Article:

Song, C.S., Xu, C., Maloney, E.A. et al. (2021) Longitudinal relations between young students' feelings about mathematics and arithmetic performance. Cognitive Development, 59. 101078. ISSN: 0885-2014

https://doi.org/10.1016/j.cogdev.2021.101078

Longitudinal Relations Between Young Students' Feelings about Mathematics and Arithmetic Performance

Charlene Shujie Song[1]

Chang Xu[1]

Erin A. Maloney[3]

Sheri-Lynn Skwarchuk[4]

Sabrina Di Lonardo Burr[2]

Anne Lafay[5]

Judith Wylie[6]

Helena P. Osana[5]

Heather Douglas[1]

Jo-Anne LeFevre[1,2]

[1] Department of Psychology, Carleton University

[2] Department of Cognitive Science, Carleton University

[3] School of Psychology, University of Ottawa

[4] Faculty of Education, University of Winnipeg

[5] Department of Education, Concordia University

[6] School of Psychology, Queen's University Belfast

Corresponding Author: Charlene Shujie Song

Department of Psychology, Carleton University

1125 Colonel By Dr,

Ottawa, ON K1S 5B6, Canada

Email: shujiesong@cmail.carleton.ca

Acknowledgements

Thanks to the Winnipeg research team and all the parents, teachers and children of the participating schools. Thanks also to the Ottawa research team*:* Stephanie Hadden, Heather Douglas, Jill Turner, Renee Whittaker, and Sarah Macintosh.

Funding

This work was supported by an Insight Grant (#435-2018-1463) from the Social Sciences and Humanities Research Council of Canada to J. LeFevre (PI), E. Maloney, S. Skwarchuk, and H. Osana.

This manuscript was accepted for publication in *Cognitive Development* on June 9, 2021. This preprint is the peer-reviewed accepted version but has not yet been copyedited and may differ from the final version published in the journal.

Abstract

Math anxiety is a common correlate of math performance for adults. Research on young children's emotional reactions to math is limited, but critical for determining how math anxiety develops. Students ($N = 244$) completed math measures (i.e., number comparison, arithmetic fluency, and math problem solving) and math anxiety assessments twice, in grade 2 ($M_{age} = 7.10$) and a year later in grade 3. Math anxiety was significantly related to arithmetic fluency, but not to others. Longitudinally, arithmetic fluency in grade 2 predicted the change in math anxiety from grades 2 to 3, but not vice versa. The growth in math anxiety was related to arithmetic fluency for students with higher working memory scores, but this moderation effect of working memory was not significant after a multiple-comparisons correction. In sum, these findings are consistent with the view that math anxiety develops in some children in response to their experiences with mathematics.

Longitudinal Relations Between Young Students' Feelings about Mathematics and Arithmetic Performance

Mathematics is an essential skill used to perform daily activities, such as buying groceries, telling time, or managing a monthly budget. Mathematics provides a solid foundation for students' success in disciplines such as science, technology, and engineering (Baker & Galanti, 2017; English, 2017). Despite its importance, many adults try to avoid mathematics and feel anxious about their math abilities (Ashcraft, 2002; Beilock & Maloney, 2015; Zhang, Zhao, & Kong, 2019). In the past 30 years, researchers have investigated the relation between math anxiety – a negative feeling or reaction when encountering situations involving numbers and calculation – and math performance (Ashcraft, 2002; Dowker, Sarkar, & Looi, 2016; Maloney & Beilock, 2012; Namkung, Peng, & Lin, 2019; Zhang et al., 2019). Determining the source and causes of math anxiety and how math anxiety develops in relation to math performance is critical for understanding when and how to intervene (Dowker et al., 2016). However, few researchers have studied the development of math anxiety among students in elementary school (Ching, 2017; Gunderson, Park, Maloney, Beilock, & Levine, 2018; Maloney, Ramirez, Gunderson, Levine, & Beilock, 2015; Pantoja, Schaeffer, Rozek, Beilock, & Levine, 2020; Vukovic, Kieffer, Bailey, & Harari, 2013; Zhang et al., 2019). Moreover, although individual differences in working memory have been shown to moderate the relations between math anxiety and math performance (Ramirez, Chang, Maloney, Levine, & Beilock, 2016; Ching, 2017; Namkung et al., 2019; Ramirez, Gunderson, Levine, & Beilock, 2013; Vukovic et al., 2013), the role of working memory has not always been considered in research (Gunderson et al., 2018; Pantoja et al., 2020). The goals of the present research were to examine the longitudinal relations between math anxiety and math performance in students from grade 2 to 3 (i.e., ages 7–9 years) and to explore the role of working memory in those relations.

Math Anxiety

Math anxiety may influence students' academic success in math-related courses and thus have a prolonged impact on their career choices and everyday life experience (Ma, 1999; Maloney & Beilock, 2012). Adults with high levels of math anxiety perform worse than their less anxious peers on many numerical and math tasks, from simple tasks such as number comparison and enumeration (Maloney, Ansari, & Fugelsang, 2011; Douglas & LeFevre, 2018; Maloney, Risko, Ansari, & Fugelsang, 2010; Núñez- Peña & Suárez-Pellicioni, 2014), to more complex activities such as multidigit arithmetic (e.g., Ashcraft & Kirk, 2001; Chang, Sprute, Maloney, Beilock, & Berman, 2017; Douglas & LeFevre, 2018) or algebra (Douglas & LeFevre, 2018). By the time students reach post-secondary studies, math anxiety is a well-entrenched trait (Maloney & Beilock, 2012) that is correlated with many aspects of math performance.

In two meta-analyses (Namkung et al., 2019; Zhang et al., 2019), the correlation between math anxiety and performance was weaker for elementary school students than for older students and adults. There are several plausible reasons for variability in the relation between math anxiety and math performance among students of different ages. First, the instruments for measuring math anxiety in elementary school students have not been as extensively studied and evaluated compared to those for adolescent and adults (Ganley & McGraw, 2016). Second, the relations between math anxiety and math performance are reportedly moderated by individual differences in working memory (Ramirez et al., 2013; Vukovic et al., 2013) but these relations have not been studied comprehensively. Moreover, only longitudinal studies can address the key question of whether there are reciprocal relations between math anxiety and math performance but there are few such studies, especially for elementary school students (Gunderson et al., 2018; Vukovic et al., 2013). In the next sections, we address these potential sources of variability in patterns of results.

Measurement of Math Anxiety in Elementary School Students

One source of inconsistent findings about the relation between math anxiety and math performance may be that the measurement tools used to assess math anxiety in young students may not adequately assess the underlying construct (Jameson, 2013; Ma, 1999). In general, developing math anxiety measures for young children is challenging because the measure must adequately tap into the construct of math anxiety, but the items must be meaningful to the children (Ganley & McGraw, 2016). Thus, variability in the validity of math anxiety instruments for children may contribute to inconsistent findings across studies.

Early versions of math anxiety scales for elementary school students were developed by adapting versions used with adults, but none was specifically designed for students in the elementary grades (i.e., grades 1, 2, or 3; see Ganley & McGraw, 2016). More recently, several different measures were designed specifically for younger students. Ganley and McGraw (2016) summarized the six measures that are most often used (see their Table 1). The measures vary on several dimensions, most prominently (a) whether scales are pictorial (e.g., faces with expressions ranging from smiles to frowns), and whether verbal descriptions are included (e.g., words such as nervousness, worry, or anxiety), (b) the number of levels of the rating scales (e.g., from 4 to 16; with four of the measures using 5-point scales), (c) whether some of the questions ask about specific math problems (e.g., from 0 to 10 of 20 items), and (d) whether the scale has multiple factors (e.g., worry, numerical confidence) or is assumed to be unidimensional. Reliabilities vary across scales as well, although typically they are high (alpha >.80) when scales are treated as unidimensional. Ganley and McGraw (2016) developed a revised version of one of these scales (i.e., the Math Anxiety Scale for Young Children or MASYC), originally developed by Harari, Vukovic, and Bailey (2013), but there are no studies available in which different scales have been compared directly and thus, the choice of a measure is guided by the inherent characteristics and apparent suitability of the scale for specific purposes.

In the present study, we used the Children's Anxiety in Math Scale (CAMS; Jameson, 2013, 2014). Jameson (2013) developed items that assessed how children feel in a variety of situations, such as doing math in class or in social situations, thinking about math, and doing challenging math activities (see Appendix A for the items). Children respond to the 16 items by selecting a facial expression that best represents how they feel about each situation. There are five facial expressions ranging from the "very anxious / frowning" face to the "not at all anxious / smiling" face. This inventory was found to be reliable and valid with a sample of 438 children across grades 1–5 (Jameson, 2013). We selected it for the present research because it was an appropriate length, the items were stated clearly, it was focused on emotions related to a range of math situations, and the pictorial rating scale seemed appropriate for young children (cf. Ganley & McGraw, 2016). The CAMS as a unitary scale had high reliability (alpha =.86) and was correlated with arithmetic computation at r =-.189 (Jameson, 2013). Jameson (2014) found that math anxiety as measured by the CAMS was strongly correlated with math self-concept for students in grade 2.

Longitudinal Studies of Math Anxiety

Another possible source of inconsistent conclusions about the directional relations between math anxiety and math performance is that there are few longitudinal studies where math anxiety and math performance were both measured at two or more time points. C.S. Song et al.Cognitive Development 59 (2021) 101078 4 Across six grades in high school (i.e., grades 7–12; n =3116), Ma and Xu (2004) found that prior poor math achievement was significantly related to later high math anxiety in all grades, whereas prior high math anxiety was only related to later low math achievement in grades 7–9. Thus, a reciprocal relation between math anxiety and math performance was found from grade 7 to grade 9 (i.e., ages

12–14). Math anxiety may be both the cause of and the outcome of poor math abilities (Ashcraft & Moore, 2009; Carey, Hill, Devine, & Szücs, 2016; Dowker et al., 2016; Maloney, 2016; Namkung et al., 2019).

The bidirectional relations between math anxiety and math performance in elementary school students have been explored in two longitudinal studies (Gunderson et al., 2018; Krinzinger, Kaufmann, & Willmes, 2009). Gunderson et al. (2018) found evidence of short-term reciprocal relations between math anxiety and math performance in a longitudinal study with 634 students in grade 1 and grade 2 (i.e., mean age of 7.2 years). Students were tested twice in the same grade, at the beginning of the term (Time 1) and the end of the term (Time 2), approximately 6 months apart. Math anxiety was measured with a revised version of the Child Math Anxiety Questionnaire (Ramirez et al., 2013) in which students indicated how nervous they felt when asked to do math in a variety of different situations. Math performance at Time 1 predicted math anxiety at Time 2, and math anxiety at Time 1 predicted math performance at Time 2. Although both directions were significant, the influence of math performance in Time 1 on math anxiety in Time 2 was about three times larger than the influence of math anxiety in Time 1 on math performance in Time 2. The pattern was the same for students in grades 1 and 2.

Krinzinger et al. (2009) conducted a longitudinal study with 140 students from grade 1 to 3 (i.e., mean ages 6.8–8.5 years) with four time points (Time 1, end of first grade; Time 2, middle of second grade; Time 3, end of second grade; Time 4, middle of third grade). Students answered two types of questions about math (items were from the Math Anxiety Questionnaire used by Thomas & Dowker, 2000). Evaluation of math referred to students' own evaluations of their math ability and how much they liked math, whereas math anxiety questions were focused on negative emotional factors, such as worry about math test performance. In contrast to Gunderson et al. (2018), there was little evidence for any relations between math anxiety and math performance, with the exception that math anxiety at Time 1 was correlated with math performance at Time 2. Notably, however, students' math evaluation ratings were reciprocally related to math performance at Times 1 and 2, and math performance at Times 2 and 3 predicted evaluation of math at Times 3 and 4, respectively. Evaluation of math and math anxiety were correlated but seemed to capture different constructs in relation to calculation performance. Overall, Krinzinger et al. (2009) concluded that math anxiety and math performance were not longitudinally or concurrently related in their sample. However, the math anxiety and math evaluation constructs did share variance. These results show that the specific ways in which students' feelings and attitudes about mathematics are measured are very important.

The two longitudinal studies with young students used different math anxiety measures and different time frames to test the relations between math anxiety and math performance. Furthermore, the math performance measures were different in the two studies. In Krinzinger et al. (2009), the math performance measure focused on written arithmetic problems that the students solved orally, including single-digit and some double-digit addition and subtraction problems. In Gunderson et al. (2018), the math performance measure included a variety of orally presented items, including arithmetic, measurement, and other types of word problems (i.e., the Woodcock-Johnson Applied Problems subtest; Woodcock, McGrew, & Mather, 2001). It is quite possible that math anxiety in young children is associated with only some aspects of math performance. Notably, Zhang et al. (2019) found that the effect size for the relations between math anxiety and math performance were higher for more complex measures than for simple measures.

In summary, additional research is needed to help clarify how math anxiety and math performance are related over time for students in elementary school. Although several other studies with elementary school students evaluated math performance and/or math anxiety at different time points (e.g., Ching, 2017; Pantoja et al., 2020; Vukovic et al., 2013), none of these evaluated both math anxiety and math performance at two or more time points and thus did not test for potential reciprocal relations.

Math Anxiety and Working Memory

Researchers have argued that a transient reduction in working memory resources is the immediate cause of poor math performance for math-anxious people (Maloney, 2016). The logic is that math anxiety causes intrusive thoughts and ruminations during math-related tasks, and these thoughts co-opt the working memory resources needed to perform the math tasks (Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007; Ramirez, Shaw, & Maloney, 2018). Ashcraft and Kirk (2001) demonstrated that college students who were more anxious about math made more errors solving multi-digit arithmetic problems than students who were less anxious about math. This pattern, however, was only found for problems that placed a heavy load on working memory. Thus, among adults, math anxiety is more strongly related to performance on tasks where working memory load is high or for math-anxious participants who have also high working memory capacity, or both. For individuals who have low working memory capacity, or on tasks where working memory is not required, math anxiety is less likely to influence math performance (Maloney, 2016).

For children, only a handful of studies examined how working memory is related to math anxiety and math performance (Namkung et al., 2019). Ramirez et al. (2013) assessed math anxiety in elementary school students by adapting a version of a math anxiety scale used with adults (i.e., the Child Math Anxiety Questionnaire or CMAQ). Among 154 American children in grades 1 and 2 (mean age 7:1 only those with high working memory showed a negative correlation between math anxiety and math performance. Ramirez et al. (2016) reported the same pattern in a different sample of 564 children in grades 1 and 2 (mean age 8:1; also using the CMAQ). Ching (2017) assessed math performance of 246 children in China in both grade 2 (mean age 7:2) and grade 3 (mean age 8:2). Math anxiety was measured with a translated version of the measure originally developed by Harari et al. (2013). The results showed that children's math anxiety in grade 2 predicted calculation performance on math problems in grade 3 but this relation was moderated by working memory. Consistent with the findings for adults, math anxiety was more strongly related to performance on more difficult problems and for students with higher levels of working memory.

Vukovic et al. (2013) studied American children in grade 2 and grade 3 (N =113; mean age =7:10) using the Harari et al. (2013) math anxiety measure. Like Ching (2017), they assessed math performance in both grades, but math anxiety and working memory were assessed only in grade 2. Vukovic et al. (2013) found that concurrently in grade 2, math anxiety was related to math performance, specifically to calculation and applications, but not to geometry. In grade 3, after controlling for grade 2 math performance, math anxiety (grade 2) was related to grade 3 students' performance on math applications; specifically, children with higher levels of math anxiety in grade 2 and higher working memory scores learned less than those with lower working memory scores in grade 3.

In summary, in four studies with elementary school students, relations between math anxiety and math performance were moderated by working memory. Specifically, only students with higher working memory capacity showed relations between math anxiety and math performance. However, none of these studies were fully longitudinal because math anxiety was only measured at a single time point. Moreover, the patterns were not consistent across different math measures even within the same study (e.g., applied problems vs. computations vs. geometry; Vukovic et al., 2013). Working memory has been proposed as one mechanism for how math anxiety influences math performance and thus, further research is needed to understand how these relations develop.

Current Study

The goal of the present research was to examine both the concurrent and predictive relations among math anxiety, working memory, and math performance for students in the early grades of elementary school. Students' math anxiety and math performance were measured twice, first in grade 2 and again in grade 3. Working memory was assessed once in grade 2, because it is a stable cognitive skill. Grades 2 and 3 were selected as a key educational stage, on the assumption that children's math knowledge is progressively constructed, with the emphasis on foundational calculation and fluency skills (Gunderson, Ramirez, Beilock, & Levine, 2012). Maloney et al. (2010, 2011) found that adults with math anxiety showed basic numerical processing difficulties (such as difficulties in counting and in numerical comparison), and they argued that these difficulties may be a source of math anxiety (Douglas & LeFevre, 2018; Pantoja et al., 2020). As such, for students in grades 2 and 3, math anxiety may develop concurrently with their basic numerical skills, such as number comparison, number ordering, and simple arithmetic (Lyons, Price, Vaessen, Blomert, & Ansari, 2014; Xu & LeFevre, 2020), as well as other numerical skills such as number line performance (Pantoja et al., 2020) and word-problem solving (Ramirez et al., 2016).

Our first hypothesis was that math anxiety would be negatively correlated with math performance (i.e., symbolic number comparison, math problem solving, and arithmetic fluency) in both grades 2 and 3 (Namkung et al., 2019; Zhang et al., 2019). Second, following Gunderson et al. (2018), we hypothesized that there would be reciprocal relations between math anxiety and math performance across grades (cf. Krinzinger et al., 2009). Third, following Ching (2017), Ramirez et al. (2013, 2016), and Vukovic et al. (2013), we hypothesized that working memory would moderate the relation between math anxiety and math performance. More specifically, we expected the relation between math anxiety and performance would be stronger for children with higher working memory capacity. In these analyses, we controlled for non-verbal reasoning skill (Hembree, 1990; Primi, Ferrão, & Almeida, 2010) and receptive vocabulary (LeFevre et al., 2010). These variables are known to account for individual differences in math performance.

The current study adds to existing research in several ways: (a) We used a different measure of children's math anxiety than in previous studies, (b) we included a range of math performance measures, and (c) we assessed math anxiety and math performance at two time points, allowing us to test for reciprocal relations.

Method

Participants

Children (N = 244; 45 % boys) were recruited from schools in suburban areas in or near a large Canadian city. Most children spoke English at home (90 %). They were enrolled in schools where the language of instruction was either French (n =152; i.e., French Immersion) or English (n = 92). The data were collected as part of a larger project comparing children's learning of mathematics in either their first or an additional language. The larger project also involved children in three other locations, but only the children at this location completed the math anxiety measures. Parents received information about the study and completed consent forms. Parents' education level was collected for 229 mothers and 220 fathers. For the mothers, 14% had a postgraduate degree, 31% had a university degree, 29% had a community college degree, 24% had a high school diploma, and 2% had less than a high school diploma. Similarly, for the fathers, 11% had a postgraduate degree, 26% had a university degree, 33% had a community college degree, 29% had a high school diploma, and 3% had less than a high school diploma. The median level of education was a community college degree for both mothers and fathers.

Children were tested at two time points. The first testing session was conducted between April and May of 2018 when the children were in grade 2 (*n* =182; 63 boys; M_{age} = 7.8 years old; *SD* = 3.40, range 7.2–8.3). The second testing session was conducted between April and June of 2019 when the children were in grade 3 (*n* = 209; 109 boys, M_{age} = 8.9 years, *SD* = 1.55, range 8.1–10.9). A total of 35 children withdrew from the study between the first and second time points for personal reasons, resulting in 147 children who participated in both testing sessions. Sixty-two new participants joined the study in grade 3. In the subsequent analyses, data for children who participated at either one or both time points were included (*N* =244; see the Missing Data analysis section for details).

Procedure

Children were individually tested by a trained research assistant(s) in a quiet area of the school. All tasks were administered in a fixed order. Students completed English-language measures in two 30-min sessions on the same day. Students in French-immersion programs participated in a third 30-min session that included measures in French that were not used in the current study. After completing each testing session, students received stickers as motivational rewards, as did all students in each class whether they were included in the study or not.

Measures

As indicated above, the data used in the present study were collected as part of a larger project. Only measures relevant to the present study are described in detail here. A full list of measures is available on the Open Science Framework (osf.io/428hp).

Children's Math Anxiety Scale

Math anxiety was measured in both grade 2 and grade 3 using the 16-item Children's Math Anxiety Scale (Jameson, 2013). At both time points (i.e., grade 2 and grade 3), the research assistant read a sentence aloud and children were asked to mark the face that showed how they felt for items such as, "When I solve math problems, I feel" or "When I make a mistake in math, I feel" (see Fig. 1). Before starting the task, children were told: "Now it's time for you to answer some questions about what you feel when you do math. After I read you the question, I want you to put a dot on the face that best shows what you are feeling, Ok?" Children were given bingo dabbers (i.e., large markers with flat surfaces) to stamp on the face that represented their feelings (see Appendix A for the items). In grade 3, children provided ratings for five additional items that tapped into general anxiety or other academic activities, such as, "When I am working on science questions, I feel" or "When I play outside for recess, I feel."

Total score for the math items were calculated by adding up the numbers under the selected facial expression for all questions. Thus, total scores could range from 16 to 80, with higher scores indicating higher levels of negative affect. Reliability of the Children's Math Anxiety Scale across the 16 math items was high in grade 2 (Cronbach's α =.86) and grade 3 (Cronbach's α =.87).

Cognitive Measures

Matrix Reasoning. The Weschler Intelligence Scale for Children-Fifth Edition (WISC-5; Wechsler, 2014) was used to assess children's nonverbal intelligence in grade 2. In this task, children are presented with colored matrices (i.e., visual patterns) in which one element is missing. Children must select the correct missing piece from a range of options to complete the pattern. Children completed two practice trials followed by 32 test trials (Cronbach's α =.82). The experimenter recorded children's responses (correct or incorrect) on a separate answer sheet. Testing was discontinued after three consecutive errors. Scoring is based on the total number of correct responses, with possible scores ranging from 0 to 32.

Receptive Vocabulary. Children were assessed in grade 2 on their English receptive vocabulary using a subset of items from the Peabody Picture Vocabulary Test-Revised, Form B (i.e., PPVT; Dunn & Dunn, 2012). For each trial, children were shown four images and the experimenter read a single word aloud. Children pointed to the image that corresponded to the given vocabulary word. The test was comprised of three sets of 12 vocabulary words. The task was discontinued if a child got eight trials wrong within a given set. Scoring was based on the total number of correct words that children identified, with possible scores ranging from 0 to 36. The internal reliability was calculated based on the subscores of each set, Cronbach's α =.77.

Working Memory. Children's working memory was measured in grade 2 with three tasks: digit span forward (i.e., verbal short- term memory), digit span backward (i.e., verbal working memory), and spatial span forward (i.e., visual-spatial memory; Alloway, Gathercole, Kirkwood, & Elliott, 2008).

Digit Span Forward. In this task, an experimenter presented the child with a sequence of digits (e.g., 3-8-4) recited orally. Once the experimenter finished presenting the sequence, the child recalled the sequence, in order, from memory (e.g., 3-8-4). The experimenter recorded the child's response on a sheet of paper. Sequences ranged from two digits to nine digits; all children began with a sequence length of two. There were two trials for each sequence length. If the child correctly recalled at least one of the two trials at a given sequence length, the experimenter increased the sequence length by one digit. Testing was discontinued if the child was unable to recall both trials for a given sequence length. Scores are the total number of correct trials that participants recalled, with possible scores ranging from 0 to 16. The reliability obtained from the standardized WISC-V technical report was .83 (Wechsler, 2014).

Digit Span Backward. The task followed the same procedure as the Digit Forward task. The child had to recall the sequence in reverse order in which it was presented. Sequences could range from two digits to eight digits; all children began with a sequence length of two. Except for the sequence length of two, which had four trials, there were two trials for each sequence length. Scoring is based on the total number of correct trials that participants recalled, with possible scores ranging from 0 to 12. The reliability obtained from the standardized WISC-V technical report was .80 (Wechsler, 2014).

Spatial Span Forward. The Spatial Span task (http://hume.ca/ix/pathspan/) was used to assess children' working memory and spatial attention. For this task, the child is presented with nine green dots in fixed locations on an iPad screen. One by one, the dots light up and the child is asked to reproduce the pattern by tapping the dots in the same order. Testing began with a span length of two dots. Each span length was presented for two trials. If the child correctly recalled at least one of the trials at a given span length, the span length increased by one dot. Testing was discontinued if the child was unable to recall two trials for a given sequence length. Scores are the total number of correct sequences that participants recalled, with possible scores ranging from 0 to 16. Reliability was calculated based on the subscores of the first and second sequence at each span length, Cronbach's α =.82.

Math Measures

Number Comparison. Children's knowledge of the magnitude of Arabic numbers was assessed (Bigger Number; https:// carleton.ca/cacr/math-lab/apps/bigger-number-app/) with a number comparison task using an iPad application in grade 2 and grade 3. Children were presented with side-by-side single-digit numbers on an iPad screen. Children were instructed to tap the numerically bigger number as quickly as possible. On half of the trials, the two numbers had a small distance (i.e., the difference between the pair of numbers was 1, 2, or 3); on the other half of the trials, the two numbers had a large distance (i.e., the difference between the pair of numbers was 4, 5, 6, or 7). Children completed two practice trials to make sure they understood the task. The iPads recorded both response time (RT in seconds) and accuracy. A total of 26 trials were presented in random order. The reliability of this task based on RT (on correct trials) of individual items was high at both grade 2 (Cronbach's α =.94) and grade 3 (Cronbach's α =.94).

Children are very accurate on the number comparison task. Thus, to take both speed and accuracy into account, an adjusted response time (RTadj) was calculated using the linear integrated speed-accuracy score (LISAS) which adjusts mean correct response time for each person according to their proportion of error (PE) and a ratio of the variability for response time and errors (Vandierendonck, 2018). The formula used to calculate this measure is:

$$RT_{adj} = RT_{correct} + (PE \times [SD_{RT}/SD_{PE}])$$

where PE is proportion of errors, and SD_{RT} and SD_{PE} refers to the standard deviation of the correct RT and PE, respectively. If the proportion of errors is zero, then RT_{adj} is equal to the $RT_{correct}$. This method of adjusting response times on speeded tasks is preferred because it balances speed and accuracy and is efficient in detecting effects even when error rates are high, unlike other methods such as inverse efficiency (i.e., RT/Accuracy) which is only valid if error rates are low (i.e., Vandierendonck, 2018).

Problem Solving. Children were given the problem-solving subtest of the KeyMath (Third Edition; Connolly, 2000). This measure includes a variety of items, such as completing sequences of numbers, identification of relevant information in word problems, calculation in arithmetic word problems, and creation of word problems based on a given arithmetic equation. The experimenter read each question aloud while the child looked at corresponding images. The word problems became more complicated as the task progressed. The task was discontinued when children made three consecutive errors. Scoring is based on the total number of questions answered correctly, with possible scores ranging from 0 to 12. Reliability of this task was based on individual items and was acceptable in grade 2 (Cronbach's α =.76) and high in grade 3 (Cronbach's α =.94).

Arithmetic Fluency. Arithmetic fluency was a paper-and-pencil measure of children's ability to solve addition and subtraction problems quickly and accurately (Chan & Wong, 2020). The task was administered in both grades 2 and 3. Children were presented with one page of single-digit addition problems and one page of single-digit subtraction problems (3 columns of 20 items for a total of 60 items per page). They had one minute per page to complete as many problems as possible. They were instructed to not skip any items. Scores were the total correct summed across the two pages. Internal reliability was calculated using the total addition and subtraction scores, Cronbach's α =.76 and .85 in grades 2 and 3, respectively.

Results

Analysis Plan

For all comparison analyses, both frequentist and Bayesian *t*-tests were conducted. Bayes factors allow for the evaluation of the fit of the data under the null and alternative hypotheses. The Bayes factor, BF_{01}, is "a ratio that contrasts the likelihood of the data fitting under the null hypothesis with the likelihood of fitting under the alternative hypothesis" (Jarosz & Wiley, 2014, p. 3). For example, a Bayes factor of 2.7 indicates that the data are 2.7 times more likely to occur under the null hypothesis than the alternative hypothesis (Jarosz & Wiley, 2014). Taking the inverse, BF_{10}, puts the Bayes factor in terms of the alternative hypothesis (e.g., BF_{01} =2.7, BF_{10} = 1/2.7 = 0.37). The Bayes factors were calculated in JASP (JASP Team, 2020). With respect to the strength of the evidence for the null or alternative hypothesis in the present analyses, all interpretations of the Bayes factors are in accordance with the guidelines developed by Jeffreys (1961) and as listed in Table 4 of Jarosz and Wiley (2014). In the first step of the analyses, all measures were inspected to ensure there was a reasonable distribution. Comparisons were made across grades for those measures assessed twice. Comparisons were made between boys and girls. To test whether the relations between math anxiety and math performance were reciprocal, we used cross-lagged path analysis in Mplus (Muthén & Muthén, 1998). Moderation effects of working memory were subsequently tested in the cross-lagged path model by testing for interactions between working memory and math and between working memory and math anxiety. Model fit was examined using a combination of the chi-square goodness of fit test ($p > .05$), comparative fit index (CFI > .95), root mean square error of approximation (RMSEA < .06), and standardized root mean square residual (SRMR < .08; Hu & Bentler, 1999).

Descriptive Statistics

Descriptive statistics for all measures are shown in Table 1. All the cognitive measures were normally distributed, with reasonable ranges and no evidence of floor or ceiling effects. All math outcomes and math anxiety measure were also normally distributed. Outliers were identified as scores with *z*-scores greater than +/− 3.29 from the mean for the sample. For number comparison, there was one outlier in grade 2 and one outlier in grade 3; for arithmetic fluency, there were two outliers in grade 2 and one outlier in grade 3. Sensitivity analyses with and without outliers showed similar patterns of results, and thus outliers were included in the final analyses. To reduce the number of variables, principal component analysis (PCA) was conducted to create a working memory factor from three components that were measured in grade 2: digit forward, digit backward, and spatial span (factor loadings of .67, .70, and .58, respectively), accounting for 42.4% of the variance. The working memory factor was used in the subsequent analyses.

The mean summed math anxiety score was 36.7 in grade 2 and 39.5 in grade 3 (total score could range from 16 to 80), suggesting that on average, children selected the "somewhat positive" to "neutral" face (see descriptive information for each item in Table A1). Therefore, because mean scores were closer to the positive than to the negative end of the scale in both grades 2 and 3, these results suggest that children in the present study felt positively about school subjects, even mathematics. For the additional items added in grade 3, children rated the items even more positively, suggesting that they were not anxious about school activities in general (see descriptive information for each item in Table A1). These five additional items were not included in the further analyses.

Grade

Children's scores on the math and the math anxiety measure were compared across grades, as shown in Table 1. Children improved from grades 2 to 3 on all three math outcomes (i.e., number comparison, arithmetic fluency, and problem solving). The Bayes Factors, BF_{10}, indicate decisive evidence for the hypothesis that math scores were higher in grade 3 than in grade 2 for all three tasks. Furthermore, children's math anxiety increased from grade 2 to grade 3 (see Table 1). The Bayes Factor, BF_{10}, indicates substantial evidence that math anxiety in grade 3 was higher than in grade 2.

Gender

Notably, boys and girls did not differ in their reported math anxiety in grade 2 (M = 36.13 vs. 37.29), $t(180) = -0.66$, $p = .512$, $BF_{01} = 5.07$, or grade 3 (M =39.87 vs. 39.21), $t(207) = 0.45$, $p = .657$, $BF_{01} = 5.99$. This finding is consistent with what other researchers have found for this age group (e.g., Ramirez et al., 2013), but inconsistent with the literature on math anxiety in adults (e.g., Maloney & Beilock, 2012). There were statistically significant gender differences on only two measures. Girls outperformed boys on matrix reasoning (M =16.71 vs. 15.50), $t(180) = -2.25$, $p = .025$, however, the Bayes Factor, $BF_{10} = 1.68$, indicates only anecdotal evidence for this difference between genders. Similarly, boys outperformed girls on number comparison (M =1.18 vs. 1.25 s), $t(175) = -2.33$, $p = .021$, but again the Bayes Factor, $BF_{10} = 1.97$, indicates only anecdotal evidence for this difference between genders. Because there was no strong evidence in favour of gender differences, this variable was not included in further analyses.

Instructional Program

There were no significant differences between French-immersion students and English-instruction students on any measure (*p*s > .05; Bayes Factors ranging from BF_{01} = 1.2 (problem solving in grade 3) to BF_{01} = 6.0 (number comparison in grade 2)). Thus, instructional program status was not included in further analyses.

Correlations Among Measures

Bayesian correlations were conducted to quantify the evidence that the data provide in favor or against the null hypothesis. For ease of interpretation, Bayes Factors in support of the null hypothesis (BF_{01}) are presented in regular font in Table 2, whereas the Bayes Factors in support of the alternative hypothesis (BF_{10}) are presented in bold font. As shown in Table 2, within each grade level, all the math outcomes (i.e., number comparison, problem solving, and arithmetic fluency) were significantly correlated with each other.

Matrix reasoning was significantly correlated with problem solving and with arithmetic fluency in both grades 2 and 3. Working memory was significantly correlated with all the math outcomes. Receptive vocabulary was significantly correlated with problem solving in grades 2 and 3, but not with number comparison or arithmetic fluency. The correlations of all repeated measurements from grade 2 to grade 3 showed that students' levels of performance were generally stable across the two time points (see Table 2).

Our first hypothesis was that students' math anxiety would be concurrently correlated with their math performance. As shown in Table 2, there was strong evidence to support that math anxiety in grade 2 was correlated with arithmetic fluency in grade 2 (BF_{10} = 52.63) and modest evidence that math anxiety in grade 3 was correlated with arithmetic fluency in grade 3 (BF_{10} = 7.24). Across grades, however, there was only anecdotal evidence that math anxiety in grade 2 was correlated with arithmetic fluency in grade 3 (BF_{10} = 2.08), as compared to substantial evidence that arithmetic fluency in grade 2 was correlated with math anxiety in grade 3 (BF_{10} = 11.11). Thus, earlier arithmetic fluency was related to later math anxiety. This pattern is explored further in the cross- lagged analyses.

In contrast, there was no strong evidence of correlations between math anxiety and either number comparison or problem solving in either grade. Bayes factors (BF_{01}, shown in Table 2) indicated that there was substantial to strong evidence in support of null relations between math anxiety in grade 2, and problem solving and number comparison in grades 2 and 3 (see Table 2). The Bayes factor indicated that there was minimal evidence in support of a correlation between problem solving and math anxiety in grade 3.

In summary, children's math anxiety was only correlated with arithmetic fluency, not with number comparison or problem solving. The concurrent relations between math anxiety and arithmetic were stronger for younger than for older children. Thus, in the next section, we further examined the cross-lagged associations between math anxiety and arithmetic fluency in grades 2 and 3 using path analysis.

Model Testing

Missing Data Analysis

To determine if there were differences between participants who completed both waves of testing (n = 147) and those who completed one wave of testing (either in grade 2 or grade 3) (n = 97), *t*-tests and χ^2-tests were conducted on the following demographic and outcome variables: program (French immersion vs. English instruction), child's age (grade 2 vs. grade 3), gender (boy vs girl), first language (English vs. not English), mother's education, forward digit span (grade 2), backward digit span (grade 2), spatial span (grade 2), matrix reasoning (grade 2), vocabulary (grade 2), math problem solving (grade 2 and grade 3), arithmetic fluency (grade 2 and grade 3), number comparison (grade 2 and grade 3), and math anxiety (grade 2 and grade 3). There were no significant differences between those students who had data for one wave versus both waves. Thus, we were confident that our data met the criteria for missing at random and models were estimated by a full information maximum likelihood method (Enders, 2010). All available information is used in all observations to estimate the model.

Effect of School

To examine a potential effect of school, we tested an intercept-only multilevel model containing school (n = 7) as a random effect. We found that the intra-class correlation coefficients were low for the outcome variables, that is, math anxiety in grade 2 (.050), arithmetic fluency in grade 2 (.001), math anxiety in grade 3 (.004), and arithmetic fluency in grade 3 (.001). The low intra-class correlation coefficients indicate low variability among the classrooms in grade 2 and 3 for these measures. Thus, a cluster effect of school is not a concern in the present study and classroom was not included in further analyses.

Cross-Lagged Path Analyses

A cross-lagged model was conducted using Mplus to examine the associations between math anxiety and arithmetic fluency in grades 2 and 3. The cross-lag relations were only tested for arithmetic fluency because none of the other math measures was correlated with math anxiety. Correlational analyses showed significant correlations between number comparison and arithmetic fluency, and between matrix reasoning and arithmetic fluency. Thus, both number comparison and matrix reasoning were included as control variables in the cross-lagged model. Moreover, because we were interested in testing the moderating effect of working memory (Ching, 2017; Ramirez et al., 2013, 2016; Vukovic et al., 2013), working memory was included as a concurrent predictor and as a predictor of growth. For readability, moderation effects are not shown in the figure but are reported in the text. The model fit was excellent, $\chi^2(8) = 11.40$, p =.180, RMSEA =.036, CI [0, .09], CFI = .983, SRMR = .036.

We hypothesized that there would be reciprocal relations between math anxiety and math performance (i.e., arithmetic fluency). As shown in Fig. 2, arithmetic fluency in grade 2 was significantly predicted by number comparison and working memory in grade 2. As expected, autocorrelations were significant: Arithmetic fluency in grade 2 predicted arithmetic fluency in grade 3, and math anxiety in grade 2 predicted math anxiety in grade 3, indicating that these measures are stable over time. Importantly, the cross-lagged path from arithmetic fluency in grade 2 to math anxiety in grade 3 was significant. In contrast, the cross-lagged path from math anxiety in grade 2 to arithmetic fluency in grade 3 was not significant (see Fig. 2). Thus, growth in math anxiety was related to children's earlier arithmetic performance, whereas growth in arithmetic was not related to earlier math anxiety. These results do not support Gunderson et al.'s (2018) finding of reciprocal relations.

Although arithmetic in grade 3 was not related to math anxiety in grade 2, there were significant direct paths from number comparison and matrix reasoning to arithmetic in grade 3. These patterns show that the growth in arithmetic fluency from grade 2 to grade 3 is related to children's knowledge of symbolic number magnitude (i.e., number comparison) and their nonverbal intelligence, as measured in grade 2. These patterns support a model of arithmetic skill learning that involves both improved strategies and increasing integration between symbolic number associations (i.e., magnitude and arithmetic; G¨ obel, Watson, Lervåg, & Hulme, 2014; Maloney et al., 2015; Vanbinst, Ghesqui` ere, & De Smedt, 2015; Xu & LeFevre, 2020). Working memory was concurrently related to arithmetic fluency in grade 2, however, it did not predict growth in arithmetic fluency. Instead, working memory in grade 2 was related to growth in math anxiety in grade 3. The positive coefficient indicates that higher levels of working memory are related to increases in math anxiety. These patterns are consistent with those reported by Ramirez et al. (2013, 2018) and Vukovic et al. (2013).

Last, we hypothesized that working memory would moderate the relation between math anxiety and math performance. Notably, in the presented cross-lagged model, math anxiety and arithmetic fluency are not only predictors, but they are also outcomes. Ramirez et al.

(2013) found that math anxiety was concurrently related to arithmetic fluency for children in grades 1 and 2 who were high in working memory. To test whether we would find a similar pattern, we tested whether the interaction between working memory and math anxiety in grade 2 predicted arithmetic fluency in grades 2 (concurrently) or grade 3 (predictively). Contrary to Ramirez et al. (2013), neither of the interactions was significant, *p*s >.05. Next, we tested whether the interaction between working memory and arithmetic fluency in grade 2 predicted math anxiety in grades 2 or 3. Working memory moderated the relation between arithmetic fluency and math anxiety in grade 3 ($\beta = -.158$, $p = .018$), but not in grade 2. If we correct for the familywise error rate using the Benjamini-Hochberg method of multiple hypothesis testing (Haynes, 2013), the critical value of p is .0125 and the interaction is not significant. Thus, any conclusions about the moderating effect of working memory are tentative. Fig. 3 shows the pattern of relations between arithmetic fluency in grade 2 and math anxiety in grade 3 (controlling for math anxiety in grade 2). Thus, growth in math anxiety was most strongly related to arithmetic fluency for students with average or higher working memory scores.

Discussion

In many studies with adults and adolescents, math anxiety is negatively correlated with math performance (Maloney & Beilock, 2012; Namkung et al., 2019; Zhang et al., 2019). Similar correlations have been observed for elementary school students, although the size of the effect may be smaller than for older children (Namkung et al., 2019; Zhang et al., 2019). Although the development of math anxiety is of primary interest (Dowker et al., 2016), only two studies have examined the reciprocal relations between math anxiety and math performance longitudinally for children in early elementary school (Gunderson et al., 2018; Krinzinger et al., 2009). In the present research, we addressed three questions. First, is math anxiety correlated with math performance for elementary school students? Second, are the relations between math anxiety and math performance reciprocal over the course of one school year? Third, does working memory moderate the relations between math anxiety and math performance in this time frame?

Correlations between Math Anxiety and Math Performance

In relation to our first research question, we found that math anxiety was correlated with arithmetic fluency, but not with number comparison or problem solving. Specifically, math anxiety in grade 2 was correlated with arithmetic fluency in grades 2 and 3 and math anxiety in grade 3 was correlated with arithmetic fluency in grade 2 but not in grade 3. These results were generally consistent with previous research showing that math anxiety is concurrently correlated with children's arithmetic skills (Jameson, 2013; Namkung et al., 2019; Sorvo et al., 2017). Our findings that math anxiety was not correlated with working memory or with nonverbal intelligence is generally consistent with the findings from other research with children (see also Gunderson et al., 2018; Hembree, 1990).

Among adults, math anxiety is correlated with a range of math skills, from number comparison (Maloney et al., 2011) to algebra (Douglas & LeFevre, 2018) but the link is stronger for more complex measures, such as problem solving (Zhang et al., 2019). If math anxiety develops in response to students' difficulties in mathematics, as is suggested by the current research and that of Gunderson et al. (2018), then the connection with anxiety should be stronger for more demanding math tasks.

Gunderson et al. (2018) found that math anxiety among grade 1 and 2 students was correlated with math achievement as measured by the Applied Problems Subtest of the Woodcock Johnson III (Woodcock et al., 2001), which includes simple arithmetic, calculations with money, and measurement. The math problem solving measure used in the present research (i.e., the problem-solving subtest of the KeyMath III) involved interpretation of numerical contexts and creating or interpreting numerical word problems. Only 12 items were included on the test and children were stopped when they made three errors, so they probably did not experience a great deal of pressure during this task. In contrast, the arithmetic fluency measure used in the present study was a relatively demanding for children, in particular because they were shown many more items than they were able to complete in the time frame (e.g., the mean in grade 2 was only 15 out of a total of 120 possible items). Thus, the arithmetic fluency measure was the most demanding of the various math measures used in the present research, which may explain why it was the only one correlated with math anxiety.

Similarly, Vukovic et al. (2013) found that math anxiety was related to arithmetic performance for grade 2 students, and to a composite measure of more complex skills (including algebra, word problems, data analysis, and probability), but not to geometry scores. Thus, our research (see also Ching, 2017; Vukovic et al., 2013) is consistent with the finding that arithmetic is most often related to math anxiety among elementary school children. Timed arithmetic is a demanding task for children in early elementary school. In general, these results support the view that relatively complex math skills (i.e., relative to the participants' age and experience; Douglas & LeFevre, 2018; Zhang et al., 2019) are most strongly correlated with math anxiety. Further research that includes a range of measures of math performance that vary in difficulty is needed with this age group.

Math anxiety increased significantly from grade 2 to grade 3, although the size of the increase was small. Arithmetic fluency also increased significantly from grade 2 to grade 3, which is consistent with the finding by Krinzinger et al. (2009) that children's calculation ability generally improves during school. In sum, although children's arithmetic skill and math anxiety increased as they advanced from grade 2 to grade 3, the concurrent relations did not get stronger in the present study. More generally, math anxiety for young students may be linked to their recent experiences as well as to specific measures of performance. More detailed data will be important for understanding how math anxiety changes over time.

Reciprocal Relations between Math Anxiety and Math Performance

In relation to our second research question, we did not find fully reciprocal relations between math anxiety and arithmetic fluency. Arithmetic fluency in grade 2 predicted the change in children's math anxiety from grades 2 to 3, but the reverse was not found: Children's math anxiety in grade 2 did not predict the change in arithmetic fluency from grades 2 to 3. Instead, the results showed that poorer arithmetic fluency in grade 2 predicted higher math anxiety in grade 3. However, in some respects our results were similar to those of Gunderson et al. (2018). The effect size they reported for the relation between math anxiety in grade 2 and math achievement in grade 3, while significant, was much weaker than the reverse relation. Thus, in both studies, earlier math achievement was more strongly related to subsequent math anxiety than the reverse.

One important difference between our research and that of Gunderson et al. (2018) was in the choice of a math anxiety measure. We used the CAMS (Jameson, 2013), which asks children to rate their feelings about various math situations. As shown in Appendix A, the items children rated as most negative included challenging situations, such as questions they did not understand, that were hard, or where they might have made a mistake; in contrast, on more general questions, anxiety was low. Gunderson et al. (2018) used the CMAQ-R (Ramirez et al., 2013), which includes questions about specific math problems such as "How do you feel when you have to solve 34− 7?" Such questions may allow children to connect their feelings more directly to math-related experiences. Studies which compare relations between math measures and ways of measuring feelings about mathematics are important for understanding this construct in elementary school students (Dowker et al., 2016).

Despite some differences between the present study and Gunderson et al. (2018), we note that the mean ratings for individual items were positive in both studies. Overall, children's math anxiety scores in the present study averaged in the range of "somewhat positive" to "neutral" (i.e., equivalent to means of 2.29 and 2.47 on the 5-point scale, where 3 is the neutral face). Means on even the most negatively rated items were higher than 3 but less than 4 (i.e., between neutral and somewhat negative). Similarly, the mean ratings on the 5-point rating scale used by Gunderson et al. (2018) were also in the positive range, averaging 2.5 or lower across time and grades. Thus, we can conclude that children in this age range generally feel positively towards mathematics and towards activities related to mathematics. Further research about the nature of the latent construct, and whether it is a measure of anxiety for young children (as opposed to liking, familiarity, or perceived self-efficacy) will be very important in understanding the source and the development of math anxiety.

In summary, the present findings support Gunderson et al.'s (2018) general conclusion that the strength of the relation between earlier math performance and later math anxiety is stronger than the reverse. Krinzinger et al. (2009) similarly found that earlier calculation ability was predictive of later math related attitudes, rather than the reverse. Other studies with elementary school children did not measure math anxiety at both time points, and therefore cannot be used to test the direction of the relations between math anxiety and math performance. Overall, our findings are consistent with Gunderson et al.'s suggestion that children in early elementary grades who find it challenging to develop their math skills may be more likely to develop negative emotions towards math (Maloney, 2016). Gunderson et al. (2018) suggested that parents and educators should encourage young children to build a strong mathematical foundation to reduce the likelihood of developing math anxiety in later years. We would add, however, that further research is needed to determine the causality of the relations between earlier math anxiety and later performance.

Moderating Effects of Working Memory

The third research question we explored was whether working memory would moderate the relations between math anxiety and math performance, as was found in previous studies (Ching, 2017; Vukovic et al., 2013). Ching (2017) found that, for children with higher working memory, there was a stronger (negative) relation between math performance and math anxiety when they were solving hard problems than for children with lower working memory. Vukovic et al. (2013) found that only children with high working memory scores showed a negative relation between math anxiety and math performance (where performance was a composite of several different measures). In the present study, we found some evidence to suggest that working memory may be related to the longitudinal relations between math anxiety and arithmetic. More specifically and consistent with Ramirez et al. (2013) and Vukovic et al. (2013), working memory moderated the negative relation between arithmetic fluency in grade 2 and growth of math anxiety in grade 3 such that only children with high working memory scores showed this pattern. However, this pattern should be interpreted cautiously because the interaction was not significant when a stringent correction for multiple comparisons was applied. Further research is needed to understand how working memory capacity may influence mathematical development (Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007; Ramirez et al., 2018).

Limitations and Future Directions

One limitation is that this study had a smaller sample (n = 244) than Gunderson et al. (2018); n = 634). The larger sample size in Gunderson et al. increased the power of the study relative to the current one, and thus, the chance that any particular correlation would be significant. As noted above, the correlations between math anxiety and performance were generally lower in the present research than in Gunderson et al. although the standardized coefficients in the models were similar. Another limitation of the current research is that the math anxiety measure we used, although shown to be reliable, has not been used extensively. Even in the original study (i.e., Jameson, 2013), the size of the relation between math anxiety and performance was moderate. The correlations between math anxiety and arithmetic in the present research were similarly moderate. It is possible that a different measure of math anxiety would have resulted in higher overall correlations and potentially different conclusions. A third, more general concern is that different math performance measures were used in the present research compared to other studies. Among the few existing longitudinal projects, none had a theoretical framework that might help to provide some sense of why the results vary across studies.

In future studies, researchers should consider other factors that may influence the development of math anxiety. For example, Maloney et al. (2015) found that negative attitudes towards math may be transmitted from parents or teachers who themselves are anxious about math. Baylor, Shen, and Warren (2004) also showed that teaching techniques influence children’s self-efficacy, which in turn may influence children’s academic performance. Thus, an exploration of the relations between children’s feelings about math in elementary school and social influences may help educators and parents prevent math anxiety from becoming a long-standing problem. Moreover, although questionnaires are the most common way to measure math anxiety, studies should include other measures to capture children’s attitude towards mathematics, such as behavioural measures and physiological reactions (Dowker et al., 2016). Finally, more research is needed to understand the mechanisms linking working memory in children to math anxiety and math performance within a developmental framework (Caviola, Carey, Mammarella, & Szucs, 2017).

References

Alloway, T. P., Gathercole, S. E., Kirkwood, H., & Elliott, J. (2008). Evaluating the validity of the Automated Working Memory Assessment. *Educational Psychology*, *28*(7), 725–734.https://doi.org/10.1080/01443410802243828

Ashcraft, M. H. (2002). Math anxiety: Personal, educational, and cognitive consequences. *Current Directions in Psychological Science*, *11*(5), 181–185. https://doi.org/10.1111/1467-8721.00196

Ashcraft, M. H., & Kirk, E. P. (2001). The relationships among working memory, math anxiety,and performance. *Journal of Experimental Psychology: General*, *130*(2), 224–237. https://doi.org/10.1037/0096-3445.130.2.224

Ashcraft, M. H., & Krause, J. A. (2007). Working memory, math performance, and math anxiety. *Psychonomic Bulletin & Review*, *14*(2), 243–248. https://doi.org/10.3758/BF03194059

Ashcraft, M. H., & Moore, A. M. (2009). Mathematics anxiety and the affective drop in performance. *Journal of Psychoeducational Assessment*, *27*(3), 197–205. https://doi.org/10.1177/0734282908330580

Baker, C. K., & Galanti, T. M. (2017). Integrating STEM in elementary classrooms using model-eliciting activities: Responsive professional development for mathematics coaches and teachers. *International Journal of STEM Education*, *4*(1), 10. https://doi.org/10.1186/s40594-017-0066-3

Baylor, A., Shen, E., & Warren, D. (2004). Supporting learners with math anxiety: The impact ofpedagogical agent emotional and motivational support. In: *proceedings of the paper presented at the 7th International Conference on Intelligent Tutoring Systems (ITS)* (pp.6-12). Maceio, Brazil: Springer. http://amybaylor.com/Articles/ITS2004workshop.pdf

Beilock, S. L., & Maloney, E. A. (2015). Math anxiety: A factor in math achievement not to beignored. *Policy Insights from the Behavioral and Brain Sciences*, *2*(1), 4–12. https://doi.org/10.1177/2372732215601438

Carey, E., Hill, F., Devine, A., & Szücs, D. (2016). The chicken or the egg? The direction of therelationship between mathematics anxiety and mathematics performance. *Frontiers in Psychology*, *6*. https://doi.org/10.3389/fpsyg.2015.01987

Caviola, S., Carey, E., Mammarella, I. C., & Szucs, D. (2017). Stress, time pressure, strategy selection and math anxiety in mathematics: A review of the literature. *Frontiers in Psychology*, *8*, 1488. https://doi.org/10.3389/fpsyg.2017.01488

Chang, H., Sprute, L., Maloney, E. A., Beilock, S. L., & Berman, M. G. (2017). Simple arithmetic: Not so simple for highly math anxious individuals. *Social Cognitive and Affective Neuroscience*, *12*(12), 1940–1949. https://doi.org/10.1093/scan/nsx121

Ching, B. H.-H. (2017). Mathematics anxiety and working memory: Longitudinal associationswith mathematical performance in Chinese children. *Contemporary Educational Psychology*, *51*, 99–113. https://doi.org/10.1016/j.cedpsych.2017.06.006

Douglas, H. P., & LeFevre, J.-A. (2018). Exploring the influence of basic cognitive skills on the relation between math performance and math anxiety. *Journal of Numerical Cognition*, *3*(3), 642–666. https://doi.org/10.5964/jnc.v3i3.113

Dowker, A., Bennett, K., & Smith, L. (2012). Attitudes to mathematics in primary school children. *Child Development Research*, *2012*, 1–8. https://doi.org/10.1155/2012/124939

Dowker, A., Sarkar, A., & Looi, C. Y. (2016). Mathematics anxiety: What have we learned in 60years? *Frontiers in Psychology*, *7*. https://doi.org/10.3389/fpsyg.2016.00508

Dunn, L. M., & Dunn, D. M. (2012). *Peabody Picture Vocabulary Test—Fourth Edition*. American Psychological Association. https://doi.org/10.1037/t15144-000Enders, C. K. (2010). *Applied missing data analysis*. Guilford Press.

English, L. D. (2017). Advancing elementary and middle school STEM education. *InternationalJournal of Science and Mathematics Education*, *15*(S1), 5–24. https://doi.org/10.1007/s10763-017-9802-x

Ganley, C. M., & McGraw, A. L. (2016). The development and validation of a revised version ofthe math anxiety scale for young children. *Frontiers in Psychology*, *7*. https://doi.org/10.3389/fpsyg.2016.01181

Göbel, S. M., Watson, S. E., Lervåg, A., & Hulme, C. (2014). Children's arithmetic development: It is number knowledge, not the approximate number sense, that counts. *Psychological Science, 25*(3), 789-798. https://doi.org/10.1177/0956797613516471

Gunderson, E. A., Park, D., Maloney, E. A., Beilock, S. L., & Levine, S. C. (2018). Reciprocalrelations among motivational frameworks, math anxiety, and math achievement in early elementary school. *Journal of Cognition and Development*, *19*(1), 21–46. https://doi.org/10.1080/15248372.2017.1421538

Gunderson, E. A., Ramirez, G., Beilock, S. L., & Levine, S. C. (2012). The relation between spatial skill and early number knowledge: The role of the linear number line. *Developmental Psychology*, *48*(5), 1229–1241. https://doi.org/10.1037/a0027433

Harari, R. R., Vukovic, R. K., & Bailey, S. P. (2013). Mathematics anxiety in young children: An exploratory study. *The Journal of Experimental Education*, *81*(4), 538–555. https://doi.org/10.1080/00220973.2012.727888

Haynes, W. (2013). Benjamini–Hochberg method. *Encyclopedia of systems biology*, 78-78. https://doi.org/10.1007/978-1-4419-9863-7_1215

Hembree, R. (1990). The nature, effects, and relief of mathematics anxiety. *Journal for*

Researchin Mathematics Education, *21*(1), 33. https://doi.org/10.2307/749455

Hu, L. T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling, 6*(1), 1–55. http://dx.doi.org/10.1080/10705519909540118

Jameson, M. M. (2013). The development and validation of the children's anxiety in math scale. *Journal of Psychoeducational Assessment*, *31*(4), 391–395. https://doi.org/10.1177/0734282912470131

Jameson, M. M. (2014). Contextual factors related to math anxiety in second-grade children. *TheJournal of Experimental Education*, *82*(4), 518–536. https://doi.org/10.1080/00220973.2013.813367

Jarosz, A. F., & Wiley, J. (2014). What are the odds? A practical guide to computing and reporting bayes factors. *The Journal of Problem Solving*, *7*(1). https://doi.org/10.7771/1932-6246.1167

Jeffreys, H. (1961). *Theory of probability* (3rd ed.). Oxford University Press.

Krinzinger, H., Kaufmann, L., & Willmes, K. (2009). Math anxiety and math ability in early primary school years. *Journal of Psychoeducational Assessment*, *27*(3), 206–225. https://doi.org/10.1177/0734282908330583

LeFevre, J.-A., Fast, L., Skwarchuk, S.-L., Smith-Chant, B. L., Bisanz, J., Kamawar, D., & Penner-Wilger, M. (2010). Pathways to mathematics: Longitudinal predictors of performance: Pathways to mathematics. *Child Development*, *81*(6), 1753–1767. https://doi.org/10.1111/j.1467-8624.2010.01508.x

Lyons, I. M., Price, G. R., Vaessen, A., Blomert, L., & Ansari, D. (2014). Numerical predictorsof arithmetic success in grades 1-6. *Developmental Science*, *17*(5), 714–726. https://doi.org/10.1111/desc.12152

Ma, X, & Xu, J. (2004). The causal ordering of mathematics anxiety and mathematics achievement: A longitudinal panel analysis. *Journal of Adolescence*, *27*(2), 165–179. https://doi.org/10.1016/j.adolescence.2003.11.003

Ma, X. (1999). A meta-analysis of the relationship between anxiety toward mathematics and achievement in mathematics. *Journal for Research in Mathematics Education*, *30*(5), 520. https://doi.org/10.2307/749772

Malone, S. A., Heron-Delaney, M., Burgoyne, K., & Hulme, C. (2019). Learning correspondences between magnitudes, symbols and words: Evidence for a triple code model of arithmetic development. *Cognition, 187*, 1-9. https://doi.org/10.1016/j.cognition.2018.11.016

Maloney, E.A. (2016). Math anxiety: Causes, consequences, and remediation. In K. R. Wentzel& D. B. Miele (Eds.), Handbook of Motivation at School (2nd ed., 408–423). New York,NY: Routledge.

Maloney, E. A., Ansari, D., & Fugelsang, J. A. (2011). Rapid communication: The effect of mathematics anxiety on the processing of numerical magnitude. *Quarterly Journal of Experimental Psychology*, *64*(1), 10–16. https://doi.org/10.1080/17470218.2010.533278

Maloney, E. A., & Beilock, S. L. (2012). Math anxiety: Who has it, why it develops, and how toguard against it. *Trends in Cognitive Sciences*, *16*(8), 404–406. https://doi.org/10.1016/j.tics.2012.06.008

Maloney, E. A., Ramirez, G., Gunderson, E. A., Levine, S. C., & Beilock, S. L. (2015). Intergenerational effects of parents' math anxiety on children's math achievement and anxiety. *Psychological Science*, *26*(9), 1480–1488. https://doi.org/10.1177/0956797615592630

Maloney, E. A., Risko, E. F., Ansari, D., & Fugelsang, J. (2010). Mathematics anxiety affects counting but not subitizing during visual enumeration. *Cognition*, *114*(2), 293–297. https://doi.org/10.1016/j.cognition.2009.09.013

Muthén, L. K., & Muthén, B. O. (1998). *Mplus user's guide*. Muthén & Muthén.

Namkung, J. M., Peng, P., & Lin, X. (2019). The relation between mathematics anxiety and mathematics performance among school-aged students: A meta-analysis. *Review of Educational Research*, *89*(3), 459–496. https://doi.org/10.3102/0034654319843494

Núñez-Peña, M. I., & Suárez-Pellicioni, M. (2014). Less precise representation of numerical magnitude in high math-anxious individuals: An ERP study of the size and distance effects. *Biological Psychology*, *103*, 176–183. https://doi.org/10.1016/j.biopsycho.2014.09.004

Pantoja, N., Schaeffer, M. W., Rozek, C. S., Beilock, S. L., & Levine, S. C. (2020). Children'smath anxiety predicts their math achievement over and above a key foundational math skill. *Journal of Cognition and Development*, *21*(5), 709–728. https://doi.org/10.1080/15248372.2020.1832098

Primi, R., Ferrão, M. E., & Almeida, L. S. (2010). Fluid intelligence as a predictor of learning: Alongitudinal multilevel approach applied to math. *Learning and Individual Differences*, *20*(5), 446–451. https://doi.org/10.1016/j.lindif.2010.05.001

Ramirez, G., Chang, H., Maloney, E. A., Levine, S. C., & Beilock, S. L. (2016). On the relationship between math anxiety and math achievement in early elementary school: The role of problem solving strategies. *Journal of Experimental Child Psychology*, *141*, 83– 100. https://doi.org/10.1016/j.jecp.2015.07.014

Ramirez, G., Gunderson, E. A., Levine, S. C., & Beilock, S. L. (2013). Math anxiety, workingmemory, and math achievement in early elementary school. *Journal of Cognition and Development*, *14*(2), 187–202. https://doi.org/10.1080/15248372.2012.664593

Ramirez, G., Shaw, S. T., & Maloney, E. A. (2018). Math anxiety: Past research, promising interventions, and a new interpretation framework. *Educational Psychologist*, *53*(3), 145–164. https://doi.org/10.1080/00461520.2018.1447384

Sorvo, R., Koponen, T., Viholainen, H., Aro, T., Räikkönen, E., Peura, P., Dowker, A., & Aro, M. (2017). Math anxiety and its relationship with basic arithmetic skills among primary school children. *British Journal of Educational Psychology*, *87*(3), 309–327. https://doi.org/10.1111/bjep.12151

Thomas, G., & Dowker, A. (2000). *Mathematics anxiety and related factors in young children*. British Psychological Society Developmental Section Conference, Bristol.

Vanbinst, K., Ghesquière, P., & De Smedt, B. (2015). Does numerical processing uniquely predict first graders' future development of single-digit arithmetic*? Learning and Individual Differences, 37*, 153-160. https://doi.org/10.1016/j.lindif.2014.12.004

Vandierendonck, A. (2018). Further tests of the utility of integrated speed-accuracy measures intask switching. *Journal of Cognition, 1*(1), 1–16. https://doi.org/10.5334/joc.6

Vukovic, R. K., Kieffer, M. J., Bailey, S. P., & Harari, R. R. (2013). Mathematics anxiety in young children: Concurrent and longitudinal associations with mathematical performance. *Contemporary Educational Psychology*, *38*(1), 1–10. https://doi.org/10.1016/j.cedpsych.2012.09.001

Wechsler, D. (2014). *WISC-V: Technical and Interpretive Manual*. NCS Pearson, Inc. Woodcock, R., McGrew, K., & Mather, N. (2001). *Woodcock-Johnson III*. IL: Riverside. Xu, C., & LeFevre, J. (2020). Children's knowledge of symbolic number in grades 1 and 2: Integration of associations. *Child Development*, cdev.13473. https://doi.org/10.1111/cdev.13473

Zhang, J., Zhao, N., & Kong, Q. P. (2019). The relationship between math anxiety and math performance: A meta-analytic investigation. *Frontiers in Psychology*, *10*, 1613. https://doi.org/10.3389/fpsyg.2019.01613

Table 1

Descriptive Statistics for Control Variables and Outcome Variables

	Grade 2				Grade 3					Grade Comparison				
	Min	*Max*	*M*	*SD*	*N*	*Min*	*Max*	*M*	*SD*	*t*	*df*	*p*	*d*	BF_{10}
Matrix Reasoning[a]	3	24	16.12	3.94	--	--	--	--	--	--	--	--		--
Vocabulary[a]	9	36	29.73	4.90	--	--	--	--	--	--	--	--		--
Digit Forward[a]	4	15	8.17	2.17	--	--	--	--	--	--	--	--		--
Digit Backward[a]	3	9	5.48	1.12	--	--	--	--	--	--	--	--		--
Spatial Span[a]	0	13	5.55	2.55	--	--	--	--	--	--	--	--		--
Number Comparison[b]												<.001	-1.24	5.23E+27
Arithmetic Fluency[a]	1	61	15.49	8.79	206	2.00	62.00	23.36	11.47	12.57	146	< .001	1.04	6.93E+21
Problem Solving[a]	0	9	3.45	2.22	209	.00	12.00	5.57	2.42	14.17	146	< .001	1.17	1.05E+26
Math Anxiety[c]	16	69	36.72	10.8	209	16.00	65.00	39.49	10.55	2.79	146	.006	0.23	3.75

Note. -- represents measures not administered in that grade. Grade comparisons include those students who participated in both grades. [a]Total correct; [b]Adjusted response time in seconds (LISAS); [c]Total score (maximum possible is 90).

Table 2

Correlations Among Variables in Grade 2 and 3

	1	2	3	4	5	6	7	8	9	10	11
1. Mother's Education	-										
2. Matrix Reasoning[a] Grade 2	.08 9.27	-									
3. Receptive Vocabulary[a] Grade 2	.13 3.50	.30*** **250**	-								
4. Working Memory[d] Grade 2	-.05 13.21	.26*** 17.24	.26*** 22.73	-							
5. Number Comparison[b] Grade 2	-.01 16.18	-.06 12.92	-.02 16.39	-.13 4.10	-						
6. Arithmetic Fluency[a] Grade 2	.22** 4.88	.18* 1.22	.13 3.45	.33*** 1000	-.39*** ∞	-					
7. Problem Solving[a] Grade 2	.24** 8.06	.41*** ∞	.45*** ∞	.39*** ∞	-.22** 3.88	.43*** ∞	-				
8. Math Anxiety[c] Grade 2	-.13 3.64	-.02 16.46	.04 4.97	.06 12.88	.02 16.38	-.27*** 52.63	.09 7.67	-			
9. Number Comparison[b] Grade 3	-.03 15.93	-.13 4.93	-.15 2.94	-.17* 1.74	.57*** ∞	-.43*** ∞	-.30*** 50	.02 15.05	-		
10. Arithmetic Fluency[a] Grade 3	.16* 1.64	.22** 2.13	.11 6.24	.21* 1.54	-.47*** ∞	.67*** ∞	.45*** ∞	-.16* 2.08	.51*** ∞	-	
11. Problem Solving[a] Grade 3	.16* 1.49	.30*** 83.33	.53*** ∞	.41*** ∞	-.27*** 13.51	.36*** 1000	.63*** ∞	-.10 7.50	-.39*** ∞	.48*** ∞	-
12. Math Anxiety[c] Grade 3	-.17* 1.04	-.03 14.46	.07 11.09	.11 6.19	.11 6.32	-.26*** 11.11	-.04 13.60	.49*** ∞	.07 3.63	-.22** 7.24	-.16* 1.15

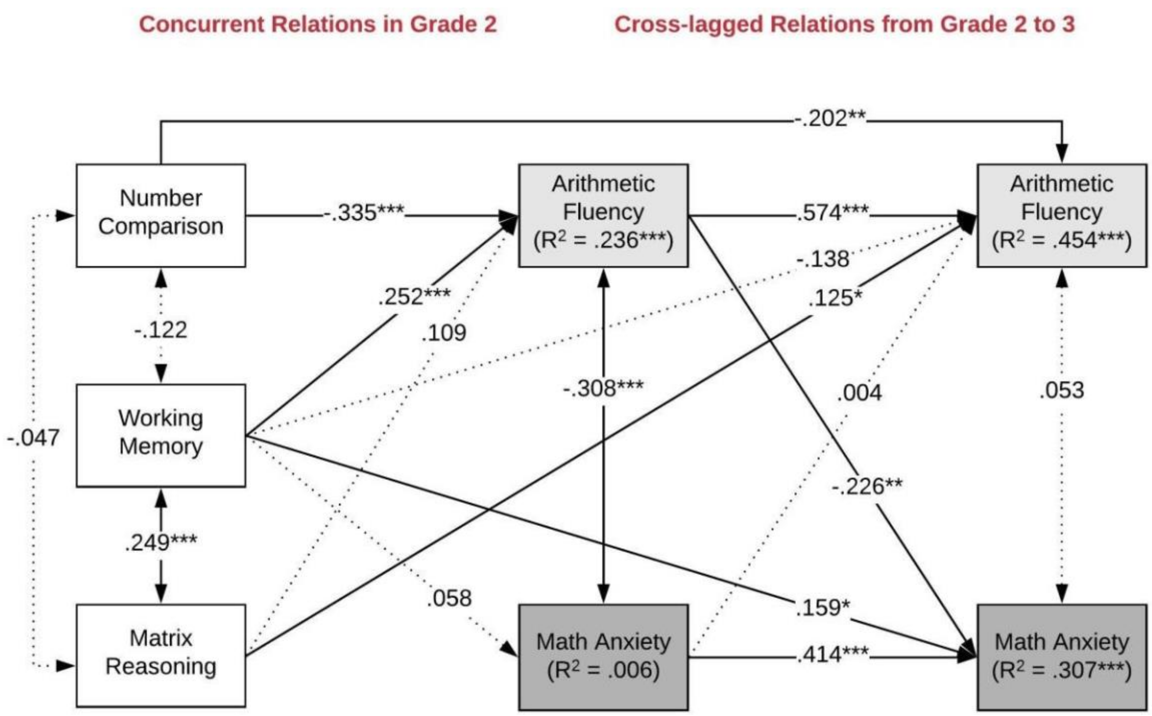
Note. $p < .05$*; $p < .01$**; $p < .001$***; Estimated Bayes Factors, with possible values ranging from 0 to ∞ are presented underneath the correlations and represent support for the null hypothesis (BF01). Higher values indicate more support for the null. [a]Total correct;[b]Adjusted response time in seconds (LISAS); [c]Total score; [d]Factor score based on PCA

Figure 1

The Facial Rating Scale from the Children's Math Anxiety Scale

Figure 2

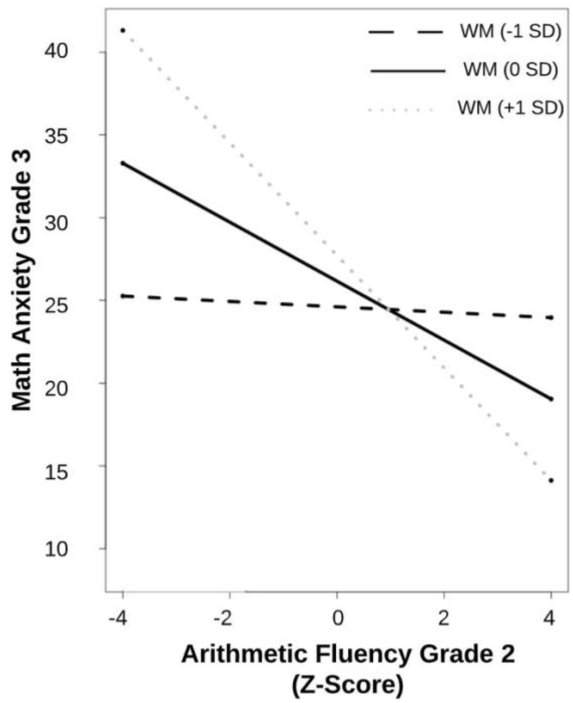
Cross-lagged Path Models for Arithmetic Fluency and Math Anxiety in Grades 2 and 3



Note. Missing values were imputed using FIML (*N* = 244); numbers on the arrows arestandardized coefficients; **p* < .05, ** *p* < .01, ****p* < .001.

Figure 3

Moderation Effects of Working Memory on the Relation between Arithmetic Fluency in Grade2 and Math Anxiety in Grade 3



Note. Slopes for the relation between arithmetic fluency in grade 2 and math anxiety in grade 3(controlling for math anxiety in grade 2) are shown for representative levels of working memory; one standard deviation below the mean (-1 SD), at the mean (0 SD), and one standarddeviation above the mean (+1 SD).

Appendix A

Child's Anxiety in Math Questionnaire

Table A1

Descriptive Statistics for Individual Items on the Anxiety Questionnaire

	Grade 2			Grade 3		
	Mean	*SD*	*Median*	*Mean*	*SD*	*Median*
Math Anxiety Items						
When I make a mistake in math, I feel	3.34	1.18	3	3.08	1.11	3
When the teacher gives the class a math problem I don't understand, I feel	3.20	1.23	3	3.53	1.09	3
When I have a hard math question, I feel	3.16	1.28	3	3.25	1.18	3
When I am working on math problems that are difficult and make me think hard, I feel	3.03	1.24	3	3.15	1.17	3
When I know that I am going to have a math test, I feel	2.39	1.35	2	2.74	1.25	3
When the teacher calls on me to answer a math problem, I feel	2.32	1.26	2	2.31	1.13	2
If I have to add up numbers on the board in front of the class, I feel	2.27	1.21	2	2.6	1.28	3
Working on math at home makes me feel	2.24	1.40	2	2.61	1.47	2
When I think about doing math, I feel	2.18	1.20	2	2.25	1.02	2
When my teacher says they are going to give me a math problem, I feel	2.05	1.20	2	2.23	1.12	2
When I know my class will be working on math at school, I feel	2.05	1.23	2	2.09	1.12	2
Thinking about working on math in class makes me feel	1.92	1.14	1.50	2.14	1.11	2
Compared to other school subjects, math makes me feel	1.90	1.12	1	2.28	1.15	2