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The causal ordering of mathematics anxiety and mathematics achievement: a longitudinal panel analysis

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Abstract

Using data from the Longitudinal Study of American Youth (LSAY), we aimed to determine the causal ordering between mathematics anxiety and mathematics achievement. Results of structural equation modelling showed that, across the entire junior and senior high school, prior low mathematics achievement significantly related to later high mathematics anxiety, but prior high mathematics anxiety hardly related to later low mathematics achievement. Mathematics achievement was more reliably stable from year to year than mathematics anxiety. There were statistically significant gender differences in the causal ordering between mathematics anxiety and mathematics achievement. Prior low mathematics achievement significantly related to later high mathematics anxiety for boys across the entire junior and senior high school but for girls at critical transition points only. Mathematics anxiety was more reliably stable from year to year among girls than among boys.

Introduction

Mathematics anxiety is generally defined as a discomfort state created when students are required to perform mathematical tasks (Cemen, 1987; Wood, 1988; Zaslavsky, 1994). Main characteristics of this discomfort state include dislike, worry, and fear, with specific behavioural manifestations such as tension, frustration, distress, helplessness, and mental disorganization (Richardson & Suinn, 1972; Tobias, 1978; Wigfield & Meece, 1988; Hart, 1989). The construct of mathematics anxiety appears to be multidimensional (Bessant, 1995; Newstead, 1995, 1998;

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Ho et al., 2000). Three common dimensions of mathematics anxiety include mathematics test anxiety (associated with anticipating, taking, and receiving mathematics tests), numerical anxiety (associated with number manipulation), and abstraction anxiety (associated with abstract mathematical content) (Rounds & Hendel, 1980; Ferguson, 1986).

Causes of mathematics anxiety can be classified as environmental, intellectual, and personal (Hadfield & McNeil, 1994). Environmental causes include experiences in mathematics classes and characteristics of mathematics teachers (e.g. being insensitive to students and being anxious about mathematics) (Tobias, 1990; Dossel, 1993; Newstead, 1995, 1998). Intellectual causes include innate characteristics of mathematics (e.g. being highly abstract and being highly logical) (Vinner, 1994; Newstead, 1998). Personal causes include self-esteem, physiological well-being, attitude toward mathematics, confidence in mathematics, learning style in mathematics, and influence of previous mathematics experiences (Miller & Mitchell, 1994; Gutbezahl, 1995; Levine, 1995; Newstead, 1995). Classroom practice reforms, alternative instructional formats, and counseling and treatments are considered general strategies to reduce mathematics anxiety (Hembree, 1990; Zyl & Lohr, 1994; Newstead, 1998).

Mathematics anxiety has been found to be related to a range of concerns and problems in the learning of mathematics. For example, students with mathematics anxiety tend to drop out of mathematics courses (particularly advanced mathematics courses) prematurely, develop negative attitude toward activities involving mathematics (including working with computers), avoid majors and careers in need of quantitative skills, and dislike teaching mathematics if becoming teachers (see Hembree, 1990; Ma, 1999; Ho et al., 2000). Among all negative impacts of mathematics anxiety, the most commonly discussed is the negative relationship between mathematics anxiety and mathematics achievement. This negative relationship describes the consistent research finding that students with a higher level of mathematics anxiety perform at a lower level of mathematics achievement (e.g. Tocci & Engelhard, 1991; Lee, 1992; Satake & Amato, 1995; Ho et al., 2000).

Hembree's (1990) meta-analysis reported an average correlation between mathematics anxiety and mathematics achievement of -0.34. In a more recent meta-analytic review on the relationship between mathematics anxiety and mathematics achievement, Ma (1999) found that the common population correlation for this relationship is -0.27. This magnitude is associated with a prediction that "measures (or treatments) that resulted in movement of a typical student in the group of high mathematics anxiety into the group of low mathematics anxiety would be associated with improvement of the typical student's level of mathematics achievement from the 50th to the 71st percentile" (Ma, 1999, p. 528). Such a magnitude is certainly important in educational practice.

Researchers have made efforts to examine individual differences in the relationship between mathematics anxiety and mathematics achievement. Gender is one of the most critical variables moderating this relationship. As Aiken (1970) pointed out, "no one would deny that sex can be an important moderator variable in the prediction of achievement from measures of attitude and anxiety" (p. 567). Specifically, Aiken (1970) stated that "measures of attitude and anxiety may be better predictors of the achievement of females than that of males" (p. 567). Eccles and Jacobs (1986) asserted that gender differences in mathematics anxiety are directly attributable to gender differences in mathematics achievement. However, Ma's (1999) meta-analysis concluded that gender differences are not statistically significant in the relationship between mathematics anxiety and mathematics achievement. In addition to this controversy, the gender gap in mathematics achievement has been diminishing in the past decade (see meta-analytic results in Frost, Hyde, & Fennema, 1994; Friedman, 1996), and this development makes it necessary to re-examine gender differences in the relationship between mathematics anxiety and mathematics achievement.

The application of this consistent negative relationship between mathematics anxiety and mathematics achievement in educational practice (e.g. for treatment programs) has long been hampered by the confusing causal priority between mathematics anxiety and mathematics achievement. Newstead (1998) stated that "this relationship…is necessarily ambiguous with respect to the direction of causality" (p. 53) (see also Reyes, 1984). There are three alternative models in the research literature regarding the causal ordering between mathematics anxiety and mathematics achievement: (a) high mathematics anxiety is a cause of low mathematics achievement, (b) high mathematics anxiety is an effect of low mathematics achievement, and (c) mathematics anxiety and mathematics achievement are reciprocally related.

Researchers adopting the first model begin their research with the assumption that mathematics anxiety is the effective disturbance of the recall of prior mathematical skills, knowledge, and experiences (the interferences model). For example, Hembree (1990) concluded that mathematics anxiety constrains performance in mathematical tasks in a serious manner. On the other hand, researchers embracing the second model start their research with the assumption that mathematics anxiety is the unpleasant remembrance of poor mathematics performance in the past (the deficits model). For example, Tobias (1985) asserted that low mathematics achievement attributable to poor study habits and deficient test-taking skills results in high mathematics anxiety. The attempt to integrate these competing frameworks introduces the reciprocal relationship between mathematics anxiety and mathematics achievement (the limited cognitive capacity formulation) (see Tobias, 1985). Overall, practices in mathematics education may not benefit from findings on the relationship between mathematics anxiety and mathematics achievement until researchers are able to discern the causal ordering between mathematics anxiety and mathematics achievement.

To a large extent, the reason why few researchers have attempted to examine the causal relationship between mathematics anxiety and mathematics achievement lies in methodological difficulties. The lack of longitudinal data makes it tempting for researchers to rely on cross-sectional data to examine the causal ordering between mathematics anxiety and mathematics achievement. Gollob and Reichardt (1987) insisted, however, that cross-sectional models are often miss-specified because these models are unable to take time lags into account (note that causal factors take time to exert effects). Only with appropriate longitudinal designs (ideally longitudinal experimental designs that assign students randomly to groups and manipulate independent variables associated with mathematics anxiety and mathematics achievement) in combination with appropriate statistical techniques are researchers able to properly infer the causal ordering between mathematics anxiety and mathematics achievement.

It is important to recognize that the use of causal modelling techniques, such as structural equation modelling, does not automatically warrant creditability to any knowledge claim on a causal relationship. A creditable causal conclusion needs to meet a number of conditions. Citing Shavelson and Bolus (1982), Byrne (1984, p. 451) summarized "three prerequisites underlying the establishment of causal predominance" as (a) establishing a statistical relationship between two variables, (b) establishing a time precedence between the two variables, and (c) specifying a model of causal relationship between the two variables. Marsh (1990) has identified longitudinal data with at least two waves as the minimal condition.

Employing structural equation modelling techniques in the current study, we took advantage of the recently available data from the Longitudinal Study of American Youth (LSAY) to examine the causal ordering between mathematics anxiety and mathematics achievement. The LSAY is a national, 6-year panel study, tracking students throughout the entire secondary schooling (from Grade 7 to Grade 12). A period of 6 years is long enough to warrant the detection of any cross-lagged effects between mathematics anxiety and mathematics achievement. We also examined gender differences in the causal relationship between mathematics anxiety and mathematics achievement.

Specifically, two main research questions were addressed. In the first research question, we explored the causal nature of the relationship between mathematics anxiety and mathematics achievement across six grade levels (from Grade 7 to Grade 12). We attempted to put the three alternative models regarding the relationship between mathematics anxiety and mathematics achievement to test by identifying the causal ordering or causal priority between mathematics anxiety and mathematics achievement. We examined this issue in a cross-lagged manner. In the second research question, we examined gender differences in the causal relationship between mathematics anxiety and mathematics achievement. We wanted to learn whether boys and girls demonstrate differential causal ordering or causal priority between mathematics anxiety and mathematics achievement. To examine this issue, we investigated the presence (or absence) of statistically significant differences between models with male data and female data.

Method

Data

Data for the current study were drawn from the Longitudinal Study of American Youth (LASY) (see Miller, Kimmel, Hoffer, & Nelson, 2000). A national probability sample of 52 public middle and high schools across the United States were involved in the LSAY (sampling probabilities were proportional to student enrollment in 12 sampling strata cross-classified by geographic region and type of community). About 60 students were randomly selected from Grade 7 in each of these schools and were followed for 6 years (from Grade 7 to Grade 12). The total sample size included 3116 students (1626 boys and 1490 girls).

The LSAY had a focus on mathematics and science education in the public school system in the United States. In each of the 6 years, students wrote achievement tests in mathematics and science and completed a student questionnaire that covered a wide range of measures including mathematics anxiety. All these features of the LSAY made it suitable for the purpose of the current study.

Measures

Main variables of interest were mathematics anxiety and mathematics achievement in the current study. These variables were treated as latent variables, and multiple indicators were used to represent various observed aspects of each variable. There were two indictors on mathematics anxiety: (a) doing mathematics often makes me nervous or upset, and (b) I often get scared when I open my mathematics book and see a page of problems. Both indicators were measured in a five-point Likert-type scale (see Table 1).

Mathematics achievement test in the LSAY contained four subscales measuring (a) basic skills (40 items), (b) algebra (30 items), (c) geometry (30 items), and (d) quantitative literacy (28 items). Accordingly, there were four indicators on mathematics achievement (see Table 1). Test scores were initially determined as the number (or percent) of correct items. To make test scores comparable across grade levels, the LSAY staff equated test scores by means of item response theory (IRT) that uses overlap items across grade levels to anchor test scores from each grade level to a common metric scale (see Kolen & Brennan, 1995). Because test scores were IRT scores, there was neither a set of top scores nor a set of bottom scores. All test scores were normed to a mean score of 50 for Grade 7.

Another variable examined in the current study was gender that came from the student questionnaire. The LSAY staff checked students' self-reported gender against their first names and verified with their parents with all mistakes corrected. Gender was used in the current study to separate boys and girls from which we compared two statistical models with male data and female data in terms of the causal ordering between mathematics anxiety and mathematics achievement.

Table 1
Descriptive statistics for indicators of mathematics anxiety and mathematics achievement by gender

	Grade 7		Grade 8		Grade 9		Grade 10		Grade 11		Grade 12	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Mathematics anxiety												
Mathematics often makes me nervous or upset												
Male	3.49	1.18	3.49	1.17	3.37	1.07	3.43	1.03	3.41	1.04	3.36	1.01
Female	3.49	1.20	3.54	1.17	3.46	1.13	3.41	1.17	3.38	1.14	3.36	1.11
I often get scared when I open my mathematics book												
Male	3.51	1.24	3.68	1.17	3.51	1.12	3.61	1.06	3.41	1.04	3.57	0.97
Female	3.70	1.16	3.80	1.12	3.65	1.13	3.62	1.11	3.49	1.13	3.51	1.08
Mathematics achievement												
Basic skills												
Male	49.85	10.50	54.07	12.24	59.52	14.10	64.10	14.53	68.80	14.35	69.85	15.10
Female	51.02	9.90	55.55	10.66	60.74	12.31	64.52	12.69	68.23	12.92	69.45	13.45
Algebra												
Male	49.58	10.09	55.97	17.29	66.71	20.02	75.84	21.44	85.18	23.17	89.63	27.09
Female	50.94	10.01	56.67	16.58	60.02	18.69	76.77	20.45	85.01	21.25	89.31	24.22
Geometry												
Male	50.43	10.61	55.80	13.48	64.29	16.80	72.50	19.89	80.04	21.30	81.71	23.39
Female	50.14	8.90	56.01	12.53	63.84	14.79	72.34	18.48	78.75	18.85	79.21	22.62
Quantitative literacy												
Male	50.37	10.44	54.39	12.21	60.36	13.39	65.23	14.67	69.78	14.46	70.87	16.91
Female	50.25	9.60	55.14	11.10	59.94	12.27	64.43	13.18	67.84	13.26	68.59	15.61

Note: Scales for mathematics anxiety indicators are 1 = strongly agree, 2 = agree, 3 = not sure, 4 = disagree, 5 = strongly disagree.

Statistical procedures

Structural equation modelling was used as the primary statistical technique in the current study. A structural equation model contains a measurement model and a structural model. We first fitted the measurement model over six waves of longitudinal data on both mathematics anxiety and mathematics achievement and assessed the adequacy of the measurement model. Based on the measurement model, we developed the structural model to specify stability effects and cross-lagged effects among mathematics anxiety and mathematics achievement and assessed various model-data-fit statistics.

Specifically, we built the measurement model using confirmatory factor analysis to determine the factor structures for the latent variables of mathematic anxiety and mathematics achievement (see Fig. 1). Following the standard modelling procedure (see Pitts, West, & Tein, 1996), we constrained the factor loadings of each indicator to be equal across all six time points. Confirmatory factor analysis also produced estimates of the stability effects that are free from both random measurement errors and impacts of a student's unique reaction to each specific indicator over time.

We generated sample variance–covariance matrices (male, female, and combined) based on aforementioned indicators of mathematics anxiety and mathematics achievement. The use of multiple indicators for both mathematics anxiety and mathematics achievement enhanced the

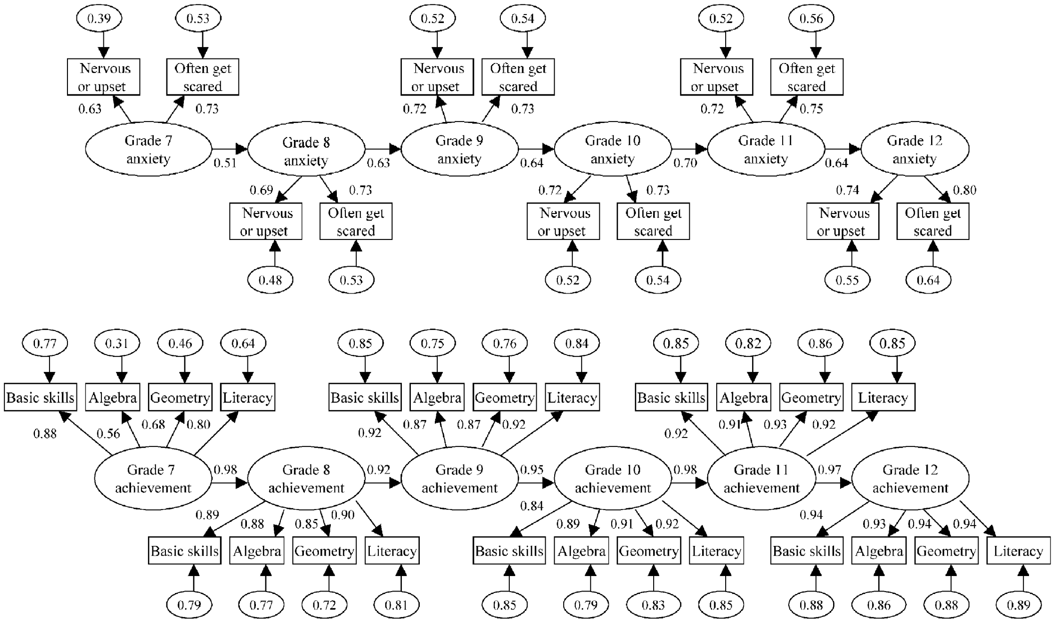

Fig. 1. Measurement model of mathematics anxiety and mathematics achievement across Grades 7–12 (*Note*: Large ovals represent latent variables. Small rectangles represent observed indicators. Values in small circles represent error variances associated with observed indicators. Values between observed indicators and latent variables are factor loadings (standardized regression weights). Values between latent variables are stability coefficients. Lines of covariances that connect measurement errors of the same indicator over time are omitted for simplicity. Lines of covariances that connect measurement errors among indicators at each time point are omitted for simplicity).

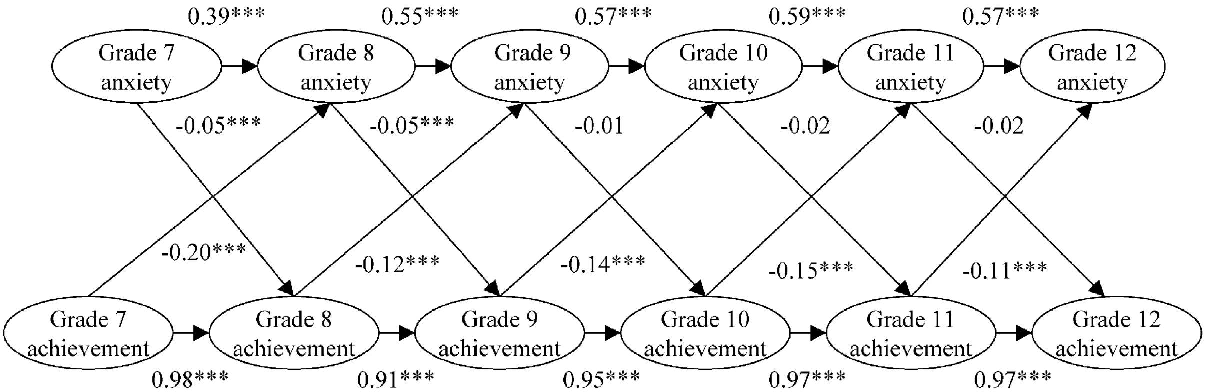

Fig. 2. Structural equation model estimating the causal relationship between mathematics anxiety and mathematics achievement across Grades 7–12 (*Note*: Large ovals represent latent factors and unidirectional arrows represent casual links. All parameter estimates for unidirectional paths are standardized. $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$).

reliability of the structural model (see Marsh, 1990) which we specified in a cross-lagged manner between mathematics anxiety and mathematics achievement as shown in Fig. 2. Essentially, the structural model hypothesized the reciprocal causal relationship between mathematics anxiety and mathematics achievement from each year to the next. The structural model also contained the stability effects for both mathematics anxiety and mathematics achievement.

This structural model included measurement errors correlated across six time points for the same indicator. This treatment of correlated measurement errors over time is a sound statistical practice when modelling longitudinal data (see Pitts et al., 1996). It speaks to the assumption that measurement errors of a repeated measure may covary. We also correlated measurement errors among indicators of each latent variable (mathematics anxiety or mathematics achievement) at each time point, in anticipation that measurement errors for indicators of the same latent variable might be correlated and this correlation in measurement errors might also be different across time points (e.g. errors in measuring basic skills might be correlated with errors in measuring quantitative literacy).

Missing data are often a concern in any longitudinal study. We did not employ traditional techniques such as listwise deletion and pairwise deletion to deal with missing data on indicators of mathematics anxiety and mathematics achievement, because we were concerned about the reduction in sample size when using these techniques. Instead, we relied on the full-information maximum likelihood (FIML) method featured in the statistical program that we used for data analysis, AMOS (analysis of moment structures, see Arbuckle, 1997), to treat missing data. We made this decision based on the research evidence that the FIML has greater statistical efficiency than conventional techniques when dealing with missing data (Little, Schnabel, & Baumert, 2000).

Results

Table 1 presents descriptive statistics on all observed indicators of mathematics anxiety and mathematics achievement across six grade levels for both boys and girls. Differences in means between boys and girls were tested statistically, using the 95% confidence intervals of male and female means with non-overlaps indicating statistically significant differences (see Glass & Hopkins, 1984). Descriptive results did not reveal any statistically significant gender differences in any indicators of mathematics anxiety and mathematics achievement.

Assessment of model-data-fit

With two latent variables (mathematics anxiety and mathematics achievement) at each time (or measurement) point, we tested these latent variables separately. In other words, we specified stability models for mathematics anxiety and mathematics achievement without considering the cross-lagged paths when we developed the measurement model. In Fig. 1, there were two indicators measuring mathematics anxiety in the top measurement model and four indicators measuring mathematics achievement in the bottom measurement model (at each of the six time points). Paths represented stability coefficients that depict the relationship of the latent variables across six time points. In each measurement model, the relationship between two latent variables was completely mediated by other latent variables in between. Based on the measurement model, we added cross-lagged paths to specify the structural model.

We used multiple model-data-fit indices to assess the degree to which the measurement and structural models fitted the data. Multiple indices provide information on model-data-fit from different perspectives, thus producing a more conservative and reliable assessment of the model (Jaccard & Wan, 1996). The conventional χ^2 test can be easily distorted by large sample sizes (Fassinger, 1987), which was the case in the current study (e.g. for the structural model, $\chi^2 = 3346$, $df = 544$, $p < 0.001$, indicating that the model fitted the data poorly). To address this concern, common sample insensitive model-data-fit indices were considered. We selected normed fit index (NFI, Bentler & Bonett, 1980) and comparative fit index (CFI, Bentler, 1990) because these indices are robust to sample size and work particularly well in large samples (Bentler, 1990).

Both NFI and CFI range between zero and one, with one indicating a perfect fit. Generally speaking, NFI and CFI above 0.90 indicate adequate fit between the model and the data. We evaluated the two measurement models that we discussed earlier (one on mathematics anxiety and one on mathematics achievement). We found that the model-data-fit indices were good, with both NFI and CFI being 0.99 for mathematics anxiety and 0.98 for mathematics achievement. These results indicate that the measurement models were adequately developed. The structural model also showed a good fit between the model and the data, with both NFI and CFI being 0.99. Note that model-data-fit statistics reported so far came from the combined model (boys and girls). We also fitted the measurement and structural models with male data and female data, and we found that model-data-fit statistics were almost identical to those reported above.

Stability effects of mathematics anxiety and mathematics achievement

Fig. 2 presents the standardized estimates for the structural model specifying the causal relationship between mathematics anxiety and mathematics achievement. The stability effects of mathematics anxiety and mathematics achievement were also assessed in this structural model through the unidirectional paths linking the same latent variable from 1 year to the next (across Grades 7–12). The stability effects were much stronger for mathematics achievement than mathematics anxiety across the six grade levels (from 0.91 to 0.98 for mathematics achievement and from 0.39 to 0.57 for mathematics anxiety). Therefore, prior mathematics achievement had impacts on later mathematics achievement in a much stronger manner than prior mathematics anxiety on later mathematics anxiety.

The other striking finding is that the stability effects were considerably consistent across the six grade levels. This is particularly true for mathematics achievement (from 0.91 to 0.98). Mathematics anxiety in the beginning grade of junior high school (Grade 7) had a smaller impact on mathematics anxiety in the next grade (0.39), in comparison with other stability effects of mathematics anxiety. But the stability effects of mathematics anxiety also became considerably consistent from Grade 8 (from 0.55 to 0.59). Stability coefficients within construct and across time points indicate that mathematics achievement had consistently high test–retest reliability coefficients whereas mathematics anxiety had a smaller test–retest reliability coefficient from Grade 7 to 8 (0.39) compared to values at other time points (0.57 on average). It seems that mathematics achievement was carried over in a steady manner across junior and senior high school. Mathematics anxiety appears to take shape in Grade 8, and once it took shape, its impacts on subsequent mathematics anxiety were consistent across time.

Cross-lagged effects between mathematics anxiety and mathematics achievement

The cross-lagged unidirectional paths between mathematics anxiety and mathematics achievement specified the causal contribution of mathematics anxiety in the previous year (e.g. Grade 7) to changes in mathematics achievement in the next year (e.g. Grade 8) as well as the causal contribution of mathematics achievement in the previous year to changes in mathematics anxiety in the next year. The paths from prior mathematics achievement to later mathematics anxiety were all statistically significant. These cross-lagged effects indicate that prior mathematics achievement significantly related to later mathematics anxiety. For example, lower scores in mathematics achievement in Grade 7 were associated with somewhat higher scores in mathematics anxiety in Grade 8.

The cross-lagged effects from mathematics achievement to mathematics anxiety were also considerably consistent since Grade 8 (from 0.11 to 0.15). This finding indicates that the causal effects of mathematics achievement were consistent, though small, on mathematics anxiety across time (from Grade 8). In contrast, mathematics achievement in Grade 7 had a larger impact (0.20) on mathematics anxiety in Grade 8. Therefore, we concluded that mathematics achievement at the beginning grade of junior high school (Grade 7) helped shape mathematics anxiety in the subsequent grade levels.

On the other hand, three out of five paths from prior mathematics anxiety to later mathematics achievement were not statistically significant. Specifically, from Grade 9, high (prior) mathematics anxiety was not a statistically significant cause of low (later) mathematics achievement. High (prior) mathematics anxiety did significantly relate to low (later) mathematics achievement in the early grades of junior high school (Fig. 2). However, the magnitude of these causal effects was much smaller than those causal effects of mathematics achievement on mathematics anxiety (4–16 times smaller) (note that cross-lagged coefficients were squared to make proportional comparisons). Therefore, we concluded that, overall, prior mathematics anxiety hardly related to later mathematics achievement. In sum, mathematics achievement demonstrated small, though significant, causal priority over mathematics anxiety, and this causal priority remained consistent in magnitude across junior and senior high school grade levels.

Gender differences in casual ordering

We performed a multi-group analysis within the framework of structural equation modelling to determine whether gender differences were present in the causal ordering between mathematics anxiety and mathematics achievement. Note that multi-group analysis in which we estimated causal effects for boys and girls simultaneously is a much more efficient statistical procedure to compare the male and female structural models. For the purpose of multi-group analysis, we constrained all stability effects and all cross-lagged effects to be equal between boys and girls. The difference between the constrained model and unconstrained (baseline) model was statistically significant ($\chi^2 = 49.67$, df = 20, $p < 0.001$). This indicates that there were statistically significant differences between boys and girls in the causal ordering between mathematics anxiety and mathematics achievement.

Gender differences in the causal ordering between mathematics anxiety and mathematics achievement can be appreciated from different perspectives. Specifically, as shown in Table 2, the stability effects for mathematics anxiety were significantly different between boys and girls (the stability effects of mathematics anxiety for girls were significantly stronger than those for boys). This indicates that mathematics anxiety passed on from year to year in a more serious (or more evident) manner among girls than among boys.

The paths from prior mathematics achievement to later mathematics anxiety were significantly different between boys and girls. The cross-lagged effects from prior mathematics achievement to later mathematics anxiety were significantly stronger for boys than girls. Therefore, the male model resembled the overall model more closely than the female model. Prior mathematics achievement significantly related to later mathematics anxiety for boys (across the entire junior and senior high school grade levels). In other words, lower scores in mathematics achievement were associated with somewhat higher scores in mathematics anxiety for boys.

Table 2
Stability effects and cross-lagged effects of mathematics anxiety and mathematics achievement by gender

	Grade 7–8	Grade 8–9	Grade 9–10	Grade 10–11	Grade 11–12
Stability effects of mathematics anxiety					
Male	0.32	0.43	0.50	0.51	0.49
Female	0.45	0.67	0.63	0.67	0.62
Stability effects of mathematics achievement					
Male	0.97	0.92	0.94	0.96	0.97
Female	0.99	0.91	0.96	0.97	0.97
Cross-lagged effects from mathematics anxiety to mathematics achievement					
Male	0.04	0.00	0.00	0.00	0.00
Female	0.06	0.06	0.00	0.00	0.00
Cross-lagged effects from mathematics achievement to mathematics anxiety					
Male	0.23	0.19	0.19	0.18	0.17
Female	0.16	0.00	0.09	0.14	0.00

Note: All non-zero effects are statistically significant at the alpha level of 0.001.

For girls, prior mathematics achievement significantly related to later mathematics anxiety both in fewer occasions and in smaller magnitude. In terms of occasions, low (prior) mathematics achievement slightly related to high (later) mathematics anxiety during critical transition points only (from elementary school to junior high school and from junior high school to senior high school). In terms of magnitude, female cross-lagged effects were between 0.09 and 0.16, whereas male cross-lagged effects were between 0.17 and 0.23.

The stability effects for mathematics achievement were not significantly different between boys and girls, and these effects were much stronger than the stability effects for mathematics anxiety for both boys and girls. Therefore, prior mathematics achievement strongly determined later mathematics achievement for both boys and girls. In addition, the cross-lagged effects from mathematics anxiety to mathematics achievement were not significantly different between boys and girls. High (prior) mathematics anxiety related to low (later) mathematics achievement only in the beginning grades of junior high school with considerably weak causal effects in comparison with the cross-lagged effects from mathematics achievement to mathematics anxiety. Therefore, for both boys and girls, prior mathematics anxiety hardly related to later mathematics achievement.

Discussion

Principal findings of the study

The purpose of our study was to determine the causal ordering (or the causal priority or the causal direction) between mathematics anxiety and mathematics achievement. Our key finding is that prior low mathematics achievement appeared to cause later high mathematics anxiety across the entire junior and senior high school grade levels, particularly for boys. In contrast, prior high mathematics anxiety hardly caused later low mathematics achievement across the entire junior and senior high school grade levels. The second key finding is that the level of mathematics achievement was more reliably stable than the level of mathematics anxiety.

We also examined gender differences in the causal ordering between mathematics anxiety and mathematics achievement. As our third key finding, there were statistically significant differences between boys and girls in the causal ordering between mathematics anxiety and mathematics achievement. Specifically, prior low mathematics achievement seemed to cause later high mathematics anxiety across the entire junior and senior high school grade levels for boys. In contrast, prior low mathematics achievement seemed to cause later high mathematics anxiety for girls during critical transition points only (from elementary school to junior high school and from junior high school to senior high school), and the female causal ordering was weaker than the male one. Finally, mathematics anxiety was more reliably stable among girls than among boys.

Significant contribution of the study

Most studies of mathematics anxiety conducted before 1990 are consistent in finding that girls have higher levels of mathematics anxiety than boys (see Hembree, 1990; Hyde, Fennema, Ryan, Frost, & Hopp, 1990, for results of meta-analyses). Does this trend continue in the 1990s?

Using the LSAY data collected from 1987 to 1992, the current analysis did not find any gender differences in mathematics anxiety across the entire junior and senior high school (see Table 1). Results of our analysis invite further studies to investigate whether a new trend developed in the last decade of the 20th century in terms of mathematics anxiety among secondary students.

The major contribution of the current analysis, however, is that it provided informative evidence to the debate on the causal relationship between mathematics anxiety and mathematics achievement (see Reyes, 1984; Newstead, 1998). As reviewed earlier, there are three competing models regarding this causal relationship, including the interferences model (high mathematics anxiety causes low mathematics achievement), the deficits model (low mathematics achievement causes high mathematics anxiety), and the reciprocal model (mathematics anxiety and mathematics achievement are reciprocally related). Although there was some minor evidence for the reciprocal model, it was certainly not as compelling as for the deficits model. Our support for the deficits model in which mathematics anxiety is believed to be the unpleasant remembrance of poor mathematics performance in the past (Tobias, 1985) highlights the imbalance of the causal relationship between mathematics anxiety and mathematics achievement. We found that, particularly for boys, the deficits model is in full function across the entire junior and senior high school, whereas the reciprocal model is in quite limited function.

The model is slightly different for girls where prior low mathematics achievement showed (minor) causal links with later high mathematics anxiety during critical transition points only. These points refer to the transition from elementary school to junior high school and from junior high school to senior high school. These findings imply that boys and girls develop mathematics anxiety from different sources. We suggest that male mathematics anxiety comes from consistent poor mathematics performance in the past, whereas female mathematics anxiety becomes sensitive to poor mathematics performance only when girls are in critical transition periods. Once girls get used to the new phase of learning, their mathematics anxiety becomes less dependent on mathematics performance. But, how can one explain this fact that female mathematics anxiety is not much a result of their mathematics performance? We found that mathematics anxiety was more reliably stable from year to year among girls than among boys. Therefore, we consider it reasonable to suggest that female mathematics anxiety is largely a ‘‘lingering effect’’ (prolonged previous mathematics anxiety).

Such observations and explanations about the possible sources of male and female mathematics anxiety are novel in the research literature, and replications of the current study are certainly in need to confirm this phenomenon. But, if this is true, then implications for educational practices are self-evident. One of the most effective ways to reduce mathematics anxiety of boys is to improve their mathematics achievement (because, for boys, decline in mathematics achievement intensifies mathematics anxiety), whereas for girls, one of the most effective ways to reduce mathematics anxiety is to prevent it from taking shape (because, for girls, mathematics anxiety has the tendency to last in a stable manner over time once it takes shape).

Our data analysis has revealed considerable stability in the levels of mathematics anxiety and mathematics achievement. We found that mathematics anxiety became stable from Grade 8 whereas mathematics achievement became stable from Grade 7. Therefore, the early grades of junior high school are critical to set the stage for an effective prevention of mathematics anxiety and a healthy growth in mathematics achievement. Programs that help students cope with the frustrations in the learning of mathematics and help students improve mathematics achievement are essential. Overall, educators need to pay more attention to the cognitive and affective well-being of students during this (and other) critical transition period, particularly for girls.

Limitations and suggestions

The major limitation of the current study comes from the fact that mathematics anxiety was measured with two indicators (items) only. This situation probably explains the relatively low test–retest reliability coefficients observed for mathematics anxiety in comparison to those for mathematics achievement with multiple items in each subscale. Although the LSAY has a focus on mathematics education, it is not possible to measure every construct in sufficient detail. We suggest that a longitudinal assessment with a focus on cognitive and affective measures of students is needed to ensure high reliability for measures of mathematics anxiety. If all possible, we recommend that researchers design longitudinal experimental studies that systematically control mathematics anxiety and mathematics achievement. Before such studies come to support findings in the current study, we consider our conclusions tentative, pending further replications.

We noticed that the cross-lagged coefficients were small, though significant, in the current study (see Table 2). The statistical significance of these small effects might partially be a result of the high analytical power afforded by the large sample size. This situation again calls for further replications of our current findings. One way to proceed which demands less on collecting new data is to employ existing data to examine the "relatives" of mathematics anxiety such as self-concept in mathematics, attitude toward mathematics, and interest in mathematics. If these relatives of mathematics anxiety could replicate our current findings in terms of their causal relationships with mathematics achievement, they would strengthen our conclusions on the causal ordering between mathematics anxiety and mathematics achievement.

We recognize that mathematics achievement tests are not pure measures of mathematics achievement. Because students perform mathematical tasks in a testing session, it is possible that those with high mathematics anxiety do poorly on a mathematics achievement test because their anxiety interferes with their test taking. Hembree (1990) showed that students who complete cognitive-behavioural interventions for mathematics anxiety are able to score near the average on mathematics achievement tests. Given that these interventions do not teach mathematics to students, improvement in mathematics achievement comes mainly from relieving students of the harmful effects of mathematics anxiety during the testing session. This understanding is important not only to our knowledge on mathematics achievement tests but also to our further investigations on the causal relationship between mathematics anxiety and mathematics achievement. Interventions that reduce mathematics anxiety may become part of the longitudinal experimental design that we advocated earlier as a way to manipulate mathematics anxiety. Interventions do not have to be psychological. Many educational activities are good interventions for reduction in mathematics anxiety, such as adopting "user-friendly" mathematics curriculum, emphasizing problem solving in the learning of mathematics, using hands-on activities in mathematics instruction, and practicing cooperative learning in small groups.

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