studies showed at least one of the five numbers with the correct combinations of tens and ones. In contrast, around 50% of the English-speaking children did not use this kind of number representation at all (Miura, Kim, Chang, & Okamoto, 1988). These studies suggest that East Asian children may differ significantly from non-East Asian children in the types of representation they used for two-digit numbers. More recently, Miura and Okamoto (2003) replicated findings from previous studies by showing that most first graders from France, Sweden, and the United States used one-to-one correspondence to represent two-digit numbers, whereas the first graders from Korea and Japan tended to represent the numerals with a canonical base-ten representation. This finding suggests that East Asian children may have developed the concept of place values as an integral part of their numerical representations at a young age, while at the same time the English-speaking children may represent numbers as a group of counted objects.

Counting with the Chinese number words may also relate to the type of strategies that children used to solve mathematical problems. For example, Geary, Bow-Thomas, Fan, and Siegler (1993) found that Chinese children abandoned finger counting and used verbal counting during preschool years, while children in the United States shifted from finger counting to verbal counting until the end of first grade. They also found that the Chinese children solved 3 times more addition problems than the children from the United States at the same age. Geary and colleagues (1993) argued that the relatively shorter Chinese number words facilitate children to keep track of the numbers, so they acquire the ability to count verbally earlier than English-speaking children. The spare working memory resources are important for mathematical development because they could be used for carrying out more efficient problem-solving procedures.

These studies suggest that language may be an important factor that affects children's understanding of the number structure, counting, and arithmetic calculation. The regular structure of the numerical sequence in the Chinese language may be beneficial for the acquisition of counting skills and the cognitive representation of numbers. Given that there are several cross-cultural differences in children's learning mathematics, the strengths and relations among various factors in relation to mathematics learning may also vary. For example, in a longitudinal study, Ching and Nunes (2016) found that procedural counting was not a unique predictor of children's performance in calculation. This finding is at odds with those obtained from children in the United States and European countries (e.g., Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Koponen, Aunola, Ahonen, & Nurmi, 2007; Koponen, Salmi, Eklund, & Aro, 2013; Passolunghi, Vercelloni, & Schadee, 2007). Ching and Nunes (2016) argue that the discrepancy may be attributable to the languages that the participating children speak in different research. They found that the children in their study performed exceptionally well in procedural counting, which makes the variation of children's performance on this task so small that reduces the strength of its connection with mathematical achievement. Would mathematics anxiety, relative to other cognitive variables, be an important factor that affect Chinese children's mathematics learning? Based on previous research, it is possible that Chinese children may generally feel not so anxious about basic arithmetic problems. In other words, mathematics anxiety evoked by these problems is low and hence, may not play a significant role in children's learning and performance. These questions clearly remain to be examined in empirical studies, testing whether past findings regarding the relative contributions of mathematics anxiety could be replicated in this understudied cultural context.

Overview of the Present Study

The aim of the present study was to investigate the connection between mathematics anxiety and mathematical performance in the early stages of mathematics learning. This study would contribute to the literature in several ways. First, it is a longitudinal study that followed a group of Chinese children from the age of 7 to 8 (grade two to grade three). No previous research has examined this population before. Second, to evaluate whether mathematics anxiety is a unique predictor of performance, this study controlled for the effects of a variety of cognitive factors that are known to contribute to children's mathematical competence. For example, some studies showed that general intelligence was the best independent predictor of a range of academic achievements, including mathematics (e.g., Deary, Strand, Smith, & Fernandes, 2007; Jensen, 1998; Stevenson, Parker, Wilkinson, Hegion, & Fish, 1976; Taub, Floyd, Keith, & McGrew, 2008; Walberg, 1984). In a large-scale 5-year longitudinal study involving 70,000 students, Deary et al. demonstrated that intelligence contributed to 60% of the variance of students' performance on a national mathematics test. In addition to general intelligence, number facts knowledge represents another important factor that contributes to children's mathematics learning (Cowan, 2003). Limited knowledge of simple addition combinations, for example, is often found in children with mathematics difficulties (e.g., Geary & Brown, 1991; Hanich, Jordan, Kaplan, & Dick, 2001; Jordan, Hanich, & Kaplan, 2003; Jordan & Montani, 1997; Russell & Ginsburg, 1984). Despite the importance of general intelligence and number fact knowledge in children's mathematics learning, these two variables were not considered in any of the previous longitudinal studies that examined mathematics anxiety in children. The present study took these factors into account when examining the relative contributions of mathematics anxiety to children's performance in different tasks.

Third, this study has dealt with the question of specificity in two ways. Mathematics anxiety seems on the face of it to be an individual difference that specifically affects children's progress in mathematics, but not in other, non-mathematical subjects. This, however, has to be checked empirically, which can be achieved in a longitudinal study by including control outcome measures (Bradley & Bryant, 1983). The issue of specificity was not commonly addressed in prior research on mathematics anxiety. In the current study, Chinese word reading was included as a control outcome measure. If the role of mathematics anxiety in children's progress in school is specific to mathematics, the levels of anxiety should predict children's success in mathematics much better than their success in word reading. To further establish that mathematics anxiety is not simply a proxy measure for general anxiety and test anxiety, the present study included all three forms of anxiety and attempted to disentangle their effects in the analyses.

Hypotheses

Prior research has been inconclusive with respect to whether and how mathematics anxiety influences children's mathematical performance, with some studies suggested that it affects children differentially depending on the types of mathematical tasks and individual differences in cognitive resources. Research has shown that working memory capacity makes a difference in performance and there have been competing hypotheses about who is more prone to performance deficits because of working memory disruption. One perspective contends that individuals with higher working memory have more cognitive resources to deal with anxiety-related thoughts and to solve the mathematical problem at hand. Another perspective postulates that individuals with higher working memory are more vulnerable to performance decline because of working memory disruption. Because it is assumed that mathematics anxiety compromise working memory resources, the effects of disruption have been found predominantly in more difficult problems that require more processing resources. Based on the research that were conducted with children (e.g., Ramirez et al., 2013, 2016; Vukovic et al., 2013; Wu et al., 2012), the present study aimed to address the following hypotheses:

Hypothesis 1: Mathematics anxiety makes an independent and negative contribution to children's mathematical performance in difficult problems beyond the influence of cognitive abilities, such as non-verbal intelligence and number skills.

Hypothesis 2: Children who are high in working memory are most susceptible to performing poorly in difficult mathematical problems as a function of mathematics anxiety. Mathematics anxiety is negatively associated with children's performance in difficult problems among high-working memory children.

Research Design

In summary, the present study was a one-year longitudinal study that followed a group of Chinese children from grade two to grade three. Several variables were assessed during the first wave of data collection (Time 1), including mathematics anxiety, general anxiety, test anxiety, working memory, non-verbal intelligence, and a variety of number skills. The second testing occasion (Time 2) (one year later during the third grade of the children) comprised two tasks that assessed mathematical performance – calculation and story problem solving. Each of these tasks was divided into two levels – easy and difficult. 'Easy' problems in the calculation tasks involved single-digit addition and subtraction, whereas 'difficult' problems involved double-digit addition and subtraction that taxed more cognitive resources (more details to be found in the Method section). The story problems were categorized on the basis of previous studies (e.g., Carpenter, Hiebert, & Moser, 1981; Carpenter & Moser, 1982; De Corte, & Verschaffel, 1987) that examined the relative difficulty of different types of story problems. Solving an additive story problem has been viewed as selecting and activating appropriate cognitive schema and filling the empty 'slots' of the activated schema with information provided in the story text. Some of these problem types (e.g., result-unknown Change problems and total set-unknown Combine problems) are suggested to link easily to counting or calculation schemes readily available in individuals' cognitive repertoire (Carpenter, Hiebert, & Moser, 1981; Carpenter & Moser, 1982; De Corte, & Verschaffel, 1987). Other more difficult problems (e.g., start-unknown Change problems) require additional re-representational steps that involve the application of the part-whole schema before a connection with a proper counting or operation scheme could be formed. These studies formed the basis of choice of 'easy' and 'difficult' story problems in the present study (more details to be found in the Method section). Finally, Chinese word reading was included as an outcome control measure to test the specificity of mathematics anxiety on mathematical performance. The independent contribution of mathematics anxiety measured at Time 1 to mathematical achievement at Time 2 was assessed by taking into account the effects of age, demographic factors, and other cognitive factors. For each child, the interval between the first and second wave of assessments was between 12 and 13 months, with 12 months being the commonest interval (93%).

Method

Participants

The final sample consisted of 246 Chinese children in Hong Kong in the third grade (132 girls). All children spoke Cantonese and attended the second year of primary school, with a mean age of 86.25 months (*SD* = 2.34 months, ranging from 83.8 to 89.1 months), during the first wave of assessment (N = 251). Five children dropped out of the study in the second wave of assessment and the mean age of the participants during this phase (third grade) was 98.25 months (N = 246). All the children were reported to have intelligence within the range accepted as normal for their ages, and did not have learning difficulties or emotional/behavioral problems, such as, dyslexia, specific language impairments, attention deficits and hyperactivity disorders, or any neurological disorders. The highest educational levels attained by the mothers of the children in the sample were as follows: No schooling/pre-primary school level – 8.1%, primary school graduates – 20.3%, secondary school graduates – 48.4%, and university graduates – 23.2%. According to the Hong Kong Population Census (2011), the distribution of educational attainment (highest level attained) was: No schooling/pre-primary school level – 10%, primary school graduates – 19.2%, secondary school graduates – 46.6%, and university graduates – 24.1%. Thus, the relative distribution of the mothers' educational levels was similar to that of the overall Hong Kong population.

Measures

Mathematics anxiety.

A Chinese version of a measure of mathematics anxiety was adapted from the one used with young children in Harari, Vukivic, and Pailey's (2013) study. In this 12-item measure, children responded to each of the 12 items (e.g., 'I am scared in math class', 'I get nervous about making a mistake in math', 'I like being called on in math class') on a 4-point Likert scale ('yes = 4, kind of = 3, not really = 2, no =1'). To standardize administration and reduce the demands on reading, the researcher read aloud each question to the children. Because some of the items had a positive valence (e.g., 'I like to raise my hand in math class') and some have a negative valence (e.g., 'Getting out my math books makes me nervous'), numerical values were assigned to each item so that higher scores showed greater anxiety. The inclusion of items of positive and negative valence encouraged children to be thoughtful about their response to each statement rather than repeating the same response by rote. The maximum possible score of this scale was 48. The internal consistency of this measure was satisfactory (Cronbach's α = 0.81).

Working memory.

The forward and backward digit span tasks on the Wechsler Intelligence Scale for Children—Third Edition (Wechsler, 1991) were adapted to create the forward and backward letter span tasks used in this study. In the forward span task, children listened to a series of letters at a rate of one letter per second and were asked to repeat the letters in the correct order (e.g., 'B, F, M').

Each set size was assessed on two trials, and children started with the smallest set size of 2 to the possible largest set size of 9. Children who completed one or both trials at a particular set size successfully were asked to complete two additional trials at the next set size. The letters used for forward and backward letter span tasks were B, F, H, J, L, M, P, Q, and R. No letter was repeated within a set. The researcher always administered the forward span task before the backward span task. For each task, two practice items were given to the children and testing was terminated when a child failed two trials of the same length. All the participating children have learned the alphabets from A to Z since kindergarten. A composite score of these tasks (number of correct trials across forward and backward tasks) represented as the children's working memory capacity. The scores of the two tasks were combined because working memory is considered to be based on memory processes tapped by forward span (phonological loop) and by central executive functions measured by backward span (Baddeley, 2000). No feedback was given to the children in any of the trials. The maximum possible score of this task was 16.

General anxiety.

Because some research showed that mathematics anxiety correlated with measures of general anxiety (e.g., Hembree, 1990), the present study included the 6-item Anxiety Problems subscale of the Child Behaviour Checklist for the ages of 6 to 18 (Achenbach, 1991; Achenbach, Dumenci, & Rescorla, 2003) at Time 1 to measure children's general anxiety. In this measure, the parents/guardians of the children were asked to rate 6 items describing whether the child was currently displaying or had displayed within the last 6 months anxiety-related problems or traits. Items were rated on a scale of 1 (not true), 2 (somewhat true), or 3 (very true). In this study, a Chinese version of the Anxiety Problems subscale was used to control for general anxiety in the children. The maximum possible score of this scale was 18. The internal consistency of this scale was satisfactory (Cronbach's α = 0.91).

Test anxiety.

A Chinese version of the Children's Test Anxiety Scale (Wren & Benson, 2004) was used to assess children's anxiety of doing tests at Time 1. This scale was included in this study in order to separate the effects of test and mathematics anxiety on children's performance in mathematics. Children were asked to respond to 30 items in terms of how they think, feel, or act during a test (e.g., 'I worry about failing' 'My heart beats fast'). Each item was responded to with the stem, 'While I am taking tests…' with four response options (i.e., almost never = 1, some of the time =

2, most of the time = 3, almost always = 4). The maximum possible score of this scale was 120. The internal consistency of this scale was satisfactory (Cronbach's α = 0.88).

Non-verbal intelligence.

Children's general intelligence was measured with Raven's Standard Progressive Matrices (Raven, Raven, & Court, 2003) at Time 1 as a control variable. This test was used because it has been a robust measure of non-verbal aspect of intelligence and has been used widely in previous research. It is a standardised test including five sets of twelve items each. Each item involves a target matrix with a missing piece. Children were asked to choose, from six or eight alternatives, the best figure to complete the target matrix. One mark was given for the correct answer for each item.

Number skills.

Children's number skills were assessed at Time 1 as a control variable and were indicated by their knowledge of numbers and procedural counting ability. The items that assessed number knowledge were adapted from the Number Knowledge test in Griffin (1997). Four subtasks were presented in the same fixed order for all children: number sequence knowledge, relative magnitude, numerical distance, and differences. Each subtask contained practice items and six test items. The researcher showed the numbers on a computer and read aloud to the children. In the *number sequence* items, children were asked to name the number in a specific position in the number sequence. The three practice items were 'What number comes right after 6?' 'What number comes before 8?' and 'what number comes two numbers after 4?' The test items were 'two numbers after 7,' 'right after 9,' 'five numbers after 49,' 'four numbers before 60,' '10 numbers after 99,' and 'nine numbers after 999.' In the *relative magnitude* items, children were asked to identify the bigger of two numbers. Practice items were 'which is bigger: 5 or 4'? and 'which is bigger: 6 or 7?' The pairs of numbers in the test items were (9 & 6), (13 & 17), (69 & 71), (32 & 28), (51 & 39), and (199 & 203). In half of the test items, the first number in each pair was the larger of the two. In the *numerical distance* items, children were asked to identify which of two numbers was closer to a particular number. Practice items were 'Which number is closer to 3: 2 or 6?' and 'Which number is closer to 4: 6 or 1?' The numbers in the test items were '7: 4 or 9?' '13: 14 or 11?' '21: 25 or 18?' '49: 51 or 45?' '28: 31 or 24?' '102: 98 or 109?' In the *differences* items, children were required to identify which of two pairs of numbers had the larger difference. The practice item was 'which difference is bigger: the difference between 4 and 2 or the difference between 6 and 3?' The test items involved the following pairs of numbers: (10 & 5) vs. (10 & 7); (9 & 6) vs. (8 & 3); (6 & 2) vs. (8 & 5); (20 & 17) vs. (25 & 20); (25 & 11) vs. (99 & 92); (48 & 36) vs. (84 & 73). For each of the above subtasks, testing was terminated after the child had made three errors. The maximum possible score is 24.

Procedural counting was assessed with two tasks: oral rote counting and object counting. In oral rote counting, children counted some numerical sequences verbally in ascending and descending orders. They were first asked to count from 5 to 16 as a practice trial. There were then eight testing trials in which children were asked to count a set of numbers in ascending orders (e.g., 25 to 32; 56 to 63; 76 to 81; 118 to 123) and in descending orders (e.g., 46 to 38; 73 to 65; 34 to 27; 121 to 115). Testing within a set was discontinued when a child had committed errors on two sequences in a set. Children received one point for each sequence completed correctly. Another task, object counting, was also included as one of the measures of procedural counting to test whether the children could count correctly using one-to-one correspondence between words and objects. In object counting, they were required to count two trials of geometric shapes (e.g., circles, squares) and two trials of recognizable objects (e.g., pens, rubber). The numbers of objects were 6, 9, 13, and 15 for rubber, pens, squares, and circles, respectively. On any given trials, the objects were identical in appearance. The order of task presentations was counterbalanced across participants. Children received one point for each correct counting. The total scores for procedural knowledge of counting for each child was the sum of his/her performance on the oral rote and object counting tasks. The maximum possible score was 12. A composite score indicating number skills for each child was form by combining the scores on the number knowledge and the counting tasks (maximum possible score = 36). The internal consistency of the entire number skills measure was satisfactory (Cronbach's $\alpha = 0.84$).

Demographic characteristics.

Other control variables included demographic information reported by parents in a questionnaire, namely children's gender and mothers' highest education level at Time 1. Mothers' highest educational level has been regarded as a proxy variable for socioeconomic status. Among various indicators of socioeconomic status, Nunes, Bryant, Sylva, and Barros (2009) showed that mothers' highest educational level was the best predictor of mathematical achievement. Therefore, it was selected as the indicator of socioeconomic status in the present study.

Calculation.

The calculation tasks were measured at Time 2, which involved twenty problems, all of which were designed with reference to the curriculum guide developed by the Hong Kong Education Bureau. Children were orally presented with addition and subtraction combinations that involved ten addition and ten subtraction problems. Half of the addition problems and half of the subtraction problems were considered as 'easy' items that consisted of single-digit addition and subtraction (e.g., 7 + 8; 9 – 5), whereas the rest of the problems were more difficult that involved double-digit addition and subtraction (e.g., 14 + 17; 32 – 14). Double-digit problems are assumed to tax more processing resources so that they were used to test whether mathematics anxiety affects children's performance on difficult items only. A printed version of each calculation problem was presented as each problem was read and kept in full view of the child during problem solving. Feedback was not provided and no time limit was set. The maximum possible score for calculation was 20. The calculation task appeared to have good internal consistency (Cronbach's $\alpha = .82$).

Story problem solving.

The story problems were categorized on the basis of previous studies (e.g., Carpenter, Hiebert, & Moser, 1981; Carpenter & Moser, 1982; Ching & Nunes, 2016, 2017; De Corte, & Verschaffel, 1987; Riley, Greeno, & Heller, 1983) that examined the relative difficulty of different types of story problems. Solving an additive story problem has been viewed as selecting and activating appropriate cognitive schema and filling the empty 'slots' of the activated schema with information provided in the story text. Some of these problem types (e.g., result-unknown Change problems and total set-unknown Combine problems) are suggested to link easily to counting or calculation schemes readily available in individuals' cognitive repertoire (Carpenter, Hiebert, & Moser, 1981; Carpenter & Moser, 1982; De Corte, & Verschaffel, 1987). Other more difficult problems (e.g., start-unknown Change problems) require additional re-representational steps that involve the application of the part-whole schema before a connection with a proper counting or operation scheme could be formed.

For example, Vergnaud (1979) hypothesised that children have an idea of addition on the basis of the schema of action of joining sets. This schema is useful for solving problems that involve transformation of a quantity by addition (e.g., 'David had 8 books. Then Peter gave him 3 more books. How many books does David have now?') or problems that involve a combination of quantities into a single whole (e.g., 'Grace has 3 flowers. Henry has 5 flowers. How many flowers do they have altogether?'). However, this schema is not sufficient for solving problems in a transformation situation in which the quantity decreases while the initial quantity is unknown (e.g., 'Alex had some cookies. He gave 3 cookies to his mother and had 8 cookies left. How many cookies did he have before?'). To solve this kind of problem, addition has to be seen as the inverse of subtraction. Thus, more cognitive resources are needed for transforming a story that on the surface is about addition into a subtraction problem and vice versa.

In some problems that involve comparisons, children must also think of the relation 'more than' as the inverse of 'less than' (e.g., Verschaffel, 1994). For example, if the reference set is the missing information (e.g., 'Tom has 9 cups. He has 5 more cups than Ivy. How many cups does Ivy has?'), the relation (described as 'more than') in this problem is inconsistent with the operation (i.e. subtraction) to be used to solve the problem. If children are not able to conceive the relation 'more than' as the inverse of 'less than' and vice versa, this kind of reference-set comparison problems is likely to be difficult for them. Similarly, more cognitive resources are necessary for children to solve these kinds of problems than those that were more straightforward.

Based on previous research, twenty-four problems were created to form the 'easy' and 'difficult' story problems in this study. Twelve 'easy' problems involved: four result unknown Change problems, four change unknown Change problems, and four unknown difference set Compare problems. Twelve 'difficult' problems included: four start unknown Change problems, four unknown reference set Compare problems, and four de-combine transformation problems (e.g., John played two games of marbles. In the second game, he lost seven marbles. His final result, with the two games together, was that he had won three marbles. What happened in the first game?). All problems involved numbers fewer than 10. To reduce the working memory demands of the task, the experimenter presented each child with a written version of the story problem as it was read and kept it in front of the child until the problem was solved. In this way, children were easier to keep track of the contents and to make relevant judgments accordingly. The maximum possible score for story problem solving was 24. The story problem solving task appeared to have good internal consistency (Cronbach's α = .88).

Chinese word reading.

A Chinese word reading task adapted from previous work (Ching & Nunes, 2015, 2016) was used in the present study. In this task, children were shown written two-character Chinese words and asked to read aloud. One point was given for each correct response. Thirty words were arranged from the easiest words at the beginning to the most difficult ones towards the end of the test. The maximum possible score for this task was 30. The internal consistency of this measure was satisfactory (Cronbach's α = 0.85). No feedback was given.

Procedure

Participating children were recruited through local schools and non-profit child-related community centers in Hong Kong. Parents were informed of the study via letters sent home by teachers or/and administrators. Upon receipt of parental consent, the children were asked for verbal assent and participated individually with the author in a quiet location, which was separate from other children in the primary school or center. At Time 1 (second grade), the children were tested in a 40-60 min sessions separated by approximately 1 week. For all children, order of task presentation was the same. At Time 2 (third grade), the children were tested in one session that lasted for approximately 20 to 30 minutes in which the Chinese word reading, calculation, and story problem solving tasks were administered. For each child, the interval between the first and second wave of assessments was between 12 and 13 months, with 12 months being the commonest interval (93%).

Results

Overview of Analyses

The aim of the present study was to investigate the relative importance of mathematics anxiety in children's mathematical performance in different tasks. Following similar studies in the past (e.g., Ramirez et al., 2013, 2015; Vukovic et al., 2013; Wu et al., 2012), multiple regression analysis was used to address the hypotheses of this study because it allows us to quantify the relation between a particular factor and mathematical achievement while holding the effects of other factors constant (Cohen & Cohen, 1983; Field, 2013; Pedhazur, 1997; Stevens, 2002; Tabachnick & Fidell, 2001). An overview of the analysis plan is described as follows.

First, the descriptive statistics were examined. The distributions of the scores of calculation and story problem solving at both waves of assessment were evaluated. If this normality assumption is violated, multiple regression analysis may not be an appropriate tool for data analysis. Second, the effects of demographic variables on mathematical performance were investigated. Demographic variables (e.g., gender of children, the highest educational levels of mothers) may explain both children's performance in working memory, general intelligence, and number skills, on one hand, and their mathematical achievement, on the other hand. Thus, it could be a third factor that explains the relation between a main predictor and mathematical achievement. There is a need to include these factors in subsequent regression models if children's performance on the predictors and mathematical performance differs across any of the demographic variables.

Third, the associations between variables were investigated. Examining the correlations allows us to have an initial idea of how each variable relates with each other. Finally, different sets of fixed order multiple regression analyses were examined. Control variables (i.e. non-verbal intelligence, working memory, number skills, trait and general anxiety) were entered as the first block, and mathematics anxiety was entered after the control variables to examine how much variance mathematics anxiety accounts for mathematical performance after the effects of all the other factors have been controlled for. An interaction term (mathematics anxiety x working memory) was created and entered in the final block after all variables to examine whether mathematics anxiety interacts with individual differences in working memory to influence children's performance on a mathematical task. In each of the regression models, we can also investigate whether individual variables are unique predictors of mathematical achievement. Thus, fixed order multiple regression analyses offer a good test of the hypotheses of this study because they indicate information regarding the relative contributions of each variable to mathematical performance (Cohen & Cohen, 1983; Field, 2013; Pedhazur, 1994; Stevens, 2002; Tabachnick & Fidell, 2001).

Insert Table 1 about here

Descriptive Statistics

Table 1 shows the descriptive statistics for each variable. Of concern is whether the scores of the outcome measures of mathematical achievement are normally distributed. The distributions of children's scores on calculation and story problem solving were analysed in relation to the z-values of Skewness and Kurtosis of each outcome variable. The z-value of Skewness was calculated by dividing the Skewness value by its standard errors, whereas z-value of Kurtosis was calculated by dividing the Kurtosis value by its standard error. Table 1 shows that none of the z-values are higher than 1.96, suggesting that the scores do not violate the normality assumption.

Influence of Demographic Factors

Demographic variables may explain differences in children's scores mathematics anxiety as well as the scores in mathematical performance. To assess the effects of demographic variables on mathematical performance, independent t-tests with children's gender and one-way analyses of variance (ANOVA) with mothers' educational level as a fixed factor were conducted for mathematics anxiety and each measure of mathematical performance. All variables showed no evidence of significant influence of children's gender and mothers' educational level (all *p* values >.05).

Associations between Variables

The next set of analyses explores the correlations between mathematics anxiety and other variables. Table 2 shows the bivariate correlations between the variables and several key findings are identified. First, mathematics anxiety correlated negatively with both the scores on calculation and story problem solving, but it did not correlate with Chinese word reading. This finding suggests that mathematics anxiety was a specific predictor of children's mathematical performance. Second, significant positive correlations were found between mathematics anxiety and the other two forms of anxiety, namely general and test anxiety. Third, children's performance on calculation and story problem solving had significant correlations with non-verbal intelligence, working memory, and number skills. Non-verbal intelligence and working memory were also associated with Chinese word reading, suggesting that they were not specific predictors of mathematical performance.

Insert Table 2 about here

Multiple Regression Analyses

On the basis of the correlation analyses only, it remains unclear whether the contribution of mathematics anxiety on mathematical performance is unique because the different predictors may share variance in explaining children's performance. Thus, multiple regression analyses were used to examine the hypotheses of this study, evaluating the independent contributions of mathematics anxiety to children's performance in calculation and story problem solving (Tables 3 and 4). Prior to each of the following analyses, assumptions of regression analyses were checked and showed no breaches to normality, linearity, homoscedasticity, multicollinearity, and auto-correction.

The first hypothesis of this study states that mathematics anxiety makes an independent and negative contribution to children's mathematical performance in difficult problems beyond the influence of other forms of anxiety and cognitive abilities, such as non-verbal intelligence and number skills. The analyses began by regressing children's scores on the difficult calculation problems on their mathematics anxiety, general anxiety, test anxiety, working memory, non-verbal intelligence, and number skills, as well as the interaction of mathematics anxiety x working memory. Significant main effects were found for mathematics anxiety ($\beta = -0.433$, $t = -7.306$ $p < .001$), non-verbal intelligence ($\beta = 0.121$, $t = 2.038$, $p < .05$), and working memory ($\beta = 0.198$, $t = 3.354$, $p < .001$). The finding that mathematics anxiety made an independent contribution to difficult calculation beyond various cognitive factors supported the first hypothesis.

The second hypothesis states that mathematics anxiety is negatively associated with children's performance in difficult problems among high-working memory children. Consistent with this hypothesis, the main effect of mathematics anxiety was qualified by a significant interaction of mathematics anxiety x working memory ($\beta = -0.299$, $t = -4.676$, $p < .001$). For children who had relatively high working memory, there was a pronounced negative association between mathematics anxiety and performance on difficult calculation problems. This association was not evident among children who had relatively low working memory. As for easy calculation problems, both the main effect of mathematic anxiety ($\beta = -0.121$, $t = -1.84$, $p > .05$) and the interaction ($\beta = -0.087$, $t = -1.183$, $p > .05$) were not significant.

Insert Table 3 about here

Converging evidence was demonstrated in the regression analyses on children's scores on the difficult story problems. Significant main effects were found for mathematics anxiety ($\beta = -0.337$, $t = -5.512$, $p < .001$), non-verbal intelligence ($\beta = 0.155$, $t = 2.512$, $p = .013$), and working memory ($\beta = 0.207$, $t = 3.401$, $p = .001$). Similar to difficult calculation problems, the main effect of mathematics anxiety was qualified by a significant interaction of mathematics anxiety x working memory ($\beta = -0.221$, $t = -3.272$, $p = .001$). A pronounced negative association between mathematics anxiety and performance on difficult story problems was observed in children with higher working memory only, but not in children with lower working memory. As for easy story problems, both the main effect of mathematic anxiety ($\beta = -0.136$, $t = -1.876$, $p > .05$) and the interaction ($\beta = 0.008$, $t = -0.109$, $p > .05$) were not significant. These findings provide further evidence that when high-working memory children have high mathematics anxiety, their performance is particularly impaired on those mathematical problems that typically demand more working memory resources.

Insert Table 4 about here

To evaluate the issue of specificity of the prediction of mathematics anxiety, the above analyses were rerun with Chinese word reading as the outcome variable. In contrast to children's mathematical performance, both the main effect of mathematics anxiety ($\beta = 0.068$, $t = 1.039$, $p > .05$) and the interaction of mathematics anxiety x working memory ($\beta = 0.001$, $t = 0.016$, $p > .05$) were not significant. Therefore, children's scores on mathematics anxiety related to mathematical performance but not reading achievement, suggesting that it carries specific contributions to mathematical achievement instead of general academic achievement.

Discussion

This study examined mathematics anxiety in a group of Chinese children followed from second to third grade. The extant research has shown mixed findings regarding the connection between mathematics anxiety and children's mathematical performance. Building on this research, the present study addressed two hypotheses: (1) Mathematics anxiety makes an independent and negative contribution to children's mathematical performance in difficult problems beyond the influence of cognitive abilities, such as non-verbal intelligence and number skills; and (2) Children who are high in working memory are most susceptible to performing poorly in difficult mathematical problems as a function of mathematics anxiety. Mathematics anxiety is negatively associated with children's performance in difficult problems among high-working memory children. Consistent with the first hypothesis, this study has demonstrated that individual differences in mathematics anxiety correlated negatively with children's performance in calculation and story problem solving. The negative relations could not be explained by individual differences in general and test anxieties, non-verbal intelligence, working memory, and number skills. Mathematics anxiety made independent contributions to variations in mathematical performance only, but not to word reading. The present study has replicated the main effects of mathematics anxiety on mathematical performance that were observed in previous research in a group of Chinese children for the first time. It provides evidence that mathematics anxiety at an earlier age is a unique longitudinal predictor of children's mathematical achievement. Little is known about the extent to which mathematics anxiety relates to Chinese children's mathematical performance. The present study has replicated the findings from previous research done with children in the United States and European countries, showing that mathematics anxiety is also a unique source of individual differences in Chinese children's mathematical performance. However, mathematics anxiety does not affect all children and all kinds of mathematical performance equally. Consistent with the second hypothesis, it appears that only children who were high in working memory were adversely affected by mathematics anxiety and only the performance in difficult mathematical problems were impacted. The key findings are elaborated more specifically in the following discussion.

Mathematics Anxiety: An Independent Predictor

Past studies suggest that the regular structure of numerical sequence in the Chinese language may facilitate children to acquire counting skills earlier and develop a stronger understanding of numbers that contributes to their superior performance in mathematics compared with non-Chinese speaking peers. It remains unclear to what extent mathematics anxiety matters for Chinese children because mathematics may not be a significant source of anxiety for them. However, although the present study showed that cognitive factors, such as non-verbal intelligence, working memory, and number skills contributed positively to children's mathematical performance, these cognitive factors do not tell the entire story about why some children perform well/poorly in mathematics. The negative association between mathematics anxiety and children's performance in both calculation and story problem solving remained significant even the effects of non-verbal intelligence, working memory, and number skills were controlled for. Thus, it appears that mathematics anxiety also represents an independent source of individual differences in mathematical performance in Chinese children, consistent with the evidence gleaned from the children in the United States and European countries. However, given that the correlations between the cognitive covariates and mathematical performance were not strong in this study, the effects of other cognitive factors that play a more significant role in Chinese children's learning of mathematics, such as logical reasoning (Ching & Nunes, 2016), may also be considered in future studies. Overall, the longitudinal findings of the current study suggest that mathematics anxiety at an earlier age predicts children's later mathematical achievements, which support a recent proposal to identify potential non-cognitive sources of children's mathematical difficulties (Fletcher, Denton, & Francis, 2005; Francis et al., 2005; Vukovic, 2012). In addition to cognitive factors, mathematics anxiety is also an important factor to consider when studying sources of individual differences in children's mathematical competence.

Some previous studies have reported differences between high and low mathematics-anxious people in tasks not requiring working memory resources, such as a visual enumeration task and comparison tasks (e.g., Maloney, Ansari, & Fugelsang, 2011; Núñez-Peña & Suárez-Pellicioni, 2014). Based on reaction time measures, both studies demonstrated that high mathematics-anxious individuals showed a larger distance effect and a larger size effect (longer reaction times to comparisons that involve larger numbers) than low mathematics-anxious individuals. Their findings suggest that people with higher levels of mathematics anxiety may have less precise representations of numerical magnitude than people with lower levels of mathematics anxiety. However, the present study reported two results that do not agree with those reported by Maloney and colleagues and Núñez-Peña and Suárez-Pellicioni. First, only performance in difficult mathematical problems was affected by mathematics anxiety. Second, the correlation between math anxiety and number skills (including comparison tasks) was not significant ($r = .022$). These results suggest that mathematics anxiety may not be related to a low-level numerical deficit. However, it is difficult to make direct comparisons of findings across these studies because the age of participants and the outcome indicators differ. The participants in previous studies (Maloney, Ansari, & Fugelsang, 2011; Núñez-Peña & Suárez-Pellicioni, 2014) were adults and participants' reaction times were used as indicators for mathematical performance. By contrast, the present study involved children and their mathematical performance was indicated by accuracies in problem solving. In addition, the current study did not require the children to complete the mathematical problems within a time limit. It is possible that mathematics anxiety may also have an impact on performance for easier items if children have time pressure to finish the tasks, but this should be verified in future studies.

The finding that children were negatively affected by mathematics anxiety only when they were asked to complete difficult mathematical problems aligns with some studies that did not show a significant relation between mathematics anxiety and basic calculation ability in children (e.g., Krinzinger et al., 2009; Thomas & Dowker, 2000; Vukovic et al., 2013; Wu et al., 2012). Vukovic and colleagues (2013) showed that there was a significant negative association between second-grade mathematics anxiety and third-grade performance on mathematical applications, but not in arithmetic problems, among children with higher working memory. They suggest that mathematics anxiety appears to be a barrier to learning mathematical applications (but not basic arithmetic problems) for children with higher working memory over time. However, the researchers did not differentiate difficult problems from easy ones for both arithmetic and mathematical applications problems. The present study suggests that the distinction may be important because mathematics anxiety did not impair the performance for all kinds of story problems – only the performance on difficult story problems that are cognitively demanding was affected. Similarly, this study showed that the performance for arithmetic problems could also be impaired by mathematics anxiety if these problems are cognitively demanding. In conjunction with the theory proposed by Vukovic et al. (2013), the longitudinal evidence from the current study suggests that mathematics anxiety may present an obstacle to learning of all kinds of difficult or cognitively demanding mathematical problems, whereas the anxiety for simple mathematical problems may not last long enough that pose a significant impact on children's learning and performance for these tasks over time.

The present findings have extended past research by disentangling the effects of mathematics anxiety from general anxiety and test anxiety. This is an important finding because some previous work has suggested that the connection between mathematics anxiety and mathematical performance is influenced by other forms of anxiety (Dew, Galassi, & Galassi, 1983; Hembree, 1990; Baloglu & Koçak, 2005). For example, Hembree (1990) showed an average correlation of 0.35 between mathematics anxiety and general anxiety. Consistent with these studies, the present findings also indicated significant correlations between mathematics anxiety and both general and test anxiety. However, the contribution of mathematics anxiety to children's mathematical performance held significant even after the effects of general and test anxiety were controlled for. This result suggests that the detrimental impact of mathematics anxiety on mathematical performance persists regardless of whether children are inclined to be anxious overall or whether they have anxiety about taking tests in general.

The current work also showed that the effects of mathematics anxiety were specific to mathematics, but not to Chinese word reading, a non-mathematical subject. In this study, a control outcome measure was put in to evaluate the issue of specificity. If the role that mathematics anxiety plays in children's progress in school is specific to mathematics, children's levels of mathematics anxiety should predict their mathematical success much better than their success in some other non-mathematical outcome measure. Thus, the finding that mathematics anxiety was not relevant to children's performance in word reading suggests that mathematics anxiety is a domain-specific predictor of mathematical achievement.

The Interaction: Mathematics Anxiety and Working Memory

Given the evidence of the connection between mathematics anxiety and mathematical performance, a further question concerns the psychological mechanism underlying this connection. The present study explored the role of working memory in modulating the relation between mathematics anxiety and children's mathematical performance. There are two competing views regarding whether individuals with high mathematics anxiety or individuals with low mathematics anxiety are more vulnerable to performance deficits as a consequence of working memory disruption. One view is that if a person has a higher working memory capacity, s/he can use the cognitive resources to deal with the anxiety and the mathematical problem at hand. By contrast, proponents of another view suggest that a person with higher working memory capacity is more susceptible to performance decline as a result of working memory disruption. For example, Ramirez and colleagues (2013, 2016) argue that children who are high in working memory are most affected by mathematics anxiety because anxiety interferes with the cognitive resources that support these children's performance in mathematics (Beilock & Carr, 2005; Beilock & DeCaro, 2007; Ramirez et al., 2013, 2016; Vukovic et al., 2013). Consistent with this perspective, the present study showed that the negative association between mathematics anxiety and mathematical performance was present only among children who were higher in working memory but not among their peers with lower working memory. These findings were consistent with past research demonstrating that the influence of mathematics anxiety is specific to mathematical performance for individuals with higher levels of working memory (Beilock & Carr, 2005; Beilock & DeCaro, 2007; Ramirez et al., 2013, 2016). Therefore, the deleterious effects of mathematics anxiety on mathematical performance may not be present in all children.

Why does mathematics anxiety influence children with higher working memory to a greater extent than children with lower working memory? Ramirez and colleagues (2013, 2016) suggest that mathematics anxiety makes high-working memory children use less developmentally advanced problem-solving strategies, which leads to a drop of performance. For example, when solving arithmetic problems, children initially resort to simple strategies such as, finger counting at the start of formal schooling. With practice, they gradually develop more automatic problem-answer associations (e.g., the answer 6 is associated with 4 + 2). These associations form the basis of more advanced problem-solving strategies, such as direct retrieval and decomposition (Siegler & Shrager, 1984). Direct retrieval refers to the direct recalling of the answer to a problem from memory, whereas decomposition requires individuals to break down the numbers in the problem into small sets and reconstruct the problem (e.g., to solve 7 + 8, a person who uses decomposition would break it down to (5 + 2) + (5 + 3), retrieving the answer to 5 + 5, and then adding the other numbers). These strategies are important for children to achieve further in mathematics and previous studies suggest that they are linked to higher conceptual understanding and mathematical achievement (Barrouillet & Lépine, 2005; Geary, 1993; Geary, 2011). Because advanced problem solving usually involve multiple steps, it places high demands on working memory, requiring individuals to retrieve number facts from long-term memory, inhibit competing answers, and maintain intermediate steps (DeStefano & LeFevre, 2004; Zbrodoff & Logan, 1986). Indeed, it has been shown that children with higher working memory used more advanced strategies and had higher achievement in mathematics than their peers with lower working memory (Barrouillet & Lépine, 2005; Geary, 1993; Geary, 2011).

However, these strategies were particularly susceptible to interference on cognitive resources (Gavens & Barrouillet, 2004; Mattarella-Micke & Beilock, 2010). Mathematics anxiety may negatively impact the mathematical performance of children with higher working memory because it co-opts the working memory resources that the children use to support advanced problem-solving strategies (Ashcraft & Kirk, 2001; Beilock & Carr, 2005; Ramirez et al., 2013), which typically help high-working memory children perform well in mathematics. Other researchers (e.g., Ramirez et al., 2016) also suggest that mathematics anxiety makes children with high working memory to shift their problem-solving strategies to less advanced ones to circumvent the burden of mathematics anxiety on working memory. The use of less advanced strategies may then result in poorer performance. By contrast, the mathematical performance of children with low working memory remains comparatively unaffected (still low) by mathematics anxiety. It is because these children typically resort to less complicated problem-solving strategies (e.g., finger counting) that demand fewer working memory resources. Recently, in support of this perspective, Ramirez and colleagues (2016) provided evidence that the negative relation between mathematics anxiety and performance was mediated by less frequent use of developmentally advanced problem-solving strategies.

If the strategy account is correct, then we should find the interaction between mathematics anxiety and working memory among difficult, but not easy, mathematical problems. The present study provides evidence that supports this account. Specifically, the present findings showed that a pronounced negative association between mathematics anxiety and performance was present only on difficult mathematical problems in children with higher working memory, but not in children with lower working memory. The results were consistent with previous research that examined the influence of anxiety on mathematical performance in both adult (Ashcraft & Kirk, 2001; Beilock & Carr, 2005; Beilock & DeCaro, 2007) and children samples (Ramirez et al., 2013, 2015; Vukovic et al., 2013; Wu et al., 2012). In sum, this study has provided evidence that mathematics anxiety does not affect all children and all types of mathematical performance in a similar manner.

Limitations and Future Directions

The present study has some limitations that raise questions for further investigations. First, the anxiety-performance link has two possible causal directions (Carey et al., 2016) – the deficit theory postulates that poor mathematical performance generates higher levels of anxiety (Maloney et al., 2011; Tobias, 1986), whereas the debilitating anxiety model suggests that anxiety hampers performance by taxing processing resources (e.g., Ashcraft & Kirk, 2001; Beilock & Carr, 2005). It is also possible that previous achievement in mathematics affects a person's level of mathematics anxiety and that anxiety in turn influences future performance in mathematics. In other words, mathematics anxiety and performance may be reciprocally related. Although the current research design is longitudinal, it does not allow us to draw a definitive conclusion about the temporal order of anxiety and performance because mathematical achievement tasks were measured at one time point only (during the second wave of assessment). However, the present study did not only show a connection between mathematics anxiety and performance, but also an interaction between mathematics anxiety and working memory. The interactive effects on mathematical performance may be easier to interpret within the debilitating anxiety framework. That is, mathematics anxiety co-opts the cognitive resources that supports the use of advanced problem-solving strategies used by children with higher working memory, which impairs their learning and performance for difficult mathematical problems over time. However, it is unclear how it works in the opposite direction– at present, for example, there is no evidence and theory that explains how poor mathematical performance may generate higher mathematics anxiety over time only in children with higher working memory. Future longitudinal studies may include mathematical achievement measures in multiple time points and use autoregressive models to address the temporal order of mathematics anxiety and performance, whereas the issue of causality needs to be addressed by experimental work.

Second, mathematics anxiety was assessed with a self-reported scale. One potential problem with questionnaire measures is that the responses may be affected by accuracy of the children's self-perceptions and by their truthfulness in responding. Future research may attempt to address this problem by incorporating physiological measures of anxiety when the participants were exposed to mathematical stimuli. Such measures may include cortisol secretion (Mattarella-Micke, Mateo, Kozak, Foster, & Beilock, 2011); EEG recordings (Núñez-Peña & Suárez-Pellicioni, 2014, 2015); functional MRI (Lyons & Beilock, 2012) as well as heart rate and skin conductance (Dew, Galassi, & Galassi, 1984). Third, the current study did not require the children to finish the mathematical problems within a time limit. It is possible that if they are given time pressure, mathematics anxiety may also have an impact on easy items. It may be interesting to test this in future studies. Fourth, based on their review, Raghubar, Barnes, and Hecht (2010) acknowledged that the connection between working memory and mathematical performance depends on factors including but not limited to "age, skill level, language of instruction, the way in which mathematical problems are presented, the type of mathematical skill under consideration and whether that skill is in the process of being acquired, consolidated, or mastered" (p. 119). The present study focused on two components of working memory only (phonological loop and the central executive) because phonological loop was shown to be the best predictor of children's mathematical performance from primary school onwards (Rasmussen & Bisanz, 2005) and consistent evidence shows that the central executive strongly predicted children's performance in mathematics (e.g., Ching & Nunes, 2016; Cowan & Powell, 2014; Gathercole & Pickering, 2000; Holmes & Adams, 2006; Keeler & Swanson, 2001; Lee, Ng, Ng, & Lim, 2004; Lehto, 1995; Noel, Seron, & Trovarelli, 2004; Swanson & Beebe-Frankenberger, 2004; Wilson & Swanson, 2001). Given that the complex relation between working memory and mathematical achievement may complicate the findings, future studies on mathematics anxiety may consider other types of memory that is assessed, how it is coded (e.g., verbal, visual, visual-spatial) and what it is being used to do (e.g., maintenance versus processing). Finally, the order in which measures are administered may affect children's responses. To counteract this, researchers may use a counterbalanced design in the future, which reduces the chance of the order of test administration adversely influencing the results.

Conclusion

In conclusion, the present study underscores the potential of mathematics anxiety to negatively influence Chinese children's mathematical performance. The findings suggest that mathematics anxiety has a more pronounced impact on mathematical problems that require more processing resources, as opposed to simple arithmetic problems and straightforward story problems. Children who are higher in working memory should have a great potential to perform well in mathematics; however, this study suggests that they are more vulnerable to the adverse effects of mathematics anxiety. Understanding the sources of children's mathematics anxiety is a critical step in developing early interventions that ameliorate these anxieties and their negative impacts on mathematical achievement.

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Table 1. Descriptive statistics for predictors and criterion variables (N = 246)

	Possible range	Mean	Standard deviation	Minimum	Maximum	Skewness z-value	Kurtosis z-value
1. Mathematics Anxiety	0-48	31.00	7.81	7	45	-1.36	1.56
2. General Anxiety	0-18	8.90	2.45	3	15	0.74	0.10
3. Test Anxiety	0-120	64.93	19.80	23	114	1.19	1.49
4. Working Memory	0-16	9.04	1.73	6	14	1.74	0.55
5. Non-Verbal Intelligence	0-60	36.94	5.38	24	48	-1.12	-1.41
6. Number Skills	0-36	32.64	2.64	26	36	-1.36	-0.87
7. Chinese Word Reading	0-30	24.13	2.57	19	30	1.23	-1.68
8. Calculation	0-20	15.02	2.30	9	20	0.79	-1.24
9. Story Problem Solving	0-24	15.90	2.73	7	23	-0.61	-0.52

Table 2. Bivariate correlations among variables (N = 246)

	1	2	3	4	5	6	7	8	9
1. Mathematics Anxiety	1								
2. General Anxiety	0.186**	1							
3. Test Anxiety	0.196**	0.053	1						
4. Working Memory	0.081	0.016	0.049	1					
5. Non-Verbal Intelligence	0.07	0.027	0.086	0.153*	1				
6. Number Skills	0.022	0.003	0.016	0.233**	0.264**	1			
7. Chinese Word Reading	0.085	0.021	0.02	0.142*	0.153*	0.108	1		
8. Calculation	-0.318**	0.034	0.062	0.208**	0.159*	0.132*	0.075	1	
9. Story Problem Solving	-0.261**	0.096	0.094	0.239**	0.176**	0.063	0.035	0.545**	1

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

Table 3. Multiple regression models showing the relations between children's performance in difficult calculation problems and various predictors (N = 246)

Model	Variables entered into model	Unstandardized beta	Standard error	Standardized beta	t	Sig.	R^2	R^2 change	F change	Sig. F change
1	Non-Verbal Intelligence	0.033	0.021	0.103	1.572	0.117	0.051		2.572	0.027
	Number Skills	0.017	0.044	0.027	0.399	0.69				
	General Anxiety	-0.006	0.044	-0.008	-0.125	0.9				
	Test Anxiety	0.002	0.006	0.027	0.434	0.665				
	Working Memory (WM)	0.293	0.112	0.17**	2.613	0.01				
2	Non-Verbal Intelligence	0.039	0.019	0.121*	2.038	0.043	0.224	0.173	53.38***	<0.001
	Number Skills	0.015	0.039	0.023	0.386	0.7				
	General Anxiety	0.048	0.041	0.068	1.164	0.246				
	Test Anxiety	0.009	0.005	0.105	1.805	0.072				
	Working Memory	0.341	0.102	0.198***	3.354	0.001				
	Mathematics Anxiety (MA)	-0.746	0.102	-0.433***	-7.306	<0.001				
3	Non-Verbal Intelligence	0.036	0.018	0.113*	1.983	0.049	0.289	0.065	21.867***	<0.001
	Number Skills	0.038	0.038	0.057	0.986	0.325				
	General Anxiety	0.031	0.039	0.045	0.8	0.424				
	Test Anxiety	0.005	0.005	0.061	1.084	0.28				
	Working Memory	0.418	0.099	0.243***	4.224	<0.001				
	Mathematics Anxiety	-0.963	0.108	-0.559***	-8.887	<0.001				
	MA x WM Interaction	-0.544	0.116	-0.299***	-4.676	<0.001				

*significant at the 0.05 level, **significant at the 0.01 level, ***significant at the 0.001 level

Table 4. Multiple regression models showing the relations between children's performance in difficult story problems and various predictors (N = 246)

Model	Variables entered into model	Unstandardized beta	Standard error	Standardized beta	t	Sig.	R^2	R^2 change	F change	Sig. F change
1	Non-Verbal Intelligence	0.055	0.026	0.141*	2.157	0.032	0.067		3.462**	0.005
	Number Skills	0.021	0.053	0.026	0.393	0.695				
	General Anxiety	0.040	0.054	0.046	0.743	0.458				
	Test Anxiety	0.006	0.007	0.057	0.903	0.367				
	Working Memory (WM)	0.391	0.136	0.185**	2.877	0.004				
2	Non-Verbal Intelligence	0.061	0.024	0.155**	2.512	0.013	0.172	0.105	30.378***	<0.001
	Number Skills	0.023	0.050	0.029	0.458	0.648				
	General Anxiety	0.091	0.052	0.105	1.755	0.080				
	Test Anxiety	0.012	0.006	0.117*	1.947	0.053				
	Working Memory	0.437	0.128	0.207***	3.401	0.001				
	Mathematics Anxiety (MA)	-0.711	0.129	-0.337***	-5.512	0.000				
3	Non-Verbal Intelligence	0.058	0.024	0.149**	2.463	0.014	0.208	0.036	10.703***	0.001
	Number Skills	0.003	0.049	0.003	0.053	0.958				
	General Anxiety	0.076	0.051	0.088	1.498	0.135				
	Test Anxiety	0.009	0.006	0.085	1.418	0.157				
	Working Memory	0.506	0.128	0.240***	3.963	0.000				
	Mathematics Anxiety	-0.907	0.140	-0.430***	-6.482	0.000				
	MA x WM Interaction	-0.492	0.150	-0.221***	-3.272	0.001				

*significant at the 0.05 level, **significant at the 0.01 level, ***significant at the 0.001 level

Mathematics anxiety and working memory: Longitudinal associations with mathematical performance in Chinese children

Highlights:

- There is a lack of longitudinal study on math anxiety.
- Math anxiety made independent contributions to mathematical performance.
- It has a more pronounced impact on problems that require more processing resources.
- Children high in working memory are more vulnerable to its negative impacts.