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Riikka Sorvo

Math Anxiety and Its Relation to Arithmetic Achievement in Primary School and across the Transition to Lower Secondary School

UNIVERSITY OF JYVÄSKYLÄ
FACULTY OF EDUCATION AND PSYCHOLOGY

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ABSTRACT

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Learning and studying are associated with many kinds of emotions, but one of the most frequently reported is anxiety. Learning mathematics, in all related difficulties, has been found to seriously affect later life, and research into the development of math anxiety and its negative relation to achievement in one's early years of education is thus needed. The overall aim of the present dissertation was to increase our understanding of the development of math anxiety and its relationship with arithmetic achievement in the primary school years and during the transition from primary school to lower secondary school. This aim was achieved through the completion of three substudies, which relied upon data collected in two longitudinal studies on Finnish primary school children in Grades 2 to 5 (Substudies I and II, N = 1,327) and Grade 6 (Substudy III, N = 858). The results showed a negative relationship between math anxiety and achievement across all age groups. Various operationalizations of math anxiety were found to be differently related to arithmetic achievement, suggesting that previous contradictory results might be dependent on the operationalization. There was a decreasing trend in the level of math anxiety in primary school, but an increasing trend during the transition from primary to secondary school. From the point of view of causality, the results of the substudies revealed versatile findings: among primary school students, after controlling for previous levels of math achievement and math anxiety, lower achievement predicted higher math anxiety later on, whereas during the transition to secondary school, higher math anxiety predicted lower achievement later on. Aside from the longitudinal association, the results also showed a situational association between anxiety and performance: students who were given individually challenging and non-challenging arithmetic tasks underperformed compared to others in their skill level when their anxiety was activated. The findings of this dissertation expand upon the established understanding of the existence of math anxiety and its development from the early school years onwards. In doing so, they highlight the importance of the careful operationalization of math anxiety. Moreover, the results support the reciprocal model in which math anxiety and arithmetic achievement are seen to affect each other in a vicious circle. In conclusion, the results of this dissertation highlight the importance of paying attention to math anxiety from the very beginning of primary school.

Keywords: math anxiety, arithmetic achievement, basic education,

TIIVISTELMÄ

Sorvo, Riikka
Matematiikka-ahdistus ja sen yhteys matematiikassa suoriutumiseen alakoulussa ja siirryttäessä alakoulusta yläkouluun
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Oppimiseen ja opiskeluun liittyy monenlaisia tunteita, joista yksi yleisimmistä on ahdistus. Matematiikan oppimisen ja varsinkin siihen liittyvien haasteiden tiedetään vaikuttavan myöhempään hyvinvointiin ja osallisuuteen yhteiskunnassa. Matematiikan oppimisvaikeuksien on esimerkiksi havaittu olevan yhteydessä aikuisiän mielenterveysongelmiin ja korkeampaan työttömyyteen. Siksi matematiikkaan liittyvästä ahdistuksesta ja sen yhteydestä matematiikassa suoriutumiseen tarvitaankin tutkimusperustaista tietoa heti ensimmäisistä kouluvuosista lähtien. Tämän väitöskirjatutkimuksen tarkoitus oli lisätä ymmärrystä matematiikka-ahdistuksen kehityksestä ja sen yhteydestä matematiikassa suoriutumiseen alakouluikäisillä ja siirryttäessä alakoulusta yläkouluun. Tutkimus koostui kolmesta osatutkimuksesta, joissa käytetty aineisto kerättiin kahdessa eri pitkittäistutkimushankkeessa. Osatutkimuksissa 1 ja 2 osallistujina oli 1 327 lasta, jotka olivat tutkimuksen alkaessa 2. – 5. -luokkalaisia ja osatutkimuksessa 3 osallistujina oli 858 lasta, tutkimuksen alkaessa 6.-luokkalaisia. Tulokset osoittivat, että matematiikka-ahdistus on yhteydessä heikompaan suoriutumiseen jo alakoulun alkuvuosista lähtien. Matematiikka-ahdistuksen taso laski alakoulun aikana, mutta nousi taas siirryttäessä alakoulusta yläkouluun. Tulokset matematiikka-ahdistuksen ja suoriutumisen välisestä syy-seuraussuhteesta olivat vaihtelevia. Alakouluikäisten kohdalla aiempi heikompi suoriutuminen lisäsi myöhempää matematiikka-ahdistusta, kun taas siirryttäessä alakoulusta yläkouluun korkeampi matematiikka-ahdistus ennusti heikompaa suoriutumista. Lisäksi tuloksissa tuli esille tilannesidonnainen yhteys matematiikka-ahdistuksen ja suoriutumisen välillä – kun oppilaille annettiin heidän osaamistasoonsa nähden helppoja ja haastavia tehtäviä, ahdistuksen aktivoituminen oli yhteydessä alisuoriutumiseen. Tämän väitöstutkimuksen tulokset tuovat lisää ymmärrystä matematiikka-ahdistuksesta ja sen kehittymisestä ensimmäisistä kouluvuosista lähtien. Tulokset tukevat käsitystä, jonka mukaan matematiikka-ahdistus ja matematiikassa suoriutuminen vaikuttavat toinen toisiinsa muodostaen negatiivisen kehän. Kaiken kaikkiaan tulokset korostavat sitä, että koulun aikuisten on hyvä olla tietoisia matematiikka-ahdistuksesta ja sen vaikutuksista jo alakoulun alusta lähtien.

Avainsanat: matematiikka-ahdistus, aritmetiikka, peruskoulu

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LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following publications:

Study I 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

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Study III Sorvo, R., Kiuru, N., Koponen, T., Aro, T., Viholainen, H., Ahonen, T., & Aro, M. (2022). Longitudinal and situational associations between math anxiety and performance among early adolescents. *Annals of the New York Academy of Sciences*, *1514*(1), 174-186. https://doi.org/10.1111/nyas.14788

As the author of this thesis, I am the first author of all three original publications and have had the main responsibility of writing process. My contribution to the articles has been conceptualization the research questions, implementation of data analyses, writing the original drafts of the articles, considering the comments of the co-authors, and editing the articles in the review processes. Additionally in Studies I and II, I participated in the research project (Self-efficacy and Learning Disability interventions) from the beginning: planning the study design, coordinating and participating the data collection.

FIGURES

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CONTENTS

1 INTRODUCTION

Imagine the following situation: you are at the checkout line of a store, having only a limited amount of cash with you. Suddenly, you realize that the total amount of your purchases exceeds your cash reserve. Since you have collected products with quantity discounts, leaving out one product would change the price of the remaining ones. The queue behind you grows, and you feel people's eyes piercing your neck as you try to calculate in your head what items you should leave out. Suddenly, your head feels completely empty. You probably notice your heart beating faster and your palms starting to sweat. Your mind becomes filled with worrisome thoughts: "What do these people think of me? How can I get out of this situation?" Does this sound like an imaginable scenario? What if, during your school years, these kinds of thoughts and feelings had taken over your mind and body every time you had to answer a teacher's question in math class or take a math exam? This kind of experience is quite familiar to many of us. In fact, while writing this dissertation, I unintentionally ended up collecting informal empirical data on the prevalence of this phenomenon. The most common reactions to my topic of math anxiety have been, "Hey, you could study me!" or "I would have so much to say about that topic!"

People working with children and teenagers would likely have noticed the connection between emotions and learning: big emotions, sometimes negative and sometimes positive, can at worst become an obstacle to learning. In my work as a special education teacher in a lower secondary school, I have noticed that the emotions related to learning and studying are already quite strong at this stage of schooling. This should be no surprise, since students at this point have already had several years of formal schooling behind them. Mathematics is one of those subjects that can be especially emotional for some students. The anxiety related to mathematics can be so dominant that it prevents teachers from seeing the real competence of students. In such cases, this emotion can cause some students to refuse to study mathematics even before they know what they are expected to do.

1.1 Math anxiety

Although anxiety related to mathematics is a familiar phenomenon for many, there is still relatively little research on the topic, especially among primary school children. Traditionally, such research has focused on adolescents and adults, but recently, there has been a growing body of studies on math anxiety among primary school children (Carey et al., 2017; Gunderson et al., 2018; Hill et al., 2016; Szczygieł & Pieronkiewicz, 2022). Among adolescents and adults, math anxiety has been found to be negatively related to achievement, including basic number skills (e.g., Ashcraft, 2002), as well as more complex arithmetic operations (Ashcraft & Faust, 1994). However, in their first years of school, children are supposed to learn the basic math skills that are essential for being able to function in our numerate society (Butterworth, 2005). That is why it is particularly important to learn more about math anxiety of primary school students, including how early the anxiety appears, how it develops during primary school years, and how it is related to the development of basic mathematical skills.

1.1.1 Math anxiety – An achievement emotion

Research on math anxiety is located at a cross-section of two rather separate areas of study. First, math anxiety is studied specifically from the perspective of math, for example, from the point of view of learning math or mathematical learning difficulties. Second, math anxiety can also be considered from the perspective of achievement emotions. The former view provides us with important information about math anxiety itself and its cognitive consequences. For instance, it is possible that mathematics as a subject has specific characteristics that make it particularly likely to cause anxiety. In fact, learning mathematics, and more specifically difficulties in it, has been found to have serious consequences in later life (Aro et al., 2019). However, to understand math anxiety as a distinctive phenomenon, it is necessary to take a slightly broader perspective, as math anxiety is only one of the many emotions that arise in achievement situations. All learning and studying behaviors are associated with many kinds of emotions, and mathematics is by no means the only cause of anxiety in school. For example, test anxiety has been studied for decades, and research on reading anxiety has recently increased. The significant effect of emotions on learning has also begun to receive significant attention. Positive emotions can foster learning, for example, by enhancing cognitive processes and studying capabilities, whereas negative emotions usually distract attention and lead to reduced efficiency (Tan et al., 2021). Unfortunately, one of the most frequently reported emotions in academic contexts is anxiety (Pekrun et al., 2002).

Emotions are complex, multi-component processes. From a neurobiological perspective (Damasio, 2004), emotions are bioregulatory reactions, which means that they are chemical and neural responses that our brain induces when we, whether consciously or unconsciously, detect an emotionally triggering stimulus.

The aim of these reactions is to promote physiological states that secure survival and well-being. Unfortunately, the consequences are not always positive for us and our well-being; the same reactions that have helped our ancestors to survive tens of thousands of years ago do not necessarily enhance our survival in modern life situations – solving mathematical problems in a classroom, for instance.

Pekrun (2006) has defined achievement emotions as those "tied directly to achievement activities or achievement outcomes." The antecedents of achievement emotions have been theorized by the control-value theory (Pekrun, 2006, p. 317). According to the control-value theory, achievement emotions are divided into two groups: activity emotions, which focus on the actual achievement activity, and outcome emotions, which arise in relation to the outcome of the achievement situation. Emotions that focus on the outcome are divided into prospective and retrospective outcome emotions, depending on whether the outcome is considered beforehand (e.g., emotions like hope or anxiety) or afterwards (e.g., pride or shame). Besides the attentional focus on either the outcome of the achievement situation or the activity itself, all the achievement emotions are assumed to result from self-related and situational appraisals, such as expectations of failing or succeeding in the achievement situation, perceptions of one's own control over the outcome, or the value placed on the outcome.

According to the control-value theory of achievement emotions (Pekrun, 2006), anxiety can be defined as a prospective outcome emotion, since the attentional focus is on the outcome or the expected failure. However, anxiety is not evoked by the expected failure alone. The occurrence of anxiety is assumed to depend on subjective values, such as how important it is to succeed or how harmful the failure would be. If students expect failure but do not care about it, they are unlikely to feel anxious. Moreover, anxiety is assumed to be related to *uncertainty* about one's control over the outcome (Folkman & Lazarus, 1985; Miceli & Castelfranchi, 2005; Pekrun, 2006). If the student feels that the failure is preventable, instead of anxiety, they are more likely to feel relief, and if they feel that there is nothing that will prevent them from failing, they will probably feel hopelessness instead of anxiety (Pekrun, 2006). Overall, anxiety is an emotion resulting from a situation in which a person anticipates failure, sees it as subjectively harmful, and does not expect to have much control over the outcome.

1.1.2 Components and specificity of math anxiety

Math anxiety has been defined in terms of "tension and anxiety that interfere with the manipulation of numbers and the solving of mathematical problems in a wide variety of ordinary life and academic situations" (Richardson & Suinn, 1972, p. 551). Richardson and Suinn's commonly used definition of math anxiety originates from a 50-year-old study in which the notion was investigated with a rating scale. In fact, the existence of math anxiety had already been recognized in the 1950s, when Dreger and Aiken (1957) introduced the concept of "number anxiety" in their study.

Math anxiety, like other emotions, consists of different components (Damasio, 2004; Pekrun, 2006; Scherer, 1984). The idea of cognitive and affective components, previously identified in test anxiety research (Liebert & Morris, 1967), was first applied in the context of math anxiety by Wigfield and Meece (1988). By the cognitive component, these researchers were referring to worries about one's performance and the consequences of failure. The affective component, in contrast, was associated with nervousness, tension, and their respective autonomic reactions in actual situations. At least some of the autonomic reactions could also be classified as belonging to the physiological component of anxiety, which includes peripheral physiological activation in anxiety-triggering situations (Pekrun, 2006). Besides the cognitive, affective, and physiological components, math anxiety can also be considered to include motivational components (e.g., avoiding math-related situations) and exhibiting expressive components (e.g., anxious facial expressions; Pekrun, 2006).

Math anxiety has been found to correlate with different forms of anxiety, including general anxiety (correlation .35 in Hembree, 1990) and test anxiety (correlation .52 in Hembree, 1990). However, in 1957, Dreger and Aiken had already found that "number anxiety" could be separable from general anxiety, and their findings about math anxiety as a unique construct have been replicated since. The results of Carey et al.'s (2017) study with primary and secondary school students suggest that math anxiety and general anxiety are separate constructs, despite their overlap. Based on their meta-analysis, Hembree (1990) noted that math anxiety and test anxiety had a shared variance of only 37%, indicating that math anxiety is unlikely to be entirely restricted to testing. Aside from testing, math anxiety has also been found to be triggered by different types of mathematical activities, including numeric processing (Richardson & Suinn, 1972; Suinn et al., 1988; Wu et al., 2012), executing math tasks in front of classmates, and making errors in math (Jameson, 2013).

In control-value theory (Pekrun, 2006), achievement emotions, including math anxiety, are assumed to be domain-specific, as are the other control- and value-related constructs. This assumption has been confirmed by a factor analysis indicating that academic emotional experiences are organized in a domain-specific manner (Goetz et al., 2006). Furthermore, among primary school children, math anxiety has been found to be specifically related to performance in mathematics, but not in reading (Hill et al., 2016).

1.1.3 Measuring and operationalizing math anxiety

The complexity of math anxiety is also evident in its operationalization and measures. The most frequently used math anxiety measure, the Mathematics Anxiety Rating Scale (MARS), was developed by Richardson and Suinn in 1972 to measure the math anxiety of university students. Since the original measure consisted of 98 items, there was clearly a need for a shorter one, and the revised version of the MARS (MARS-R; Plake & Parker, 1982) with 24 items was published in 1982. MARS and its shortened versions (e.g., MARS-R and the Abbreviated Math Anxiety Scale; Hopko, 2003) are still the most widely used measures of math anxiety among adolescents and adults. In addition to the specific math anxiety measures, there are also math anxiety items in the Achievement Emotions Questionnaire (AEQ; Pekrun et al., 2011) that have also been used in some studies on math anxiety (e.g., Bieg et al., 2015; Goetz et al., 2013).

Some years later, the first measures assessing children's math anxiety were developed based on the MARS. The evolution of math anxiety measures for children is described in Figure 1. The elementary form of the MARS (MARS-E), with 26 items, was published by Suinn et al. in 1988, and the Mathematics Anxiety Scale for Children (MASC) was proposed by Chiu and Henry in 1990, both of which targeted children in the fourth grade and above. Gierl and Bisanz (1995) aimed to widen the age scale a bit by adapting the questions from the MARS-E so that they were suitable for third graders in their Mathematics Anxiety Survey (MAXS). The first self-reporting scale considered appropriate for children as young as even six years old was the Math Anxiety Questionnaire (MAQ) constructed by Thomas and Dowker (2000), being one of the few math anxiety measures that was not developed based on the MARS or its descendants. As shown in Figure 1, later on in the 2010s, several measures for assessing young children's math anxiety were developed, with most having their roots in the MARS (Richardson & Suinn, 1972).

Different math anxiety measures have emphasized different aspects and dimensions of math anxiety. As shown in Figure 1, most of the math anxiety measures used for children are based on either the MARS-R or MARS-E. Both measures have been found to reveal two separate aspects of math anxiety: one related to math testing and the other related to more general math performance or math learning. Consequently, these two aspects have been differentiated in the measures based on the MARS-R and MARS-E. In contrast, Wigfield and Meece (1988) developed their own measure by applying the idea of the cognitive and affective components of math anxiety. Harari et al. (2013) combined these two views by deriving questions from both the MARS-E (Suinn et al. 1988) and the Math Anxiety Questionnaire (Wigfield & Meece, 1988) in their Mathematics Anxiety Scale for Young Children (MASYC; Harari et al., 2013), resulting in three dimensions: negative reactions, worry, and numerical confidence.

Besides emphasizing the different dimensions of math anxiety, math anxiety measures also differ with respect to how math anxiety is operationalized and articulated in the questionnaires for the participants. The original MARS (Richardson & Suinn, 1972) consisted of brief descriptions of math-related situations, in which the participants were asked to rate their feelings using a five-point scale, ranging from "not at all anxious" to "very much anxious." Since then, measures developed based on the MARS have followed this operationalization: participants have simply been asked how anxious they felt in different math-related situations, usually without having to define whether they expected to succeed or fail. On the contrary, in the MAQ (Thomas & Dowker, 2000), participants were asked how anxious they would feel if they performed poorly or were unable to accomplish a task, which emphasized the expected negative outcome. There are also measures combining these two operationalizations. In the MASYC (Harari et al., 2013) and the Children's Anxiety in Math Scale (Jameson, 2013), items without any specified outcome expectancy and those with expected negative outcomes have both been used.

In the first two substudies of the present dissertation, these two ways of operationalizing math anxiety are examined more closely, the first one (without any specified expected outcome) being conceptualized as anxiety in math-related situations, and the latter (with an expected negative outcome) being construed as anxiety about failure. These two aspects of operationalization should not be confused with the components of math anxiety. Even if items measuring the cognitive component of math anxiety sometimes have a negative valence, it would be oversimplifying to assume that emphasizing an expected failure would directly measure only worries about performance, thereby leaving out the other components of anxiety, such as affective reactions. It cannot be assumed that measuring anxiety in math-related situations would only tap into the affective component of math anxiety. The most essential difference between these two operationalizations is whether the outcome (i.e., failure) has already been defined in the question.

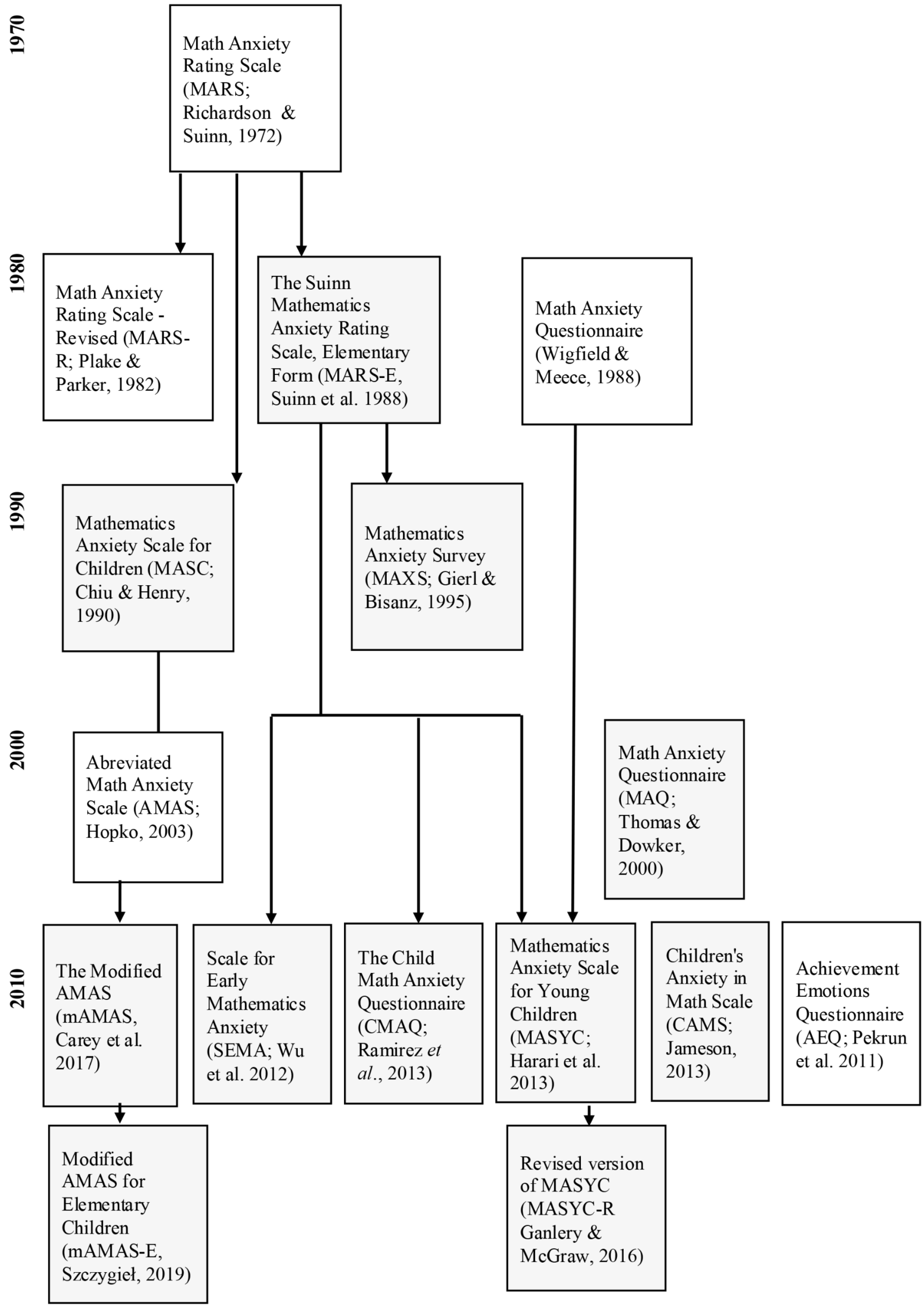

FIGURE 1. Evolution of math anxiety measures for children. The measures for the children are marked in gray.

1.1.4 Two views: Personal trait vs. emotional state

In the existing research, math anxiety has traditionally been viewed as an individual trait; in some cases, it has even been described as a math learning disability (Aschcraft et al., 2007). At the same time, it is an emotion that nearly every one of us can recognize, at least in some math-related situations. When examining math anxiety, the focus is either on the *individual* having the emotion or the *situation* triggering the emotion. This separation had initially been introduced in research on general anxiety (Spielberger, 1966): anxiety, as any other emotion, can be considered as (1) a trait of an individual (trait anxiety; Spielberger, 1966; for achievement emotions, see Pekrun, 2006), which implies that it is a habitual, recurring emotion more typical to some individuals than others, or as (2) a situation- and time-specific momentary occurrence of an emotional state (state anxiety; Spielberger, 1966; Pekrun, 2006).

State and trait anxiety should not be thought of as separate constructs or dimensions of math anxiety, but rather as a continuum, along which trait anxiety is a series of momentary state anxieties. According to Spielberger (1966), if someone is an anxious person (i.e., having anxiety as an individual trait), he or she should chronically have a higher level of state anxiety than most other people do. Pekrun (2006) points out that trait emotions differ from state emotions because of their temporal generality. In contrast, math anxiety as a personal trait is considered to be something in the individual, whereas state math anxiety can be seen as an emotional state in which the individual *is* at a specific moment. Buckley and others (Buckley et al. 2016; Buckley & Sullivan, 2021) have suggested that state math anxiety can be conceptualized as anxiety symptoms, whereas trait math anxiety is more attitudinal in nature and more linked to causes of anxiety, like persistent negative beliefs about oneself and the perceived nature of mathematics (e.g. "I'm not a math person").

Even though the two above-mentioned perspectives have been differentiated in research on math anxiety (Buckley et al. 2016), the empirical focus has traditionally been on math anxiety as a personal trait. Even if most math anxiety measures (e.g., MARS and measures based on MARS; see Figure 1) differentiate between various math-related situations, they are usually based on asking participants how they would feel in those hypothetical situations. Therefore, these measures seek a typical reaction for the individual in different situations; the focus is thus on trait math anxiety. As Buckley et al. (2016) remarked, measuring state math anxiety would require ratings of math anxiety when completing mathematical tasks. The results of a study by Levy and Rubinsten (2021) suggest that math anxiety is a unique phenomenon with specific behavioral and physiological manifestations that are related especially to complex math stimuli. This approach has been implemented in only a few math anxiety studies among adolescents and adults.

1.1.5 Prevalence of math anxiety and the effect of gender

It is relatively common to feel anxious about math-related situations. In PISA 2012 study of 15- to 16-year-olds (OECD, 2013), about 60% of the students reported being worried about poor math grades, and nearly as many expressed concern about difficulties encountered in mathematics classes. Other common emotions included feeling very tense about having to do math homework and getting very nervous or feeling helpless when doing mathematical problems. All of these were reported by more than 30% of the students.

When considering the findings regarding the prevalence of math anxiety, it is worth noting that math anxiety is an emotion, not a disorder. In existing research, anxiety is usually investigated as a continuous variable, and cut-offs dividing participants into those experiencing high and low levels of anxiety are used solely for statistical purposes, and not for diagnosing "highly anxious" individuals. As Aschraft and Moore (2009) have pointed out, conclusions about the prevalence of math anxiety in the studied populations should not be drawn based on these cut-offs alone.

Females are usually found to have less positive attitudes toward mathematics and to report more anxiety about mathematics than males. In PISA 2012 study of 15- to 16-year-old adolescents (OECD, 2013), while girls and boys performed equally well in math, girls reported less perseverance and motivation to learn math, weaker belief in their own skills, and higher levels of math anxiety. Other studies among adolescents and adults have also revealed this gender difference in math anxiety (Else-Quest et al., 2010; Hart & Ganley, 2019; Hembree, 1990; Kyttälä & Björn, 2010). However, it remains unclear whether this difference exists among children. Most studies among primary school children suggest no gender differences in math anxiety (Dowker et al., 2012; Erturan & Jansen, 2015; Harari, Vukovic, & Bailey, 2013; Wu, Willcutt, Escovar, & Menon, 2014), but there are also studies that have found higher levels of math anxiety among girls than boys (Hill et al., 2016).

1.1.6 Development of math anxiety

As indicated above, research on math anxiety has usually involved mostly adults or adolescents, with less of a focus on young children. Nevertheless, it seems that children have reported feeling math anxiety as early as the beginning of formal schooling (Ma, 1999; Ramirez et al., 2013), but the developmental trends of math anxiety after that remain somewhat unclear. This is because the results of the few studies examining the development of math anxiety during primary school years are contradictory.

The first approach taken to investigate the development of math anxiety has involved a look into whether the average level of math anxiety increases, decreases, or stays stable during schooling (*mean-level change*). The findings regarding the precise levels of math anxiety in different grades in primary school are contradictory. Krinzinger et al. (2009) found that math anxiety increased from the first to the third grade, whereas Gunderson et al. (2018) found that the level of math anxiety was lower among second graders than among first graders. It should be noted that there are some methodological differences in these studies regarding the levels of math anxiety in different grades. For instance, some studies have examined differences between age groups cross-sectionally (Gierl & Bisanz, 1995; Gunderson et al., 2018), whereas others have investigated the development of math anxiety longitudinally (Krinzinger et al., 2009).

The development of math anxiety is unlikely to be linear throughout schooling. It seems that the transitions between educational stages are especially apt to affect math anxiety and other math-related attitudes and emotions. In an Australian study (Deieso & Fraser, 2019), compared to primary school students, secondary school students were found to report less involvement, more negative attitudes toward mathematics, less enjoyment of mathematics, and more math anxiety. During secondary school, math anxiety has often been found to increase, peaking in the ninth and tenth grades (Hembree, 1990). However, in a recent study by Wang et al. (2021), students reported modest levels of math anxiety in the seventh grade that remained relatively stable over secondary school. After all, there are various school systems and curricula in these studies: some may place more pressure on students than others, and critical transitions may occur at different ages in different school systems. Accordingly, this diversity might lead to different trajectories of math anxiety. Therefore, findings on the development of math anxiety cannot necessarily be generalized across all school systems.

The second approach to investigating the development of math anxiety attends to the stability of math anxiety in individuals. In other words, the question of whether the same students are anxious about mathematics year after year is central here. In this respect, some longitudinal studies have investigated the stability, or change, of an individual's relative position within a group (*rank-order stability*). Krinzinger et al. (2009) found that from the first to third grades, the rank order of math anxiety level was relatively stable (one-year stability coefficients ranged from 0.49 to 0.60) but still less stable than the rank order of math achievement level (one-year stability coefficients ranged from 0.79 to 0.91). Ma and Xu (2004) found that the rank order of math anxiety remained relatively stable from Grade 8 onward (one-year stability coefficients were slightly below 0.60), but not as stable as the rank order of achievement in mathematics (one-year stability coefficients were over 0.90).

These two approaches (mean-level change and rank-order stability) are rarely used in the same studies. However, they are complementary. This is because the findings about the stability or change in the mean level of math anxiety do not reveal anything about the relative position of the individuals within a group with respect to their anxiety level. Similarly, findings about the stability or change in the rank order of individuals do not give us any information about the mean level of the group. If we want to gain a more comprehensive picture of the development of math anxiety, we need both approaches.

1.2 Math anxiety in relation to achievement

1.2.1 Are math anxiety and achievement related?

It seems incontrovertible that, at least among adolescents and adults, high math anxiety is related to low mathematical achievement. This relationship has been found to exist for basic number skills (Ashcraft, 2002; Maloney et al., 2010; Maloney et al., 2011) as well as for more complex arithmetic operations (Ashcraft & Faust, 1994), and the results of various meta-analyses also support the existence of this relationship (Barroso et al., 2020; Hembree, 1990; Ma, 1999; Namkung et al. 2019; Zhang et al., 2019).

As for children, the existence of any relationship between math anxiety and achievement has remained unclear. Most recent studies have already found this relationship to hold among primary school students (Cargnelutti et al., 2017; Carey et al., 2017; Ramirez et al., 2013; Ramirez et al., 2016; Rawlings et al. 2023; Wu et al., 2012). However, there are also studies suggesting that math anxiety and achievement are not yet related during the first school year (Dowker et al., 2012; Haase et al., 2012; Hill et al., 2016; Krinzinger et al., 2007, 2009; Thomas & Dowker, 2000; Wood et al., 2012).

When the above-mentioned studies among primary school children are explored in detail, it seems that there is at least one distinct feature, aside from their contradictory results, that differentiates these studies: the operationalization of math anxiety. A detailed description of the measures employed is presented in Table 1. Those studies emphasizing expected negative outcomes and anxiety about failure in math (Dowker et al., 2012; Haase et al., 2012; Krinzinger et al., 2007; Krinzinger et al., 2009; Wood et al., 2012) have not found a correlative relation between math anxiety and achievement. On the contrary, most studies that focus on the process of doing mathematics, without specifying the outcome expectancy (i.e., anxiety about math-related situations), have revealed a relationship between math anxiety and achievement (Cargnelutti et al., 2017; Carey et al., 2017; Ramirez et al., 2013; Wu et al., 2012, 2014). Considering the above-mentioned studies together suggests that the operationalization of math anxiety affects the results about the relationship: anxiety about math in general seems to be more directly related to achievement in math than anxiety specifically about failure in math. A few studies (Harari et al., 2013; Jameson, 2013; Vukovic et al., 2013) have used items without any specified outcome expectancy (anxiety in math-related situations) as well as those with expected negative outcomes (anxiety about failure), with the result that math anxiety and achievement are related. However, since these studies did not analyze the two ways of operationalizing separately, no conclusions can be drawn as to whether the observed finding is independent of the item type.

TABLE 1. Previous research examining the relationship between math anxiety and achievement in children below Grade 6

Study/studies	Measure	Operationalization: Failure	Operationalization: Math-related situations	Relation to achievement?
Dowker et al., 2012; Haase et al., 2012; Krinzinger et al., 2007; Krinzinger et al., 2009; Wood et al., 2012	MAQ (Thomas & Dowker, 2000); math anxiety items consisted of the questions "How worried/unhappy would you be if you did badly in. . ." targeted at different types of math tasks (e.g., math in general, written sums, math tests, and understanding the teacher).	X		No
Wu et al., 2012; Wu et al., 2014	Scale for Early Mathematics Anxiety (SEMA) items of nervousness when answering math-related questions (e.g., "Is this right? 9 + 7 = 18") or being in math-related situations (e.g., "You are in math class, and your teacher is about to teach something new…").		X	Yes
Harari et al., 2013	Mathematics Anxiety Scale for Young Children (MASYC), with 12 items measuring numerical confidence (e.g., "Figuring out if I have enough money to buy cookies and a drink is fun"), worry (e.g., "I get nervous about making a mistake in math") and negative reactions (e.g., "Math gives me a stomachache").	X	X	Yes for numerical confidence and negative reactions; no for worry.
Jameson, 2013	Children's Anxiety in Math Scale, which consists of 16 items measuring general math anxiety, math performance anxiety, and math error anxiety.	X	X	Yes, the relationship between the two aspects is not examined separately.
Ramirez et al., 2013	Child Math Anxiety Questionnaire (CMAQ), which assesses how they feel when they have to solve a math task/problem or when they are in a math-related situation.		X	Only for children with high working memory.
Vukovic et al., 2013	MASYC (Harari et al., 2013).	X	X	Yes, the relationship between the two aspects is not examined separately.
Ramirez et al. 2016	CMAQ (Ramirez et al., 2013).		X	Only for children with high working memory.

Study/studies	Measure	Operationalization		Relation to achievement?
		Failure	Math-related situations	
Hill et al,. 2016	Abbreviated Math Anxiety Scale (AMAS; Hopko et al., 2003).		X	No.
Carey et al., 2017	Modified version of the AMAS (Hopko et al., 2003).		X	Yes.
Cargnelutti et al., 2017	SEMA (Wu & Menon, 2012).		X	Yes.
Szczygieł, 2020	Modified Abbreviated Math Anxiety Scale for Elementary Children (mAMAS-E; Szczygieł, 2019).		X	Yes, in the second grade; in the first grade, only for boys.

1.2.2 Causality between math anxiety and arithmetic achievement

Given that at least some kind of association between math anxiety and arithmetic achievement exists, the causality of the relationship remains unclear, even among adolescents and adults. Three competing models explicating the direction of the relationship have been suggested. First, according to the *deficit theory*, anxiety is a result of poor achievement. Second, the *debilitating anxiety model* maintains that anxiety debilitates performance, and third, according to the *reciprocal theory,* the two variables affect each other in a vicious circle (Carey et al., 2016 Carey et al., 2017).

According to the deficit theory difficulties in mathematics probably result in negative experiences in mathematics, which are then likely to cause math anxiety in the future (Carey et al., 2016). Children with low mathematical skills are more likely to fall behind their peers in school and receive negative feedback, which is a plausible risk for the development of negative attitudes toward mathematics and math anxiety (Ashcraft et al., 2007). There are studies giving empirical support to this theory: among secondary (Kyttälä & Björn, 2010) and high school students (Ma & Xu, 2004), low math performance has been found to predict high levels of math anxiety later on, but not the other way round.

According to the debilitating anxiety model, high math anxiety leads to lower performance. Ashcraft et al. (2009) have shown that math anxious individuals usually underperform in timed math tasks, referring to this phenomenon as an "affective drop" in performance caused by math anxiety. The debilitating anxiety model has also been explained by attentional-control theory (Eysenck et al., 2007). This latter theory is based on the two attentional systems differentiated by Corbetta and Shulman (2002): goal-driven processes and stimulus-driven processes. In goal-driven processes, our attention is directed by our current goals (e.g., solving a math task correctly). In the stimulus-driven process, our attention is directed by unexpected, salient stimuli; if something sufficiently unexpected happens, we are likely to notice it, even if our attention was previously completely drawn to solving the task. According to attentional-control theory (Derakshan & Eysenck, 2009), anxiety might disrupt the balance between these two systems by enhancing the stimulus-driven processes over goal-driven ones. When experiencing anxiety, we are more likely to pay attention to task-irrelevant stimuli, and it therefore becomes more difficult to shift attention in or between tasks.

Some studies have also supported the debilitating anxiety model by showing that anxiety has an immediate effect on achievement. In his meta-analysis, Hembree (1990) found that interventions aimed at reducing math anxiety could help students with high math anxiety improve their math performance to reach the level of students with low math anxiety. The results of some other studies (Ashcraft & Kirk, 2001; Ramirez et al., 2016) suggest that math anxiety strains working memory and disrupts performance in mathematical tasks. Specifically, Ashcraft and Kirk (2001) pointed out that since mathematics as a subject specifically requires the execution of sequential steps of processing and, similarly, keeping information in the substages in memory, math anxiety and its possible effects on working memory should be given close attention.

Some studies of children have identified a long-term effect that supports the debilitating anxiety model. Cargnelutti et al. (2017) found that the level of math anxiety experienced in the second grade (indirectly) predicted math achievement in the third grade, and Vukovic et al. (2013) found an association between second graders' math anxiety and math achievement in the third grade. However, math anxiety was not controlled longitudinally in the latter study, so strong conclusions about causal relations cannot be made based on the results. It also seems that in some cases, math anxiety leads to the avoidance of mathematics. Based on the findings of their previous studies (Ashcraft & Faust, 1994; Faust, 1996), Ashcraft (2002) has suggested that individuals with high math anxiety tend to minimize their involvement in mathematics by speeding through math-related problems, which in turn leads to an increased number of errors. The avoidance behavior of students with high math anxiety can also have long-term effects. Hembree (1990) found that such students were less likely to choose mathematics courses in high school and college.

Carey et al. (2016) have suggested that the above-mentioned conflicting results regarding the causal relationship between math anxiety and achievement could be attributed to a bidirectional relationship between the variables. Thus, they are inclined to support the reciprocal theory, which suggests that math anxiety and achievement affect each other in a vicious circle. In the control-value theory (Pekrun, 2006), emotions and achievement are linked reciprocally over time by either positive or negative feedback loops. This means that our previous achievements affect our expectations about the current outcome, as well as our own interpretations of the possibilities of acting, and therefore have control over the outcomes in achievement situations. Consequently, our expectations about the outcome, together with our own values, affect the emotions arising in achievement situations. These emotions, in turn, affect our cognitive resources, motivation, strategies, and self-regulation of learning, which all have an impact on how we achieve in academic situations, completing the circle between achievement and emotion. The reciprocal theory is supported by the longitudinal studies of Gunderson et al. (2018) and Szczygieł et al. (2024). The findings of these studies indicated that math anxiety negatively predicted later math achievement, and that math achievement negatively predicted later math anxiety. Additionally, in a meta-analysis on math anxiety interventions (Sammallahti et al. 2023), interventions targeting on reducing math anxiety and interventions targeting on supporting math skills were both found to reduce math anxiety and affect math performance.

The conflicting results about the direction of the association between math anxiety and achievement might stem from the methodological constraints and the perspectives taken on math anxiety. The mechanisms of the deficit theory (i.e., poor performance causing anxiety) are more likely to be long-term, whereas those of the debilitating anxiety model (i.e., anxiety straining working memory and affecting attention) are more likely to have an immediate effect. This might explain why longitudinal studies (Kyttälä & Björn, 2010; Ma & Xu, 2004) often support the deficit theory, whereas experimental studies (Ashcraft & Moore, 2009) tend to endorse the debilitating anxiety model. According to Carey et al. (2016), to get a wider picture of the association between math anxiety and achievement, both longitudinal and situational designs should be used. It is also possible that the relationship between math anxiety and achievement is affected by educational stage.

Using both longitudinal and situational designs to obtain a more comprehensive understanding of the association between math anxiety and achievement should also entail looking at math anxiety from different perspectives—that is, not only as the trait of an individual (trait anxiety) but also as a situational state (state anxiety). Generally, math anxiety has been measured by asking the participants to imagine themselves in a math-related situation and report how anxious they would feel. In such cases, the focus is on the participants and their typical reactions. To gain a more complete picture, we need more research with a focus on the situations causing anxiety. Therefore, anxiety should also be measured *in the specific moment*, when the participants are actually doing (or have just finished doing) math.

1.2.3 Measuring arithmetic achievement

When considering the relationship between math anxiety and mathematical achievement, it must also be noted that mathematical achievement is not a single entity but consists of different components. One of the most important components of mathematics is arithmetic. Mastering the basic arithmetical skills of addition, subtraction, division, and fractions is considered essential for being able to function in our numerate society (Butterworth, 2005).

In the development of basic arithmetical skills, the main goal is learning to retrieve discrete arithmetical facts from memory and evolving through hierarchical strategies and automatization (Geary, 1990). This seems to be a crucial feature differentiating students with mathematical learning difficulties from their peers: whereas the strategies of children without mathematical difficulties develop gradually throughout primary school, those of children with mathematical learning difficulties might peak as early as the second grade (Ostad, 1998).

Math anxiety research has considered different kinds of mathematical skills, including basic number skills (Ashcraft, 2002; Maloney et al., 2010; Maloney et al., 2011) and complex arithmetic operations (Ashcraft & Faust, 1994). In general, arithmetic skills have mainly been used as outcomes, even if some other skills have also been measured. For this reason, and because arithmetic skills play an important role in everyday life and are thus essential to the difficulties in learning mathematics, this dissertation will focus specifically on arithmetic.

To measure math anxiety as a situational state, we need to create situations that might incite anxiety in students with varying mathematical skills. Therefore, tasks with varying degrees of difficulty are needed. According to the control-value theory (Pekrun, 2006), anxiety is an emotion resulting from expected failure and uncertainty about one's control over a particular outcome. If all the participants are given the same time-limited arithmetical tasks, those with low arithmetical fluency will assumably expect more failures and feel more uncertainty than those with fluent and automatized arithmetical skills. In attentional-control theory (Eysenck et al., 2007), it is assumed that anxiety impairs performance only in challenging tasks, which is supported by findings showing that the difficulty is related to the level of math anxiety (Conlon et al., 2021; Szczygieł & Pieronkiewicz, 2022) as well as relationship between math anxiety and performance (Ashcraft & Faust, 1994; Faust, 1996; Trezise & Reeve, 2018). The broad range of students' mathematical skills in basic education (Aunola et al. 2004) should be considered in the study design when investigating the relationship between math anxiety and achievement. Instead of using the same tasks for all students, individually adapted tasks should be used to provide all the participants with more and less challenging circumstances.

1.3 Aims of the research

The aim of the present study was to improve our understanding of the relationship between math anxiety and arithmetic performance in primary school and during the transition from primary school to lower secondary school.

The first aim was to examine whether the different operationalizations of math anxiety used in previous research explain the contradictory results regarding the relationship between math anxiety and achievement in primary school. This was studied by examining whether anxiety about failure in math and anxiety about math-related situations are separable aspects of math anxiety (Study I), and whether they are differently related to basic arithmetic skills cross-sectionally (Study I) and longitudinally (Study II).

The second aim was to study the development of math anxiety in primary school and during the transition from primary school to lower secondary school. This development was studied by considering the two operationalizations of math anxiety, during one year in primary school, from two perspectives: the stability and change in the mean level of anxiety, and the stability and change in the rank order of the individuals in math anxiety (Study II). Additionally, the development of math anxiety was examined during the transition from primary school to lower secondary school by focusing on the stability and change in the mean level of anxiety about math-related situations (Study III).

The third aim was to examine the causality in the relationship between math anxiety and arithmetic performance. Specifically, the objective was to determine whether prior performance predicts later math anxiety, whether prior math anxiety predicts later performance, or whether both predict each other. The causality was studied from the perspective of the two operationalizations of math anxiety among primary school students (Study II) and from the perspective of anxiety about math-related situations during the transition from primary to lower secondary school (Study III). In addition, the situational association between math anxiety and arithmetic performance was examined by giving the participants both challenging and non-challenging math tasks adapted to their respective skill levels (Study III).

2 METHODS

2.1 Participants and procedure

2.1.1 Studies I and II

Studies I and II are based on data collected in a longitudinal study (Self-Efficacy and Learning Disability Interventions, SELDI, 2013–2015) that focused on the development of self-beliefs and academic skills among primary school children. The participants, 1,327 children (48% girls), were from 20 Finnish schools in urban and semi-urban areas in Central Finland. The participating schools and teachers were recruited via the basic education officials of the municipalities. Participation was voluntary for the schools, teachers, and the students. Written informed consent was obtained from the participants' guardians. At the beginning of the study, 178 (13.4%) participants were second graders (M = 8.35 years, SD = 0.32), 471 (35.5%) were third graders (M = 9.34 years; SD = 0.31), 383 (28.9%) were fourth graders (M = 10.4 years; SD = 0.35), and 295 (22.2%) were fifth graders (M = 11.39 years; SD = 0.36).

The data for Study I were collected in November 2013, and the data for Study II were gathered at two time points: November 2013 (T1 of Study II) and September 2014 (T2 of Study II). The data collections included tests of academic skills, as well as questionnaires concerning learning-related motivational and factors and self-efficacy beliefs. Trained research assistants carried out and supervised the assessments in group situations in classrooms during school hours. They read the items aloud for the students, who then responded on their own answer sheets. In the data collection for Studies I and II, the assessments were structured in such a way that the math anxiety questions were not presented immediately after the basic arithmetic tasks.

Complete data for both time points T1 and T2 of Study II for math anxiety and basic arithmetic skill measures were available for 73.9% of the sample. The highest percentage of missing data (13%) was for the items of arithmetic achievement and anxiety in math-related situations in T2. The missing values were not completely random according to Little's (1998) Test of Missing Completely at Random. However, since the missing data could be tracked to school absences, participants moving during the study, the missing data were considered random (MAR).

2.1.2 Study III

Study III was based on data collected in a longitudinal study (STAIRWAY, From Primary School to Lower Secondary School Study, 2014–2016) that focused on learning, motivation, and problem behavior. The participants, 858 students (55% girls), were from 56 school classes from one larger (sample included about half of the age cohort) and one middle-sized (sample included the whole age cohort) town in urban and semi-urban areas in Central Finland. The guardians of the participants gave their written informed consent for their children's participation. The schools and teachers of the participating classes also provided their permission for the data to be collected during school days.

At the beginning of the data collection, the participants were sixth graders (primary school), aged 12.58–13.75 years (M = 12.32 years, SD = 0.36), and they were followed to the seventh grade (i.e., lower secondary school). The longitudinal data for Study III were collected at two time points: in the fall of 2014 during sixth grade (T1 of Study III) and the spring of 2016 in the seventh grade (T2 of Study III). The data collection included tests of academic skills, as well as questionnaires concerning students' motivation, social relationships, and well-being. The tests and questionnaires were administered by trained research assistants during group assessment sessions.

Complete data for both time points T1 and T2 of Study III for math anxiety and arithmetic achievement measures were available for 85.8% of the sample. The highest percentage of missing data (9%) was for math anxiety items in T2 due to school absences. The missing data were considered random.

Additionally, 149 of the participants took part in individual assessments in the spring semester of the sixth grade. These students were selected based on the 3-minute Basic Arithmetic Test, which was carried out in the fall semester of sixth grade. The sample was non-random: both students with difficulties (scoring below the 16th percentile) and those without difficulties (scoring above the 16th percentile) in arithmetic fluency were selected, since the subsample was part of the sampling procedure of the broader study, of which one aim was to investigate learning difficulties. These two groups were matched according to gender distribution and general cognitive ability. In the end, 83 of the students scored below the 16th percentile in the arithmetic test, and 66 of the participants scored above the 16th percentile. The assessments consisted of challenging and non-challenging achievement tasks carried out with a computer and short questionnaires filled in before and after each task. Trained research assistants carried out the experiment during regular school hours. Of all the individual tests, we focused on the two types of arithmetic tasks (challenging and non-challenging) and questionnaire items assessing state math anxiety after each task (the procedure is illustrated in Figure 2).

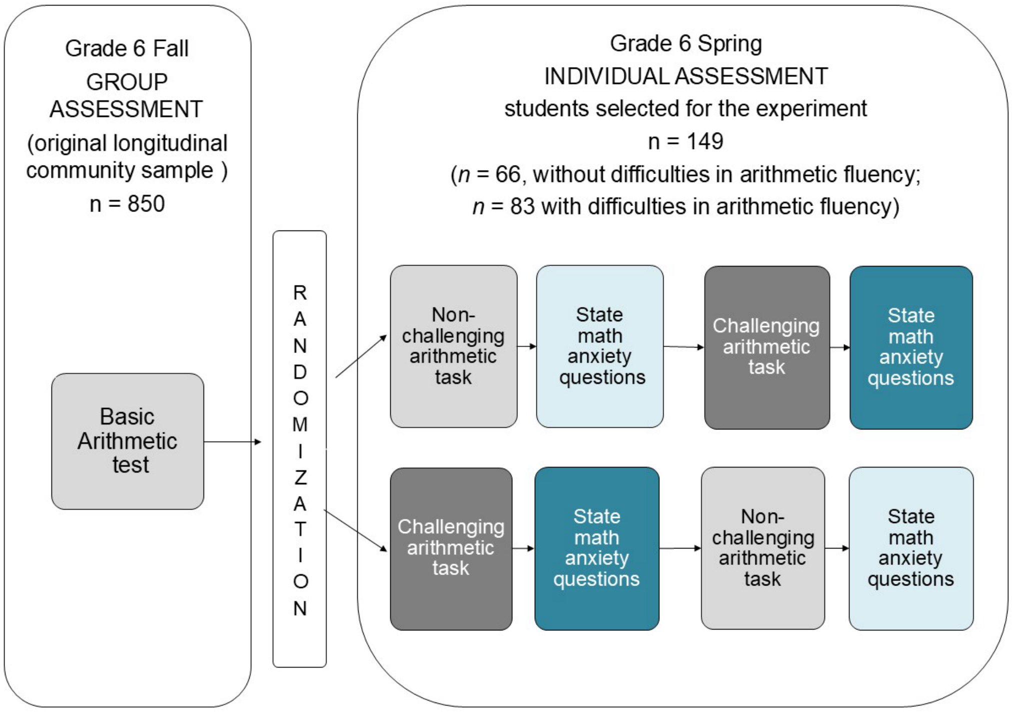

FIGURE 2. Procedure for the individual assessment in Study III

2.2 Ethical considerations

This dissertation follows the guidelines for the responsible conduct of research developed by the Finnish National Board on Research Integrity. The research procedures of the SELDI and STAIRWAY projects have been evaluated by the Committee of Ethics at the University of Jyväskylä. Participation was voluntary in all three studies for the schools, teachers, and students. Written consent was obtained from the participants' guardians, and the students and guardians were informed of the possibility of withdrawing from the study at any point without any negative consequences. The parents and participants were offered the opportunity to receive information on the details of the studies. The identifying information of the participants was used only to combine the information obtained from the different measurements. When the data were transferred into electronic format, the identifying information was replaced with a numerical code from which the individuals could not be identified. The research materials are stored in secure archives and the data in secure servers at the University of Jyväskylä.

2.3 Measures

2.3.1 Studies I and II

Anxiety about failure in mathematics was assessed with three items (see Table 2) from the Finnish translation of the MAQ (Thomas & Dowker, 2000). Two items were from the original measure: how anxious or calm the participant would be if they were unable to do something in math in general and if they were unable to do a mental calculation. Additionally, a question targeting math homework was included in the measure. As in the original MAQ, children responded to the items on a visualized 5-point scale, with pictures of faces depicting emotions from very anxious (rated as 5) to very calm (rated as 1).

Anxiety about math-related situations was assessed with three items adopted from a subscale initially designed to measure sources of self-efficacy (based closely on the ideas of Usher and Pajares, 2008): "I get anxious when I have to answer the teacher's questions in math class," "I get anxious when I start doing math," and "I feel tension when I have to do math." Children responded to the items on a 7-point scale from 1 = false to 7 = true). Cronbach's alpha for items of the Anxiety about Math-Related Situations was .71 and for the items of the Anxiety about Failure in Math .82.

Basic arithmetic skills were assessed with three time-limited paper-and-pencil tests administered in groups: the 2-minute Addition Fluency Test (Koponen 2010a), the 2-minute Subtraction Fluency Test (Koponen & Mononen, 2010b), and the 3-minute Basic Arithmetic Test (Aunola & Räsänen, 2007). Both the 2-minute addition and subtraction tests consisted of 60 simple tasks, with the addends of the addition tasks and the results of subtraction tests being smaller than 10. The Basic Arithmetic Test consisted of 30 addition, subtraction, division, and multiplication tasks. The scores of the three arithmetic tasks were standardized at both time points for each grade level. Cronbach's alpha for the basic arithmetic skills items was .92.

2.3.2 Study III

Basic arithmetic performance (in the first substudy of Study III) was assessed with the 3-minute Basic Arithmetic Test (Aunola & Räsänen, 2007). The sixth-grade version of the test consisted of 10 additions, 11 subtractions, and seven tasks including additions and subtractions or multiplications or divisions. The seventh-grade version consisted of eight additions, 11 subtractions, and nine tasks including both additions and subtractions or multiplications or divisions. The number of correct responses was the score of the test, with the maximum being 28. The scores were standardized according to the mean and standard deviation of the age group.

Trait math anxiety (in the first substudy of Study III) was assessed with three items from the AEQ (Pekrun et al., 2011), which were translated into Finnish and adapted for students from grades six to seven (Sainio et al., 2019). These items included the following: “Studying makes me anxious/nervous,” “Thinking about lessons makes me nervous,” and “I am anxious during tests.” The responses were provided on a 5-point scale ranging from 1 = disagree to 5 = agree.

Challenging and non-challenging arithmetic tasks (in the second substudy of Study III) consisted of 4-minute tasks comprising a maximum of 40 items adopted from the 3-minute Basic Arithmetic Test (Aunola & Räsänen, 2007). Based on their basic arithmetic performance (measured at the first time point of the first substudy of Study III), participants were divided into three different skill levels. All the participants completed two arithmetic tasks (challenging and non-challenging), and the order of the tasks was counterbalanced between the students (Figure 2). The tasks were different between the skill levels but the same within each skill level (for more information on the adaptation of the difficulty levels in the original article, see Sorvo et al., 2022). Altogether, the error rate of the challenging task (40.3%, SD = 24.7) was twice that of the non-challenging task (18.4%, SD = 15.5), indicating successful adaptation of the difficulty levels.

State math anxiety (in the second substudy of Study III) was assessed with three items adopted from the broader questionnaire entitled the Emotions in Achievement Situations Scale (Kiuru et al. 2014), which was developed based on the AEQ (Pekrun et al. 2011) and the Positive and Negative Affect Scale (PANAS; Watson et al., 1988). The questionnaire was presented immediately after both the challenging and non-challenging arithmetic tasks. Participants were asked how they felt during the tasks, and they responded on a 5-point scale (1 = disagree; 5 = agree). The state math anxiety items included the following: “I was nervous/restless,” “I was panicky/anxious,” and “I was worried about how well I could do the task.” For the analyses, the sum scores of state math anxiety were calculated separately for the challenging and non-challenging tasks. Cronbach’s Alpha for the math anxiety scale was .64 at first time point (factor score reliability =.84) and .72 at second time point (factor score reliability =.87).

TABLE 2. Summary of the design, participants, and variables of math anxiety and arithmetic achievement in Studies I, II, and III

Study	Design (data collection)	Participants	Observed variables	
			Math anxiety	Arithmetic achievement
Study I	Cross-sectional (11/2013)	SELDI study, 2^{nd} to 5^{th} graders, n = 1,327	**Anxiety about failure in math:** *How anxious or calm would you be if you were unable to do something in mathematics?* *How anxious or calm would you be if you were unable to do a mental calculation task?* *How anxious or calm would you be if you were unable to do mathematics homework?* **Anxiety about math-related situations:** *I get anxious when I have to answer the teacher's question in math class.* *I get anxious when I start doing math.* *I feel tension when I have to do math.*	2-min Addition Fluency Test 2-min Subtraction Fluency Test 3-min Basic Arithmetic Test
Study II	Longitudinal (11/2013 and 09/2014)			
Study III	Longitudinal (Fall 2014 and Spring 2016)	STAIRWAY study, community sample of 6^{th} graders, n = 850	**Anxiety about math-related situations:** *Studying makes me anxious/nervous.* *Thinking about lessons makes me nervous.* *I am anxious during tests.*	3-min Basic Arithmetic Test
	Cross-sectional (Fall 2014)	STAIRWAY study, subsample, n = 149	**State math anxiety:** *I was nervous/restless.* *I was panicky/anxious.* *I was worried about how well I could do the task.*	Challenging math task Non-challenging math task

2.4 Data analysis

The main analyses of all three studies were conducted using Mplus software, version 7.3–8.0. (Muthén & Muthén, 1998–2017), with weighted least square parameter estimates with a diagonal weight matrix with standard errors (WLSMV) estimator for the analyses (Muthén, 1984) in Study I and maximum likelihood with robust standard errors (MLR) in studies II and III. The full-information maximum-likelihood procedure (FIML) was applied to estimate the parameters of missing data. The measurement invariances between grade levels and genders in Study I was tested using chi-square difference test implemented in Mplus (Asparouhov & Muthén, 2006), and in Study III using the Satorra–Bentler scaled chi-square difference test (Satorra & Bentler, 2001). In Study II, the measurement invariance between grade levels and over time in Study II was tested using the root mean square error of approximation (RMSEA; Steiger, 1990) values of nested models, using the procedure of MacCallum et al. (2006). The goodness-of-fit of the final models was evaluated using the chi-square test (Asparouhov & Muthén, 2006), the RMSEA (RMSEA; Steiger, 1990), the comparative fit index (CFI; Bentler, 1990), the Tucker–Lewis index (TLI; Hu & Bentler, 1999), and standardized root mean square error (SRMR; Hu & Bentler, 1999).

In Study I, the distributions of participants reporting anxiety among girls and boys and different grade levels were compared using IBM SPSS Statistics by splitting the sample into those who reported anxiety and those who did not and analyzing the results with cross-tabulation (anxiety group against grade and gender) and a chi-square test with adjusted standard residuals. Aspects of math anxiety were investigated using confirmatory factor analysis (CFA). The main idea of CFA is to test a theoretical model (based on prior research) consisting of observed variables and hypothesized latent variables which presumably generate the covariance of the observed variables. The consistency of the hypothetical model and the data is assessed using statistical fit criteria (Knoke, 2005). In the present study, CFA was used to compare two math anxiety models with each other: a model with one latent math anxiety factor and a model with two latent math anxiety factors. The relationship between math anxiety aspects and basic arithmetic skills was examined using structural equation modeling (SEM) in which the consistency a hypothetical model (representing the relations of several latent factors) with the data tested using statistical fit criteria. The invariance of the factorial structure and the associations between math anxiety aspects and arithmetic achievement between grade levels and genders were tested using the Satorra–Bentler scaled chi-square difference test.

In Study II, the change/stability of the mean levels of the math anxiety aspects over the course of a year was examined within each grade level by comparing the values of different time points using the Wald test of parameter constraints (Muthén & Muthén, 1998–2017). The stability/change of the rank order of individuals, as well as the developmental relationships between math anxiety aspects and achievement, were examined using cross-lagged modeling. The regression coefficients and cross-lagged relationships were compared between grade levels using the Wald test.

In Study III, the mean-level stability/change of math anxiety from sixth to second grade was tested using the Wald test. The longitudinal relationships between math anxiety and arithmetic performance were examined using cross-lagged modeling. The cross-lagged associations were compared between genders using the Wald test. In addition, the situational association of math anxiety and performance in challenging and non-challenging tasks was analyzed using IBM SPSS Statistics (version 22) by comparing the performance of math anxiety groups (no anxiety arousal in either of the tasks, anxiety arousal in the challenging task, and anxiety arousal in both tasks) through repeated measures ANOVAs. To ensure that the results were not biased because of the task adaptation (i.e., participants in different performance levels getting different tasks), analyses were reconducted with performance scores standardized separately within the three performance levels. Consequently, each student's standardized performance score represents the student's performance in relation to the average performance in their own skill level on challenging or non-challenging tasks.

TABLE 3. Summary of the subjects of the research and statistical analyses in Studies I, II, and III

Subject of research	Statistical analyses
Study I	
Are anxiety about failure in math and anxiety about math-related situations separable aspects of math anxiety?	Confirmatory factor analysis Multi-group invariance comparison
Are math anxiety aspects differently related to basic arithmetic skills?	Structural equation modeling Multi-group invariance comparison
Study II	
Stability/change in the mean levels of math anxiety aspects during a school year.	Wald test of parameter constraints
Stability/change in the rank order of individuals with respect to math anxiety aspects during a school year. Longitudinal relationships between math anxiety aspects and arithmetic achievement.	Cross-lagged modeling Multi-group invariance comparison
Study III	
Longitudinal relationship between math anxiety and performance during the transition from primary school to lower secondary school.	Cross-lagged modeling
Situational association between math anxiety and achievement in challenging and non-challenging math tasks.	Repeated measures ANOVA

3 OVERVIEW OF THE ORIGINAL STUDIES

3.1 Study I

In Study I, the aim was to examine the different operationalizations of math anxiety used in previous studies and to determine their cross-sectional relationships with arithmetic achievement among second to fifth graders. It was assumed that varying operationalizations of math anxiety might explain the contradictory results of previous studies among primary school children, as some studies have established a correlation between math anxiety and achievement, while others have not.

The findings showed that the two operationalizations of math anxiety—anxiety about math-related situations and anxiety about failure in mathematics—are separate but correlated aspects of math anxiety. Reporting anxiety about failure was more common than reporting anxiety about math-related situations. About one-third of the students reported feeling anxiety about failure, whereas the prevalence of anxiety about math-related situations varied from nine to 19 %, depending on the item.

The only gender difference was that girls reported anxiety about answering teacher's questions more often than boys. The proportion of students reporting high levels of anxiety about math-related situations was relatively larger in the second grade and smaller in the fifth grade when compared to the whole sample. Over 15% of second graders and less than 5% of fifth graders reported anxiety about starting to do math or tension about having to do math. Anxiety about answering teacher's questions was also relatively more common among third graders. With respect to anxiety about failure in math, there were only small grade-level differences: anxiety about not being unable to do a mental calculation was relatively more common among fourth graders and less common among fifth graders, and the fourth graders also reported more anxiety about being unable to do something in mathematics in general.

Both anxiety about failure and anxiety about math-related situations were negatively correlated with basic arithmetic achievement. However, when the shared and unique variances of the aspects were examined more closely, the association from anxiety about failure to achievement appeared to derive mostly from its shared variance with anxiety about math-related situations (see Figure 3). In contrast, anxiety about math-related situations had a unique association with achievement (see Figure 4).

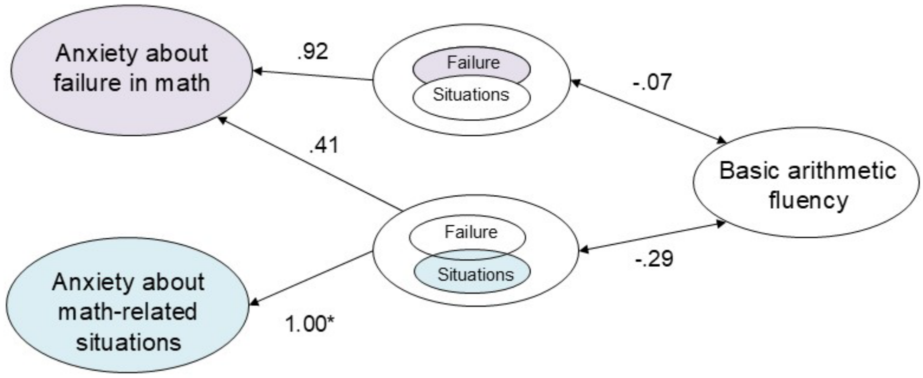

FIGURE 3. Model of the unique variance of anxiety about failure in mathematics (Sorvo et al., 2017). All estimates were standardized. For all paths, $p < .05$.

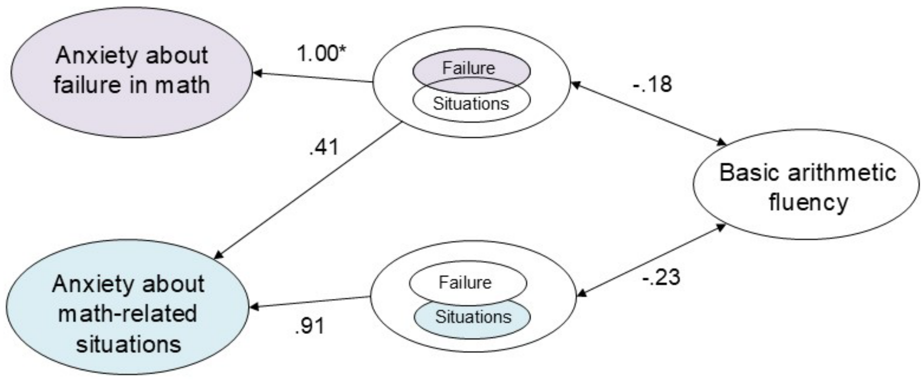

FIGURE 4. Model of the unique variance of anxiety about math-related situations (Sorvo et al., 2017). All estimates were standardized. For all paths, $p < .05$.

These results, indicating the different kinds of relationships between arithmetic achievement and the two operationalizations of math anxiety, support the assumption that the varying operationalizations might explain the contradictory results of previous studies (Dowker et al., 2012; Haase et al., 2012; Krinzinger et al., 2007, 2009; Vukovic et al., 2013; Wood et al., 2012; Wu et al., 2012, 2014). Consistent with previous research (Ma, 1999; Ramirez et al., 2013), the results suggest that math anxiety is already present among second graders. Thus, examining math anxiety in primary school is important to gain a better understanding of its early development. In particular, anxiety about math-related situations should be addressed, since it seems to be directly related to arithmetic achievement.

3.2 Study II

In Study II, the aim was to shed light on the development of the two operationalizations of math anxiety—anxiety about math-related situations and anxiety about failure in math—and their cross-lagged relationships with arithmetic achievement, which were examined longitudinally, during a year, among children in Grades 2 to 5.

The results showed that the level of anxiety about math-related situations declined significantly among second to fourth graders, and that the level of anxiety about failure in math declined significantly among third to fifth graders. The rank order of participants with anxiety about math-related situations was higher (one-year stability coefficient of 0.51) than the rank order of anxiety about failure (0.33). However, both were distinctly less stable than the rank order of arithmetic achievement (0.91).

The findings (see Figure 4) also revealed that prior higher anxiety about math-related situations predicted high anxiety about failure later on, and prior lower arithmetic achievement predicted higher anxiety about failure in math at a later time. Neither arithmetic achievement nor anxiety about failure predicted anxiety about math-related situations, and neither of the two aspects of math anxiety predicted later arithmetic achievement. There were no grade-level differences in the cross-lagged relationships between math anxiety and achievement.

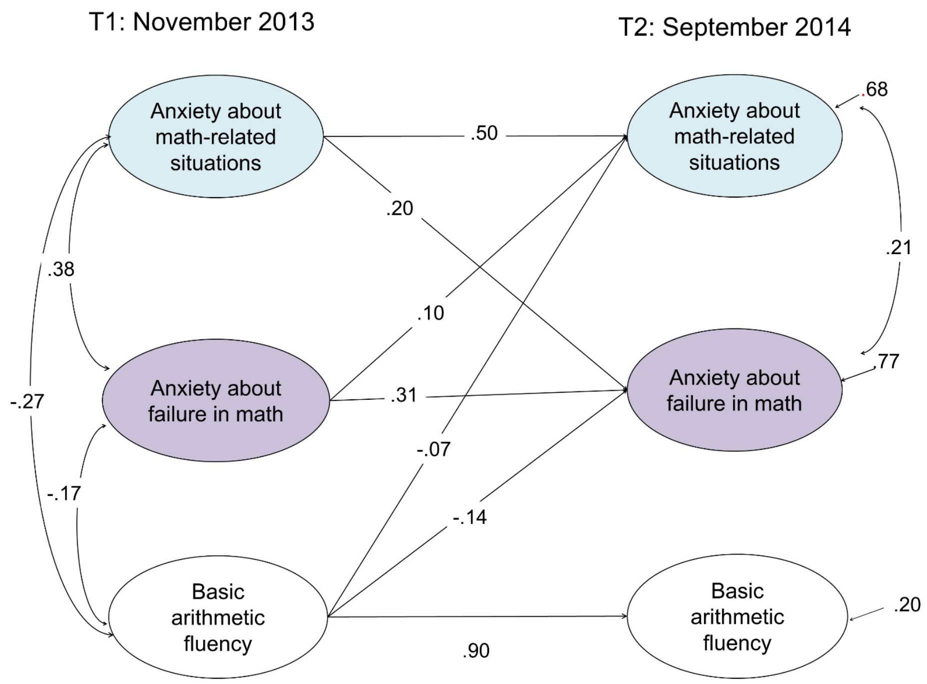

FIGURE 5. Stability effects and concurrent and cross-lagged relationships between anxiety about math-related situations, anxiety about failure, and arithmetic achievement (Sorvo et al., 2019). All estimates were standardized. For all paths, $p < .05$.

The results of Study II with respect to prior low arithmetic achievement predicting high levels of anxiety about failure in math later on support the deficit theory (Carey et al. 2016), suggesting that difficulties in mathematics result in negative experiences about mathematics, which thereby cause math anxiety in the future. These results underline the importance of paying attention to math anxiety, since anxiety about math-related situations seems to be relatively stable in primary school.

3.3 Study III

The aim of Study III was to examine the development of math anxiety and its longitudinal and situational associations with arithmetic achievement during the transition from primary school to lower secondary school. Unlike in the majority of previous studies, the relationship was examined from two perspectives. First, it was examined developmentally by focusing on trait anxiety with a longitudinal design and predicting changes in both math anxiety and achievement, while controlling for previous levels. Second, the relationship was examined cross-sectionally focusing on the situational effect of state math anxiety on performance in more and less challenging math task situations.

The results showed that the level of math anxiety slightly increased from sixth to seventh grade. The one-year stability coefficient of anxiety about math-related situations was 0.64, and the corresponding value for arithmetic achievement was 0.74. Anxiety was negatively correlated with adolescents' math achievement at both time points. Even after controlling for previous level of math fluency, math anxiety in the sixth grade negatively predicted math performance in the seventh grade. In turn, math achievement in the sixth grade did not predict math anxiety in the seventh grade. There were no significant differences between girls and boys in the strength of the cross-lagged associations between math anxiety and math achievement.

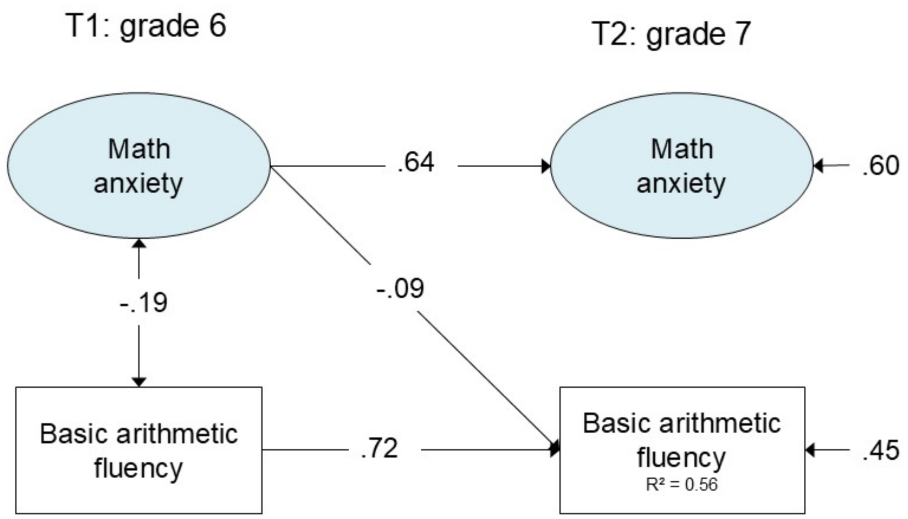

FIGURE 6. Model of the longitudinal relationships between math anxiety and arithmetic achievement (Sorvo et al., 2022). All estimates were standardized. For all paths, $p < 0.05$.

Additionally, the situational relationship between math anxiety and performance was investigated through challenging and non-challenging math tasks adapted to their skill levels. Math anxiety was measured immediately after each task. Most of the students (66%) did not report anxiety in either of the tasks, but about 16% reported at least some levels of anxiety in both tasks, and about 16% only in the difficult task. All three groups (no anxiety at all, anxiety in both tasks, and anxiety in difficult tasks only) had fewer correct answers and reacted more slowly in the difficult task than in the easy task. When the performance was examined *in relation to the average performance of each skill level*, those who were anxious only in the difficult task had fewer correct answers (see Figure 6) and performed slower (see Figure 7) in that task compared to the easy task in which they did not report anxiety. The other two groups performed evenly in both tasks: the ones who did not report anxiety at all performed approximately averagely (compared to their skill level) in both tasks, and the ones reporting anxiety in both tasks performed below the average of their skill level in both tasks.

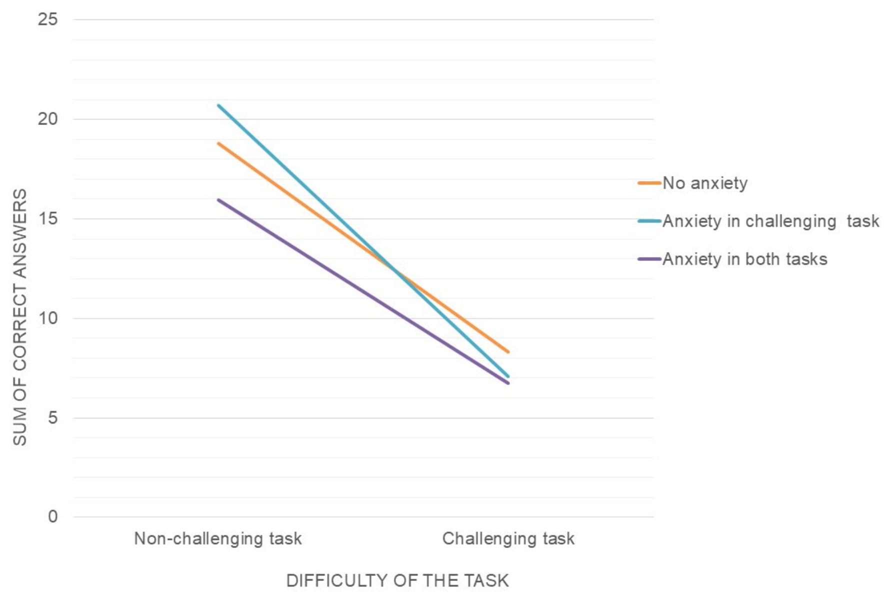

FIGURE 7. Means of the sums of correct answers for the three anxiety groups in non-challenging and challenging tasks (Sorvo et al., 2022)

FIGURE 8. Means of the overall mean reaction times for the three anxiety groups in non-challenging and challenging tasks (Sorvo et al., 2022)

The results, along with previous research, underline the complexity of the relationship between math anxiety and arithmetic achievement. Furthermore, they adduce the two-fold relationship between anxiety and achievement. Specifically, math anxiety seems to have both a real-time association with performance when occurring and a long-term effect on the development of basic arithmetic skills.

4 GENERAL DISCUSSION

4.1 Effects of various operationalizations of math anxiety

The aim of Study I was to investigate the different operationalizations of math anxiety used in previous studies. The results suggest that the operationalization matters. In other words, emphasizing the expected failure in the math anxiety measure seems to bring up more anxiety arousal than leaving the expected outcome open, but the latter operationalization appears to reveal the relationship between anxiety and achievement more directly. The essential difference seems to be whether the anxiety is aroused only when one is specifically provoked to imagine themselves failing, or whether it is caused by math-related situations per se. The results support the assumption that varying operationalizations of math anxiety might explain the previous contradictory results regarding the relationship between math anxiety and achievement in children. Previous studies that have focused on anxiety about failure in mathematics (Dowker et al., 2012; Haase et al., 2012; Krinzinger et al., 2007, 2009; Wood et al., 2012) have generally not found an association between math anxiety and achievement, whereas studies emphasizing anxiety about math-related situations have revealed an association (Cargnelutti et al., 2017; Carey et al., 2017; Ramirez et al., 2013, 2016; Wu et al., 2012).

One reason for the different kinds of relationships between the two aspects of math anxiety and achievement might be the different experiences of students at different skill levels. Students at all skill levels can experience the thought of failing as distressing. According to the control-value theory (Pekrun, 2006), anxiety is even seen as a natural consequence of the appraisal of expected failure when it is found to be subjectively harmful and hard to prevent. Still, for students with good mathematical skills, failures and anxiety about them can be relatively hypothetical, at least in the first school years. Even if nearly 30% of the participants in this study responded that they would feel anxious if they were unable to do something in mathematics, this does not necessarily mean that they come across these situations and emotions regularly. Besides, concern over mistakes has also been found to be a dimension of perfectionism (Frost et al., 1990), which is relatively common among gifted students (Parker, 1997) and may, in its lighter forms, even stimulate healthy needs for achievement (Parker, 2000).

At the same time, children with low math skills are more likely to experience failures in math, which might negatively affect how they feel about math-related situations in general. For these children who reported getting anxious when they started doing math, comprising less than 10% of the participants in this study, anxiety was less likely to be a hypothetical emotion, since they reported feeling it in a situation they concretely faced at school every day. However, this should not be interpreted to mean that anxiety about math-related situations is not related to expectancies of failure. Instead, it is likely that the appraisal of expected failure is also an antecedent of anxiety in general math-related situations (see control-value theory; Pekrun, 2006). It just does not need to be emphasized separately.

Furthermore, asking students how anxious they would be *if they were unable* to do something in mathematics might even contradict assumptions about the nature of anxiety as an emotion (Pekrun, 2006). In the control-value theory, anxiety is defined as a *prospective* emotion related to expected failure (Pekrun, 2006). Asking students about being unable to do something can lead them to think beyond the actual task situation and instead direct their attention to a moment at which they realize that the failure *has already happened*. In that case, the point of view is more retrospective than prospective, and the emotions in question are most likely retrospective emotions like disappointment, rather than anxiety. Additionally, according to control-value theory, emphasizing the expected failure in the operationalization of math anxiety might remove the aspect of *uncertainty* that is assumed to be inherent in anxiety, according to control-value theory. In fact, feeling that the failure is unpreventable is more likely to lead to hopelessness than to anxiety. Altogether, the operationalization of math anxiety in the questionnaires, as well as the interpretation of the results, should be done carefully; when asking about anxiety evoked by math-related situations, leaving the expected outcome open and emphasizing expected failure will most likely lead to investigating at least different aspects of anxiety and, in some cases, even completely different emotions.

4.2 Development of math anxiety

In Study I, the prevalence of math anxiety among children was compared between different grade levels from second to fifth grade with a cross-sectional set of data. In Study II, the development of math anxiety was examined during a one-year follow-up among students in Grades 2 to 5 at the beginning of the study. In Study III, anxiety about math-related situations was assessed longitudinally during the transition from primary school to lower secondary school (i.e., from

Grade 6 to Grade 7). Aside from the mean-level change, the rank-order stability of math anxiety was also investigated in both longitudinal studies.

In Study I, the children at various grade levels differed, especially in their average level of anxiety about math-related situations. The results indicated that the lower the grade level, the more anxiety the students felt in math-related situations. Since the results of Study I were based on cross-sectional data, longitudinal analyses were also needed. The results of Study II were in line with the cross-sectional results about math anxiety decreasing with age: both the level of anxiety about math-related situations and anxiety about failure in math declined at almost all grade levels during the one-year follow-up. The results of Study III revealed an opposite direction in the development: from the fall of the sixth grade to the spring of the seventh, the level of math anxiety increased.

Based on these research results, it seems that the level of math anxiety decreases during primary school. This supports the results of Gunderson et al. (2018), who found a similar downward trend in the early primary school years. However, there are also studies comparing different age groups above third grade that have reported anxiety increasing with age at that stage of schooling (Gierl & Bisanz, 1995; Krinzinger et al., 2009). One reason for the contradictory results about these developmental trends might be differences in cultures, school systems, and curricula. It is unlikely that the development of math anxiety is a universal process, independent of the different expectations and different levels of pressure to which students in different cultures and school systems are exposed.

However, the downward trend seems to discontinue at the end of primary school; when moving from primary school to lower secondary school, the level of math anxiety in this study increased. The result of math anxiety increasing from sixth to seventh grade is in line with the findings reported in previous research. Overall, the level of positive academic emotions has been found to decrease, and the level of negative emotions increases, during the transition from primary school to lower secondary school (Sainio et al., 2022). Additionally, compared to primary school students, secondary school students have been found to report more negative attitudes toward mathematics, less enjoyment of the subject, and more math anxiety (Deieso & Fraser, 2019).

It is also possible that, rather than decreasing during primary school, math anxiety changes its form, and the anxiety that emerges at different ages stems from different kinds of situations. In the study of Gierl and Bisanz (1995), sixth graders reported more mathematics test anxiety than third graders, but there was no grade-level difference in mathematics problem-solving anxiety. Unfortunately, there were no measures of math test anxiety in Study II, so it might just be that the possible effect of increasing math test anxiety remains hidden. In Study III, math test anxiety was measured with one item, the mean of which increased from the sixth to seventh grade. However, there was a similar increase in the items measuring anxiety about studying mathematics and math lessons. Therefore, it cannot be assumed that the increase in math anxiety during the transition from primary school to lower secondary school would be due to math test anxiety alone.

Even though math anxiety seems to decrease during primary school, there is no reason to conclude that math anxiety in primary school would be a meaningless phenomenon. The rank order in math anxiety between students was relatively stable, and this stability was similar in all grade levels from the second grade onward. It seems that those who are the most anxious about mathematics compared to others are often still the most anxious in the following school year, even if the mean level of anxiety would have decreased. Nevertheless, there seemed to be more changes in the rank order of the students in terms of math anxiety, as compared to arithmetic achievement. Overall, these results are in line with previous research indicating that the rank order of individuals in math anxiety, especially in anxiety about math-related situations, was relatively stable but still less stable than the rank order in arithmetic achievement (Gunderson et al., 2018; Krinzinger et al. 2009; Ma & Xu, 2004).

Altogether, it seems that big changes in school are apt to activate anxiety. In primary school students, the youngest children reported the highest levels of anxiety, which then decreased with age. The reason for this might be that young children are still adjusting to school, and with time, they develop more adequate coping strategies for facing the difficulties of learning mathematics. The transition to lower secondary school seems to increase the level of math anxiety again. In the Finnish school system, the transition from sixth to seventh grade usually brings many kinds of changes: in primary school, students are generally taught by their own class teachers, in their own classrooms, at least in most of the school subjects. The transition to lower secondary school often means moving to a new group in a new school, which can itself increase stress. At the end of lower secondary school, students also have to make choices about applying to upper secondary school or vocational education, which can increase the pressure to succeed in school.

One of the biggest changes from sixth to seventh grade is transitioning to a system in which different school subjects are taught by several previously unfamiliar subject teachers. In lower secondary school, students also spend only a fraction of the time with one subject teacher that they used to spend with their class teachers in primary school, and usually, younger children's relationships with teachers tend to be closer than those of adolescents (Eccles & Roeser, 2011). This may explain the increase in negative emotions, since emotionally warm and close teacher relationships have been found to be related to increased positive academic emotions (Goetz et al. 2021; Sainio et al. 2022) and decreased negative emotions (Goezt et al. 2021). At the same time, lower teacher closeness has been found to be associated with increased negative academic emotions (Sainio et al., 2022).

4.3 Causality of the relationship between math anxiety and achievement

Besides focusing on the development of math anxiety, the aim of Studies II and III was to examine the relationship between math anxiety and arithmetic achievement, especially from the point of view of causality. Specifically, these studies focused on whether anxiety is a result of poor achievement (the deficit theory; Carey et al. 2016), whether anxiety debilitates performance (the debilitating anxiety model; Carey et al. 2016), or whether the two affect each other in a vicious circle (the reciprocal theory; Carey et al. 2016). In Study II, the causal relationships between anxiety about math-related situations, anxiety about failure in mathematics, and arithmetic achievement were investigated in primary school children over the course of one year. The results showed that prior low achievement predicted higher levels of anxiety about failure in math later on when the prior anxiety level was taken into account, but not anxiety about math-related situations more generally. Neither of the aspects of math anxiety predicted later achievement among primary school children, thereby supporting the deficit theory. In Study III, the relationship between math anxiety and achievement was investigated longitudinally during the transition from primary school to lower secondary school. The results revealed an opposite direction of the relationship as compared to the results of primary school children in Study II: in this case, high math anxiety in the sixth grade predicted low achievement in the seventh grade, but achievement in the sixth grade did not predict math anxiety in seventh grade, thereby giving support to the debilitating anxiety model.

In addition to the longitudinal association between math anxiety and achievement, the situational association was examined in Study III to obtain a wider picture of their complex relationship. The situational association was examined among sixth graders who were provided individually non-challenging and challenging arithmetic tasks adapted to their arithmetic skill level. In this investigation, math anxiety was viewed as state anxiety, a situation-specific emotional state, and was therefore measured immediately after each task. The findings revealed that anxiety had a situational association with performance: when anxiety was activated, the participants performed more poorly compared to their skill level. These results indicate that activated math anxiety is situationally related to underperformance in task situations.

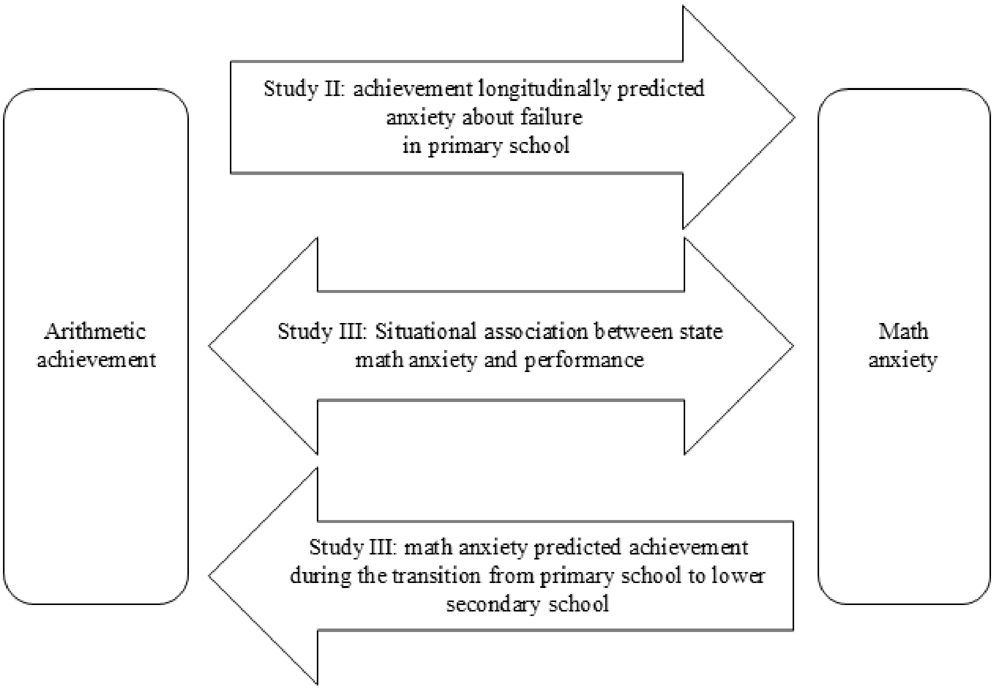

FIGURE 9. Longitudinal and situational associations between math anxiety and achievement in Studies II and II

Even though cross-sectionally (Study I), arithmetic achievement was more strongly related to anxiety about math-related situations than anxiety about failure in mathematics, when considered longitudinally, low achievement directly predicted high anxiety about failure, but not anxiety about math-related situations. It seems that developmentally, the association between achievement and math anxiety arises specifically from failures, since prior lower achievement, and therefore more experiences of failures, led to increasing anxiety about failure in the future. This association supports the results of Kyttälä and Björn (2010), who reported that the effect of prior mathematics achievement on anxiety is mediated by outcome expectancies and can be interpreted via the mechanisms of the control-value theory of achievement emotions (Pekrun, 2006). More specifically, past failures will probably lead to lower appraisals of subjective control over the outcome and higher expectations of failing, consequently leading to higher levels of anxiety.

Additionally, a developmental association from high math anxiety to lower achievement during the transition from primary school to lower secondary school was found, indicating that math anxiety affects the development of arithmetic skills. One explanation may be that the longitudinal effect arises through the same mechanisms as the immediate effect, which would be attentional system disruption (attentional-control theory; Derakshan & Eysenck, 2009) and the burden of working memory (Ashcraft & Kirk, 2001). If math anxiety is habitual, trait-like, and thus arises regularly in certain math-related situations, its consequences for attention and working memory might even be that it disrupts skill learning and the development of arithmetic fluency. Another possible explanation for the longitudinal effect is avoidance behavior. Students with math anxiety may try to minimize their involvement in mathematics (Ashcraft, 2002), which, over time, can lead to less practice and result in slower development of arithmetic skills.

The situational association of math anxiety and underperformance gives support to the suggestion of an "affective drop" in performance (Ashcraft & Moore, 2009). In such cases, when math anxiety is activated, the true ability of the individual is rarely revealed, especially under timed, high-stakes conditions. The immediate effect of math anxiety on performance has been explained by anxiety disrupting the attentional system (attentional-control theory; Derakshan & Eysenck, 2009) and burdening working memory (Ashcraft & Kirk, 2001). Unfortunately, however, causal claims about the situational association cannot be made based on the present study's results. Anxiety disrupting performance is one explanation for this relationship, but it is also possible that students' own estimates of failure or underperformance cause the activation of anxiety.

The situational effect was especially observable in the challenging tasks. About one-third of the participants felt anxiety in the challenging task, and one-fifth of them felt this way in the easy task. The effect was similar regardless of the skill level of the students: the anxiety groups did not differ in their performance on the previous arithmetic test. The results suggest that even if math anxiety is related to arithmetic achievement, it is not just a problem for students with low skills; rather, it is relatively common to get anxious about difficult tasks, regardless of how good one is in math. This is in line with the results of Devine (2018), showing that nearly 80% of students with high math anxiety had typical or high performance in math. This underlines the importance of state math anxiety measures in real task performance situations. In other words, measuring trait math anxiety reveals only one part of the phenomenon, since students of different skill levels are not equally provided with easy and difficult math tasks at school.

Overall, the results of the present study support the reciprocal model of math anxiety and achievement (Carey et al., 2016). Relationships from prior achievement to later anxiety (Study II) and from prior anxiety to later achievement (Study III) were both found, although it appears that the direction of the association might be different in various stages of schooling. However, especially in primary school, there was very little variation in the rank order of arithmetic achievement (i.e., not much variation to be explained by math anxiety development). Therefore, the conclusion that anxiety in primary school children does not affect achievement at all should not be made based on these results. In addition to the longitudinal associations between math anxiety and achievement, a situational association was found, indicating that math anxiety is related to underperformance in mathematics. Based on these results, it seems that math anxiety and achievement affect each other in a multi-level vicious circle: lower achievement increases anxiety about failure over time, high math anxiety affects the development of arithmetical skills, and math anxiety is also related to underperformance in actual task performance situations.

4.4 Limitations of the present study

Certain limitations should be noted when interpreting the results of the present dissertation. First, even if the approach in the study was longitudinal, the follow-up periods were relatively short. Second, conclusions about the bidirectional relation between math anxiety and achievement, as well as math anxiety development at different stages of schooling, have been made based on the data collected in two separate research projects. To draw firmer conclusions, more longitudinal data with a longer follow-up period would be needed. Specifically, such data should be collected through primary school and beyond the transition to lower secondary school. Another data-related limitation is that its nested structure (students nested within classes and classes nested within school) was not taken into account in the analyses. However, in the study on self-efficacy by Peura et al. (2021), using the data of the same research project as the present thesis, the intra-class correlations by school were small and nonsignificant as well as the intra-class correlations by class when the grade level was controlled. This might indicate that the differences between the schools and classes in this data are quite small.

In the present study, the focus of the mathematics achievement measures was on basic arithmetic skills. The rank order of individuals in arithmetic skills seemed to remain relatively stable, especially among primary school students. In Study II, the one-year stability coefficient was .90. It is possible that this affected the cross-lagged relationships found in the two studies. Since the rank order of individuals in arithmetic performance in Study II was remarkably permanent, there was not much variation for math anxiety to explain, even hypothetically. During the transition from primary to lower secondary school in Study III, the stability coefficient was a bit lower at .72. (i.e., not as stable), which may explain the fact that an association between math anxiety and achievement was observed. Moreover, only timed measures of performance were used in all three studies. Both timed and untimed measures should be used in future studies to understand the effects of math anxiety on mathematical performance more comprehensively (Ashcraft & Moore, 2009).

A further limitation of this study is that the dimensionality of math anxiety was not fully considered. In Studies I and II, the two previously used operationalizations of math anxiety were applied, and in Study III, the aim was to examine math anxiety not only as an individual trait but also as a situational state. However, previous studies have also confirmed other divisions into the dimensions of math anxiety. For instance, one related to math testing and another related to more general math performance or math learning have been identified (Hopko et al. 2013; Richarson & Suinn, 1972), as have cognitive and affective dimensions of math anxiety (Wigfield & Meece, 1988), as well as negative reactions, worry, and numerical confidence (Harari et al. 2013). These dimensions were not investigated in the present study, although anxiety about failure and anxiety about math-related situations might, to some extent, overlap with these different dimensions. Furthermore, general anxiety was not controlled in this study, which is a limitation since general anxiety might explain some of the variation in math anxiety (Hembree, 1990) and it is suggested to be a predictor of math anxiety (Szczygieł et al. 2024).

Moreover, in the present study, the development of math anxiety and its associations with achievement have been studied only at the group level, with the aim of generalizing the results to the entire age group. The potential existence of different developmental pathways has not been examined here. On the individual level, the development of math anxiety might often be nonlinear; the amount of experienced math anxiety varies at different stages of schooling and life and is affected by many factors. Recently, Wang et al. (2021) found three different developmental patterns of math anxiety in relation to math self-concept and math utility value: one with modestly stable math anxiety, one with increasing math anxiety, and one with curvilinear changes in math anxiety. Furthermore, the associations between anxiety and achievement might also be nonlinear. Sometimes, to some extent, stress and even anxiety might be a sign of the value placed on the subject and even function as a booster that improves concentration and performance. Presumably, there is interindividual variation in the effects of anxiety, and some children might be more vulnerable to the detrimental effects of math anxiety than others.

4.5 Suggestions for future research

There are some points from the present study worth highlighting that should be noted in future research. First, the results of the present study underline the importance of the careful operationalization of math anxiety in questionnaires, since different operationalizations will probably lead to different aspects of math anxiety being investigated and, thus, different kinds of results. If the purpose is not to specifically investigate anxiety about failure, it is advisable not to emphasize failure in the questionnaires, and to instead leave the expected outcome open. Simple, straightforward questions are preferable in such cases, as it is more likely that the students' attention will be drawn to real, not just hypothetical, emotions when they are asked about their anxiety in various math-related situations. This operationalization will also help to maintain the uncertainty about the outcome that is assumed to be inherent in anxiety (Pekrun, 2006).

In addition to the traditional view of anxiety as an individual trait, anxiety should also be considered a situational state. This would entail measuring math anxiety in real task performance situations, or at least right after them. Viewing math anxiety as a situational state enables the investigation of the situational relationship between math anxiety and performance. In addition, this view might even help some students recognize their emotions more effectively. It requires a variety of metacognitive skills on the part of a child to review their past math-related experiences and then answer questions based on some kind of generalization about their emotions in those situations. Instead, examining emotions aroused by just one recent task performance situation can be easier and much more concrete. Furthermore, all students do not equally encounter challenging math-related situations at school, and, therefore, measuring math anxiety trait-wise is not always sufficient to reveal the math anxiety of students with different skills.

Moreover, it should be noted that there is likely to be a group of students whose emotions cannot be brought out with traditional self-reported math anxiety questionnaires. Some students might have difficulties in identifying, understanding, and/or describing their emotions; some might simply consider the recognition of anxiety or fear a sign of weakness. In these cases, to obtain a more detailed picture of the phenomenon, it could be useful to include other measures, such as assessments of autonomic physiological reactions and parent/teacher report questionnaires about avoidance behavior and expressions of anxiety in math-related situations.

Not only should math anxiety measures be paid attention to, but the selection of measures of math achievement should also be performed carefully. This is especially important when investigating the situational effect of math anxiety, as *all participants* should be provided with challenging and non-challenging tasks. Measures of various math skills—not just basic arithmetical skills but also more complex skills with less stability—are also needed to explore the long-term developmental relationships between math anxiety and achievement. In addition, using both timed and untimed measures might provide more information about the effects of math anxiety on achievement.

Finally, future research should consider the fluctuation in both the development of math anxiety and the associations between math anxiety and achievement at different stages of schooling and between individuals. Longitudinal research with long follow-up periods is needed, which would ideally run through primary school and beyond the transition to lower secondary school. More person-centered and group-based approaches are also needed to establish a better understanding of math anxiety and its different developmental patterns, since every student may be affected by math anxiety arousal in their own way, based on their own prior experiences, beliefs, and background. The extent to which this phenomenon can even be understood by studying large groups of people and generalizing the results should also be examined.

4.6 Practical implications

The results of the present study showed both situational and developmental associations between math anxiety and math achievement. Since math anxiety and achievement in math are so closely linked, it might be the case that influencing anxiety is one way to influence learning. Therefore, more attention should be paid to math anxiety throughout schooling.

When considering practical implications, it is important to pay attention to the antecedents of math anxiety. From the point of view of the control-value theory of achievement emotions (Pekrun, 2006), one of the antecedents of anxiety is the value given to the subject, and mathematics has traditionally been highly valued in school contexts. Bleazby (2015) argues that most school curricula include an inherent but problematic assumption that school subjects requiring abstract reasoning, especially mathematics, are more valuable than others, and this epistemology of education can be traced back as far as Plato. In Finland, the value of mathematics has been increasingly emphasized in recent years. In 2020, the admissions procedures at higher education institutions were reformed to give more weight to the grades on matriculation examinations, and as a result, the weight of mathematics grades increased in the certificate-based fields of education, the humanities, and the social sciences. This change is reflected in the proportion of students taking the advanced mathematics matriculation exam, which has risen above the proportion of those choosing the basic mathematics exam (Tähkä, 2021).

In addition to the instrumental value of securing a career, the high value of mathematics is also visible in how the students see themselves. If, from the student's point of view, performance in mathematics directly reflects their intelligence, the stakes for success are high: failure can be interpreted as a direct sign of not being intelligent, and math as a subject may even be infused with a sense of one's own worth and dignity. It is not unusual for teachers to end up discussing the value of mathematics with students, but the point of view of the students is usually that of questioning the value and practicality of the subject for them in the future (e.g., "Where am I ever going to need quadratic equations?"). It may therefore be useful to have discussions about the value of mathematics from other perspectives. For instance, what is the value of the subject to the students themselves? Do they fear the consequences of failure? Do they associate math with intelligence or even their own value as a person?

One of the antecedents of anxiety is assumed to be the experience of having little control over an outcome (control-value theory; Pekrun, 2006). This assumption is supported by the results of the present study. The effect of previous skills on later anxiety appeared to run through failing, since lower previous achievement predicted especially anxiety about failure in mathematics. Therefore, it seems that low control over the outcome increases anxiety. It is possible that mathematics is a school subject in which losing one's sense of control is relatively easy. Compared to other intellectual skills, mathematics is more often associated with a fixed mindset. In other words, math ability is viewed as a gift that one simply has or does not have (Dweck, 2008), which may reduce the students' beliefs that they have control over math learning. Moreover, mathematical skills are hierarchically structured (Aunola et al., 2004; Koponen et al., 2019), and if the student's basic skills are not fluent, which is a typical situation among those with learning difficulties in mathematics (e.g., Geary et al., 1999; Ostad, 1998), compensating for the missing skills can be difficult. From the beginning of primary school, mathematical problem solving also requires a certain type of cognitive effort, including abstract reasoning, keeping various steps in mind simultaneously, and applying previously learned information in new contexts. These kinds of complex processes can be particularly vulnerable to a perceived lack of control.

From the point of view of fostering students' experiences of control, it would be particularly valuable to provide them with tasks suitable to their own skill levels, which would allow them to experience success and see the impact of their own actions. Pekrun (2006) has suggested that matching task demands to students' capabilities is likely to support both their cognitive learning and positive achievement emotions. Students' sense of competence can also be fostered by supporting their autonomy in the learning process. Higher autonomous self-regulation of learning has been found to be related to higher perceived competence and lower anxiety, at least among older students (Black & Deci, 2000). However, Pekrun (2006) has also shown that learning environments of a too-challenging nature and unfavorable social comparisons can induce anxiety, which is especially important to note when working with children with low skills and learning difficulties. In addition to giving students tasks that match their skill levels, the learning environments and their demands should also be matched to the students' capabilities.

To foster the students' perceived control of math learning, students' perceptions about the stability or malleability of both math anxiety and mathematical abilities should also be considered. Interventions targeting changing mindsets about math ability have been found to affect students' math anxiety (Hekimoglu & Kittrell, 2010; Samuel & Warner, 2021; Tzohar-Rozen & Kramarski, 2013), as well as their grades (Blackwell et al., 2007; Good et al., 2003). There is also evidence that the belief that anxiety may be fixed and unchangeable predicts future stress (Schroder et al., 2019). Reappraisal of anxiety in other ways could also be useful. Even if there is a relation between math anxiety and achievement, anxiety should not be interpreted as a direct indicator of low skills by either the student themselves or the educator. Buckley and Sullivan (2021) argue that teaching students emotional regulation skills, especially the skill of reappraisal, might be useful in reframing anxiety, and that uncertainty in math classrooms should be normalized and approached by *embracing challenge*. They also pointed out that rather than trying to remove anxiety, teachers should encourage students to manage it and thus develop mathematical resilience.

Educators might also benefit from shifting the view from anxiety being a personality trait to anxiety being an emotional state. In other words, is math anxiety interpreted as something that is *in the person*, or as something *the person is in*? From the point of view of reducing math anxiety, do we see the educator's task as changing the trait of the individual, helping the student out of that emotional state, or perhaps even proactively moving them away from the path leading to the state of anxiety? It must be noted that these insights do not imply that math-related situations should be avoided; on the contrary, situational exposure has been found to be an effective method in the treatment of anxiety disorders (Gould et al., 1997; Zaider & Heimberg, 2003). Altogether, the existence of emotions related to learning should be acknowledged. For instance, simply asking students to write about their thoughts and feelings before a math test has been found to lessen the gap between students with high and low levels of math anxiety (Park et al., 2014).

4.7 Conclusions

Overall, the results of the present study highlight the importance of paying attention to math anxiety in education, as well as achievement emotions more generally. Teachers should be increasingly aware of math anxiety and its consequences. Specific attention should be paid to students who continuously become anxious in math-related situations, since math anxiety affects the development of arithmetic skills. Furthermore, the results of the present study support the assumption of a reciprocal relationship between math anxiety and achievement. It seems that developmentally, the association between achievement and math anxiety arises specifically from failures, since prior lower achievement, and therefore more experiences of failures, leads to increasing anxiety about failure in the future. Those who struggle with mathematics should be provided with targeted support for learning, which would enable positive experiences and a sense of control and prevent the development of negative emotions and attitudes, which, in turn, are apt to affect skill development.

Support in coping with learning-related negative emotions can be useful for many students, not just those who are continuously and visibly anxious about mathematics. It is possible that for some students, math anxiety is activated later in their education course, for example, during school transitions when the content becomes more difficult, and they would then benefit from tools for dealing with those emotions at that time. Since situational math anxiety, when activated, is related to underperformance, effective instruction should either aim to minimize the arousal of stress and anxiety or provide students with the means to cope with difficult emotions. The importance of emotional skills has been increasingly recognized, even in the Finnish national core curriculum for basic education (Opetushallitus, 2014). However, the focus of the national curriculum is more on teaching social skills and interactions with others, rather than the self-regulation of learning-related academic emotions. More generally, not only the observable performance, but also the underlying feelings related to learning should be considered when providing support for students. This is often self-evident to teachers, but the importance of emotions should also be considered in administrative decisions. In evidence-based decision making, the focus is often specifically directed toward learning outcomes, and the emotional aspect of learning is thereby ignored. Nevertheless, even if the present study, among many others, emphasizes the association between math anxiety and achievement, it should be noted that this is not the only reason to aim at reducing math anxiety. Math anxiety should be recognized even if it does not directly affect achievement, since school and studying should not be constantly anxiety-arousing. Altogether, the reason for paying attention to emotions is not only their effect on learning, but more generally their effect on well-being, which is important in and of itself.

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ORIGINAL PAPERS

I

MATH ANXIETY AND ITS RELATIONSHIP WITH BASIC ARITHMETIC SKILLS AMONG PRIMARY SCHOOL CHILDREN

by

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Math anxiety and its relationship with basic arithmetic skills among primary school children

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Math Anxiety and Its Relationship with Basic Arithmetic Skills among Primary School Children

Abstract

Background

Children have been found to report and demonstrate math anxiety as early as the first grade. However, previous results concerning the relationship between math anxiety and performance are contradictory, with some studies establishing a correlation between them while others do not. These contradictory results might be related to varying operationalizations of math anxiety.

Aims

In this study, we aimed to examine the prevalence of math anxiety and its relationship with basic arithmetic skills in primary school children, with explicit focus on two aspects of math anxiety: anxiety about failure in mathematics and anxiety in math-related situations.

Sample

The participants comprised 1,327 children at grades 2 to 5.

Methods

Math anxiety was assessed using six items, and basic arithmetic skills were assessed using three assessment tasks.

Results

Around one-third of the participants reported anxiety about being unable to do math, one-fifth about having to answer teachers' questions and one-tenth about having to do math. Confirmatory factor analysis indicated that anxiety about math-related situations and about failure in mathematics are separable aspects of math anxiety. Structural equation modeling suggested that anxiety about math-related situations was more strongly associated with arithmetic fluency than anxiety about failure. Anxiety about math-related situations was most common among second graders and least common among fifth graders.

Conclusions

Since math anxiety, particularly about math-related situations, was related to arithmetic fluency even as early as the second grade, children's negative feelings and math anxiety should be identified and addressed from the early primary school years.

Keywords:

Math anxiety

Mathematical skills

Primary school

Math anxiety assessment

Introduction

Math anxiety among primary school children

Math anxiety is usually defined as feelings of tension and anxiety stemming from the manipulation of numbers and solving mathematical problems (Richardson & Suinn, 1972). Previous studies suggest that different types or contexts of mathematical activities can trigger math anxiety—for example, numeric processing (Richardson & Suinn, 1972; Suinn, Taylor, & Edwards, 1988; Wu, Barth, Amin, Malcarne, & Menon, 2012), executing math tasks in front of classmates and errors in math (Jameson, 2013). Although math and test anxiety are correlated (Williams, 1994), they are separable constructs (Dew, Galassi, & Galassi, 1984; Hopko, Mahadeva, Bare, & Hunt, 2003). In his meta-analysis, Hembree (1990) found that math anxiety and test anxiety have only 37% common variance, suggesting that math anxiety comprises a general negative reaction toward mathematics, including not only testing but also math classes and homework.

Most existing studies of math anxiety have involved adults or adolescents, and few studies have focused on young children. However, there is increasing evidence that children report and demonstrate math anxiety as early as the first grade (Ma, 1999; Ramirez, Gunderson, Levine, & Beilock, 2013). Little is known about the developmental course, but some studies suggest that the level of math anxiety increases with age (Dowker, Bennett, & Smith, 2012; Gierl & Bisanz, 1995; Krinzinger, Kaufmann, & Willmes, 2009).

Previous studies have usually found no gender differences in math anxiety among young children (Dowker et al., 2012; Erturan & Jansen, 2015; Harari, Vucovic, & Bailey, 2013; Wu, Willcutt, Escovar, & Menon, 2014), but at a later point during their school career, females seem to be more anxious about mathematics than males (e.g. Else-Quest, Hyde, & Linn, 2010; Hembree, 1990; Kyttälä & Björn, 2010). It remains unclear, however, at which point during their development these differences appear. In sum, more detailed knowledge about the early manifestation of math anxiety and possible gender differences is needed if we are to find ways of circumventing the development of negative attitudes and behavioural responses toward mathematics at an early stage.

Math anxiety and its relationship to performance

It has been suggested that anxiety has an online effect on math performance by straining working memory (Ashcraft & Kirk, 2001) as well as a long-term effect, which leads to the avoidance of situations involving mathematics (Ashcraft & Moore, 2009; Hembree, 1990). This stance is supported by findings showing that math anxiety is related to lower performance in mathematics (e.g. Hembree, 1990; Ma, 1999). This relationship has been found among adolescents and adults in many mathematical subskills, including basic number skills such as counting (Maloney, Risko, Ansari, & Fugelsang, 2010) and magnitude comparison (Ashcraft, 2002; Maloney et al., 2010; Maloney, Ansari, & Fugelsang, 2011) as well as more complex arithmetical operations (Ashcraft & Faust, 1994). However, among primary school children, the relationship between math anxiety and math performance remains unclear. The findings from previous studies have been contradictory, with some studies suggesting that primary school children's math anxiety is not related to performance (Dowker et al., 2012; Haase et al., 2012; Krinzinger et al., 2007; Krinzinger et al., 2009; Thomas & Dowker, 2000; Wood et al., 2012), while others suggest that math anxiety is negatively correlated to performance even at that age (Harari et al., 2013; Jameson, 2013; Vucovic, Kieffer, Bailey, & Harari, 2013; Wu et al., 2012; Wu et al., 2014).

The contradictory findings of previous studies concerning the relation between anxiety and performance in math lead to the question of whether the variation in operationalizing math anxiety might be related to the variation in research findings. To better understand the above-mentioned contradictory findings, we reviewed how earlier studies operationalized math anxiety. From the detailed description of the measures in Table 1, we observe that some studies (Dowker et al., 2012; Haase et al., 2012; Krinzinger et al., 2007; Krinzinger et al., 2009; Wood et al., 2012) measured anxiety or unhappiness with reference to *being unable to do something* in mathematics—in other words, *anxiety about failure in mathematics*. Interestingly, none of these studies have found a relationship between math anxiety and math performance.

Other studies (Ramirez et al., 2013; Wu et al., 2012; Wu et al., 2014) have focused on *anxiety in math-related situations in general* (Table 1). In these studies, the children were asked how anxious they felt when they had to solve mathematical problems or when they were in other situations related to mathematics. In these questions, it was not defined whether the expected result was success or failure. The measures used in these studies are described in Table 1. These studies (Ramirez et al., 2013; Wu et al., 2012; Wu et al., 2014) reveal a connection between math anxiety and performance. Thus, it seems that *anxiety in math-related situations* is specifically related to perfomance in mathematics in contrast to *anxiety about failure in mathematics*. However, because these two dimensions have been examined mainly in separate studies, and thus in separate samples, this conclusion is tentative. Only few studies (Harari et al., 2013; Jameson, 2013; Vucovic et al. 2013) have simultaneously measured both anxiety about failure in mathematics and anxiety in math-related situations and they found an association between anxiety and performance in math. However, because these studies do not analyse or report on anxiety in math-related situations and anxiety about failure in math separately, they do not reveal whether these aspects of math anxiety are differently related to math skill.

Insert Table 1 about here.

The present study

Our aim was to examine math anxiety and its relationship with basic arithmetic skills in second- to fifth-grade students, as knowledge about math anxiety in this age group is scarce. The study is based on a sample of Finnish primary school children. Our first aim was to examine the prevalence of math anxiety among primary school children from second to fifth grade and to explore whether there were any gender or grade-level differences. Second, we examined whether the two ways of operationalizing math anxiety—anxiety about failure in mathematics and anxiety in math-related situations—were two empirically separable aspects of math anxiety. Third, we aimed to study whether the suggested aspects of math anxiety were differently related to basic arihtmetic skills and whether the relationship between math anxiety factors and basic arithmetic skills was independent of gender and grade level. Based on the results of previous studies (e.g. Dowker et al., 2012; Wu et al., 2012), anxiety about math-related situations could be related to basic arithmetic skills, whereas anxiety about failure might not be. However, because there are no previous studies examining these two aspects of math anxiety in the same sample, a strong hypothesis cannot be stated.

Method

Participants

Our study is based on data from the first assessment of a longitudinal study focusing on the development of self-beliefs and academic skills in children. The data for our study were collected in November 2013. A total of 20 schools in urban and semi-urban areas in Finland volunteered to participate, from which the classes were recruited for the study. Written consent was obtained from the guardians of the children, and the research procedure was evaluated by the university ethical committee.

The sample consists of 1,327 children (48.08% girls) from grades 2 to 5. Of these children, 178 (13.41%) were second graders (*M* = 8.35 years, *SD* = 0.32), 471 (35.49%) were third graders (*M* = 9.34 years; *SD* = 0.31), 383 (28.86%) were fourth graders (*M* = 10.40 years; *SD* = 0.35) and 295 (22.23%) were fifth graders (*M* = 11.39 years; *SD* = 0.36).

Complete data for the measures of math anxiety and basic arithmetic skills were available for 85.2% of the sample. The highest percentage of missing data (6.9% of the children) was obtained for three items assessing negative affective reactions in math-related situations mainly due to absence from school.

Procedure

The assessments were carried out by trained research assisstants over two school days as part of a more extensive questionnaire. The assessment was structured in a way so that none of the math anxiety questions were presented immediately after the basic arithmetic skills tasks.

Measures

Math anxiety

Anxiety about failure in mathematics was assessed with items from the Math Anxiety Questionnaire (MAQ) (Thomas & Dowker, 2000), which were translated into Finnish in cooperation with one of the authors. The original version of the MAQ consists of four different types of questions (Krinzinger et al., 2007): liking mathematics, mathematics self-evaluation, unhappiness about poor performance and math anxiety with regard to several different situations involving mathematics. We used two questions to assess anxiety: how anxious or calm the participant would be if she/he was unable to do something targeting mathematics in general as well as targeting mental calculations. We also included a question targeting math homework. Altogether, anxiety about failure was assessed using three items (Table 2). Children responded on a 5-point scale, which was visualized with pictures of faces varying from very anxious (rated as 5) to very calm (rated as 1).

Anxiety in math-related situations was assessed with three statements on anxiety or tension arousal in situations involving mathematics (Table 2). These items were adopted from a subscale initially designed for measuring affective and physical state sources of self-efficacy, which was based closely on the ideas of Usher and Pajares (2008). The participants responded to each statement using a 7-point scale (1 = false, 2–3 = mostly false, 4 = neither true nor false, 5–6 = mostly true, 7 = true). As most of the children responded 1 = false to the items (51.30–69.38% of children, depending on the item), the categories were combined as follows: 1 = 1, 2 = 2–4, 3 = 5–7.

Basic arithmetic skills

Basic arithmetic skills were assessed using three time-limited paper-and-pencil group tests. Both the two-minute addition fluency test (Koponen & Mononen, 2010a) and the two-minute subtraction fluency test (Koponen & Mononen, 2010b) consist of 60 simple tasks—the addition test with addends smaller than 10 and the subtraction test with results in the range of one to nine. The three-minute basic arithmetic test (Aunola & Räsänen, 2007) consists of 30 addition, subtraction, division and multiplication items. The scores of these tasks were standardized within each grade level.

Statistical analysis

Spearman correlations between the observed variables were calculated using IBM SPSS Statistics (version 22). To compare the distribution of participants reporting anxiety among girls and boys and different grade levels, a cross-tabulation and χ^2 test with adjusted standardized residuals (ASR) were used. For this comparison, we split the sample into two groups: those who reported anxiety (responding to anxiety statements by "mostly true" or "true" or choosing an anxious or very anxious pictorial face) and those who did not. The groups were then cross-tabulated against gender and grade level. ASR indicates the direction and size of the deviation of the observed frequencies in each cell from those expected. An ASR greater than 1.96 indicates that, in the cell in question, there are statistically significantly (at $p < .05$) more children than expected by chance.

The main analyses were conducted using the Mplus software, version 7.3 (Muthén & Muthén, 1998–2012). As some of the variables were categorical, we used weighted least square parameter estimates with a diagonal weight matrix with standard errors (WLSMV) estimator for the analyses (Muthén, 1984). As the missing data were considered random, the full information maximum likelihood procedure (FIML) was used to estimate the parameters. The FIML uses all information in the data without imputing missing values.

The aspects of math anxiety and the structure basic arithmetic skills were investigated using confirmatory factor analysis (CFA). We constructed the hypothetical two-factor model of math anxiety in which items MA1–MA3 (Table 2) were supposed to load on the "Anxiety about failure" factor and MA4–MA6 on the "Anxiety in math-related situations" factor. The two factors were set to correlate with each other. In addition, a competing one-factor model was constructed to confirm the superiority of the two-factorial model of math anxiety.

We evaluated the overall goodness-of-fit of the CFA models using the χ^2 test, the root mean square error of approximation test (RMSEA; Steiger, 1990), the comparative fit index

(CFI; Bentler, 1990) and the Tucker-Lewis index (TLI; Hu & Bentler, 1999). For a good model fit, the *p*-value of the χ^2 test should be greater than .05, the RMSEA less than .06 and the CFI and TLI greater than .95 (Hu & Bentler, 1999).

We compared the nested theoretical models of math anxiety (i.e. two factors vs. one factor) using the χ^2 difference test (Asparouhov & Muthen, 2006). A significant χ^2 difference test denotes that the model with fewer degrees of freedom (i.e. fewer constraints) fits the data better, whereas a non-significant difference test denotes that the simpler model with greater degrees of freedom (i.e. more constraints) is not significantly worse than the model with fewer degrees of freedom.

After choosing the best math anxiety model, the invariance of the math anxiety model separately across genders and grade levels was examined using multigroup invariance comparison tests. The group invariance was tested by comparing the fit of the baseline model (i.e. the parameters of the model were freely estimated in all groups under investigation) to that of the constrained model (i.e. the parameters were constrained to be equal across the groups) using the χ^2 difference test (Satorra & Bentler, 2001).

Finally, we explored the associations between the dimensions of math anxiety and basic arithmetic skills. Before the examination, the factorial structure of basic arithmetic skills was checked using CFA and the Satorra-Bentler scaled χ^2 difference test. The relationship between the math anxiety factors and basic arihtmetic skills were examined using structural equation modeling (SEM). The goodness-of-fit of the SEM model was evaluated using the same overall indices as in the math anxiety models.

Results

The prevalence of math anxiety

The descriptive statistics for the observed variables are reported in Table 2 and the correlations between the observed variables in tables 3 and 4. As shown in Table 5, the proportion of participants reporting anxiety varied from 8.8 to 27.4%, depending on the math anxiety variable. More girls relative to boys reported anxiety about answering teachers' questions in math class, and in most of the items, there were relatively more second graders and fewer fifth graders reporting anxiety (Table 5).

Insert tables 2–5 here.

The two ways of operationalizing math anxiety

The two-factor model of math anxiety fit the data well ($\chi^2(8) = 18.74$, $p <.05$; RMSEA = .03, CFI and TLI = 1.00), whereas the one-factor model did not ($\chi^2(9) = 1807.80$, $p < .001$; RMSEA =.39, CFI = .69; TLI = .49). Moreover, the χ^2 difference test confirmed that the best approximation of the data was achieved with the two-factorial model ($\chi^2(1) = 883.54$; $p < .001$). All loadings and residual variances in the two-factor model were statistically significant and positive (Figure 1). A significant correlation was found between the two math anxiety factors: *Anxiety about failure* and *Anxiety about math-related situations*. The factor loadings and thresholds of the observed variables of the two-factorial math anxiety model were invariant across genders and all grade levels (Table 6).

Insert Table 6 here.

Math anxiety in relation to basic arithmetic skills

Before examining the associations between the math anxiety factors and basic arithmetic skills, the factorial structure of arithmetic skills was checked and found to be satisfactory. The final basic arithmetic skill model was a saturated model ($\chi^2(0) = 0$, $p = .000$; RMSEA =

.00, CFI and TLI = 1.00; SRMR = .00). The factor loadings were high (between .78 and .94), and the residual variances of the observed variables were positive and statistically significant. The basic arithmetic skills model was fully invariant between genders and grade levels (Table 7). As the arithmetic measures were standardized within grade levels, the test of between-grades invariance of the intercepts was not relevant.

Insert Figure 1 about here.

The association between math anxiety and basic arithmetic skills was then examined. The estimated model and its fit indices are presented in Figure 1. According to the χ^2 difference test ($\chi^2(1) = 15.80$; $p < .001$), a high level of *Anxiety about math-related situations* was more strongly associated with low basic arithmetic skills than a high level of *Anxiety about failure*. The relationships between the math anxiety factors and the basic arithmetic skills factor were similar between genders ($\chi^2(2) = 2.28$; $p = .32$) and grade levels ($\chi^2(6) = 2.89$; $p = .82$).

Insert Table 6 here.

Since the math anxiety factors correlated moderately, further analyses were needed to ascertain which part of the variance of math anxiety is related to basic arithmetic skills: the unique variance of *Anxiety about math-related situations* and/or the variance common to both factors. To clarify this issue, we further elaborated the model presented in Figure 1. First, we examined whether the unique variance of *Anxiety about failure* and the variance shared by *Anxiety about failure* and *Anxiety about math-related situations* were related to basic arithmetic skills (Figure 2). Two specific factors were created: one factor captured the whole variance of *Anxiety about math-related situations*, including that part of the variance of *Anxiety about failure* which was common to both factors. The other specific factor captured the residual variance of *Anxiety about failure* (i.e. the unique variance of this factor). As shown in Figure 2, *Anxiety about math-related situations* (including its common variance with the *Anxiety about failure* factor) was more strongly related to basic arithmetic skills than the unique variance of *Anxiety about failure* ($\chi^2(1) = 16.37$; $p < .001$).

Insert Figure 2 about here.

Second, we examined whether the unique variance of *Anxiety about math-related situations* and the variance shared by both factors were related to basic arithmetic skills (Figure 3). Again, two specific factors were formed: one specific factor captured the whole variance of *Anxiety about failure*, including that part of the variance of the *Anxiety about math-related situations* factor which was common to *Anxiety about failure*. The other specific factor captured the residual variance of *Anxiety about math-related situations* (i.e. the unique variance of this factor). The unique variance of the *Anxiety about math-related situations* factor was as strongly related to basic arithmetic skills as the *Anxiety about failure* factor (including the common variance of the two factors), $\chi^2(1) = .09$; $p = .77$.

Insert Figure 3 about here.

Discussion

Our study aimed to investigate the manifestation of math anxiety among primary school children. The results showed that children report math anxiety as early as the second grade. Around one-third of all children reported anxiety about being unable to do a mental calculation task, math homework or something in math in general. About one-fifth of the children reported anxiety about having to answer teachers' questions in math class, and one tenth reported anxiety about starting to do math or tension about having to do math. More girls relative to boys reported anxiety about having to answer teachers' questions in math class. Anxiety about math-related situations was most common in second grade and least common in fifth grade.

We also investigated different aspects of math anxiety which have been used in previous studies and their association with basic arithmetic skills. Our results suggest that anxiety about math-related situations and anxiety about failure in mathematics are separable but correlated. Both of these aspects were negatively related to basic arithmetic skills, the former more strongly than the latter. When both factors were included in the same model, anxiety about math-related situations continued to demonstrate a unique association with basic arithmetic skills, above and beyond its shared variance with anxiety about failure. In contrast, anxiety about failure was only weakly uniquely related to arithmetic skills after taking into account its shared variance with anxiety about math-related situations. The model was similar among girls and boys and grade levels, and neither gender nor grade level affected the relationship between math anxiety and basic arithmetic skills.

There were no gender differences in anxiety about failure, which is consistent with previous research on primary school children (Dowker et al., 2012). There were relatively more girls than boys reporting anxiety about having to answer teachers' questions in math class, and the mean of anxiety about math-related situations was higher among girls than boys. This result is in line with studies of adolescents and adults indicating greater math anxiety in females than males (e.g. Else-Quest et al., 2010; Hembree, 1990). One possible explanation for the higher math anxiety in females might be the *stereotype threat*: females might be at risk of the stereotypical assumption that they are not as good at math as males (Steele, 1997). It has been suggested that the gender-based stereotypical beliefs of adults affect achievement differently between girls and boys (Jacobs, Davis-Kean, Bleeker, Eccles, & Malanchuk, 2005) and that children endorse the stereotype that "math is for boys" as early as in second grade (Cvencek, Meltzoff, & Greenwald, 2011). However, general anxiety is more common among girls than boys (e.g. Simonoff et al., 1997), so conclusions of gender differences should be made with caution. Children's stereotypical beliefs and relationship with math anxiety and achievement should be further explored, particularly in relation to culture and society, since stereotypical gender-based expressions are cross-culturally inconsistent (Dowker, 2005; Passolunghi, Rueda Ferreira, & Tomasetto, 2014).

The existence of math anxiety in early grades has also been noted in previous research (Ma, 1999; Ramirez et al., 2013). However, our study suggests that grade level has an effect on the proportion of participants who report anxiety in primary school. There were some differences between grade levels in the prevalence of anxiety about failure: there were relatively more fourth graders than expected reporting anxiety about being unable to do a mental calculation or something in mathematics, in general, and fewer fifth graders than expected reporting anxiety about being unable to do mental calculations. A substantial number of participants from all grades reported anxiety about being unable to do math homework.

In the items assessing anxiety about math-related situations, in general, the grade differences were more notable: there were more second graders and fewer fifth graders than expected reporting anxiety in all these items, and over 15% of second graders but less than 5% of fifth graders reported anxiety about starting to do math or tension about having to do math. Moreover, there were more third graders than expected reporting anxiety about having to answer teachers' questions. This result—representing a higher proportion of younger and a lower proportion of older children reporting math anxiety—is interesting, considering previous research suggesting that anxiety increases with age (Dowker et al., 2012; Gierl & Bisanz, 1995). Young children's stronger negative affective reactions in math-related situations might be elevated by the fact that they are still adjusting to school and have not yet developed adequate coping strategies for facing the difficulties of learning mathematics. Another possible explanation is that young children tend to use the extremes of the scale. However, in this case, the same kind of effect should have been found in anxiety about failure, which was not the case. It is also possible that some features of the Finnish school support system or mathematics education, such as the relatively extensively offered part-time special education (Kivirauma & Ruoho, 2007), lead to a reduction in mathematics anxiety over time. As this study was cross-sectional, no firm conclusions can be made regarding causal relationships or the development of math anxiety. More diverse research on math anxiety is needed.

Our results on the different kinds of relationships between math anxiety and arithmetic fluency support the assumption that varying operationalizations of math anxiety might explain the contradictory results in previous math anxiety research among primary school children (Dowker et al., 2012; Haase et al., 2012; Krinzinger et al., 2007; Krinzinger et al., 2009; Vucovic et al., 2013; Wood et al., 2012; Wu et al., 2012; Wu et al., 2014). In our study, anxiety about failure in mathematics was close to normally distributed among all age groups. Further, roughly one-third of our participants reported anxiety about failure. Anxiety about math-related situations was more dichotomic by distribution, and its prevalence in the whole sample varied from nine to 19%, depending on the item.

One possible explanation for the finding that anxiety about math-related situations was more related to basic arithmetic skills than anxiety about failure might be that the anxiety experienced by low- and high-achieving students stems from different kinds of experiences. One can assume that children with low basic skills in mathematics become anxious in various kinds of situations involving mathematics and calculations because of their earlier failures and negative experiences. By contrast, children across all skill levels can feel anxious about being unable to do something. Further, "concern over mistakes" has also been seen as a dimension of perfectionism (Frost, Marten, Lahart, & Rosenblate, 1990), which is also present among gifted students (Parker, 1997) and may, at least in its lighter forms, even stimulate healthy needs for achievement (Parker, 2000; Wang et al. 2015). However, it has been shown that among gifted students, concern over mistakes is also positively correlated with math anxiety (Tsui & Mazzocco, 2006).

Regarding the age group of primary school children, only a few studies (Harari et al., 2013; Jameson, 2013) have simultaneously assessed both anxiety about math-related situations and anxiety about failure in mathematics. Usually, either one or the other of these two ways of operationalizing has been used (Dowker et al., 2012; Haase et al., 2012; Krinzinger et al., 2007; Krinzinger et al., 2009; Vucovic et al., 2013; Wood et al., 2012; Wu et al., 2012; Wu et al., 2014). Since they seem to tap into different kinds of anxiety, at least from the second grade onward, this should be taken into consideration in measuring math anxiety.

Some limitations of the study should be noted. Our study supports the stance that more attention should be paid to understanding the structure and dimensions of math anxiety. As we focused on only two aspects of anxiety, future research is needed to better understand how different constructs introduced in the math anxiety literature are related to each other and to math performance as well as what the effect of contextual factors is (e.g. test or social situation). Different kinds of math anxiety dimensions have been found in previous studies, for example "test anxiety", "calculation anxiety" and "social anxiety" (e.g. Richardson & Suinn, 1972; Gierl & Bisanz, 1995) and, on the other hand, affective and cognitive dimensions of math anxiety, specifically "negative affective reactions" and "worry about performance" (e.g. Wigfield & Meece, 1988). Anxiety about failure and anxiety about math-related situations are, to some extent, overlapping with these different dimensions. Anxiety about failure is somewhat similar to "worry about performance"; however, they are not necessarily equal constructs. In the items relating to anxiety about failure, children were not asked whether they were worried about or afraid of failure. Instead, they were asked to imagine how anxious they would be if they noticed they were unable to do something.

Becoming anxious *when a failure occurs* does not necessarily mean being worried or afraid of it *beforehand*.

We assessed only basic arithmetic skills, and it is worth considering that mathematics is not a single entity but rather consists of many components (see, e.g., Dowker, 2005). In future studies, the relationships between math anxiety and achievement in a wider range of mathematical skills should be explored. Moreover, we used only timed measures. To understand the effects of math anxiety on mathematical performance more comprehensively, math anxiety should be assessed using both timed and untimed measures (Ashcraft & Moore, 2009). There are some limitations of group tests that should also be considered with regard to the present findings. For example, compared to individual assessments, in group tests it is more difficult to monitor and control for a correct understanding of the tasks or problems in maintaining attention. Further, our math anxiety measure consisted of a rather limited number of items. Nevertheless, among adolescents and young adults, short scales with three items and even single-item measures have been found to be reliable in assessing domain-specific academic anxieties and math anxiety (Gogol et al., 2014; Núñez-Peña, Guilera, & Suárez-Pellicioni, 2014).

In future studies, the effect of operationalizing math anxiety on the relationship between math anxiety and achievement, as well as the development of math anxiety, should be explored longitudinally and cross-culturally. The present study, consistent with previous research, shows that anxiety about math-related situations is related to arithmetic fluency. However, the causal connection between anxiety and achievement among children remains unexplored. Further knowledge about the development of math anxiety is needed to determine whether it is linear or whether there are some points during the educational career that propel an increase in the risk of math anxiety. We lack an understanding of the early development of negative math-related feelings and math anxiety. However, since math anxiety is reported as early as the second grade, it is possible that some children become anxious about mathematics during their first year at school or even earlier.

Conclusion

Consistent with previous research (Ma, 1999; Ramirez et al., 2013), the current study suggests that even in a country in which math anxiety has been reported to be low compared to many other countries (Lee, 2009), it is present in children as early as in the second grade. Thus, it is important to investigate mathematics anxiety even in young children and to gain a better understanding of its origins. In particular, a key focus should be on anxiety about math-related situations, because it seems to be directly related to arithmetic fluency. Negative math-related emotions should be identified and addressed at school at an early stage so as to prevent negative outcomes in skills development. Math anxiety should also assume great significance when planning mathematics education in primary school.

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Table 1.
Previous Research Examining the Relationship between Math Anxiety and Achievement in Children below Grade 6

Study/studies	Measure	The type of math anxiety measured	Relation to achievement?
Dowker *et al*., 2012; Haase *et al*., 2012; Krinzinger *et al*., 2007; Krinzinger *et al*., 2009; Wood *et al*., 2012	MAQ (Thomas & Dowker, 2000); Two components (Krinzinger *et al*., 2007): evalution of mathematics and math anxiety. The first component consists of items relating to self-rating and liking math. The math anxiety component consists of questions "*How worried/unhappy would you be if you did badly in. . .*" targeted at different types of math tasks (*math in general, written sums, mental sums, easy and difficult maths, math tests, understanding the teacher*).	Anxiety about failure	No
Wu *et al*., 2012; Wu *et al*., 2014	Scale for Early Mathematics Anxiety – created based on MARS (Richardson & Suinn, 1972) and MARS -E, X items measuring nervousness when answering math-related questions (e.g., *"Is this right? 9 + 7 = 18")* or being in math-related situations (e.g., "*You are in math class and your teacher is about to teach something new*").	Anxiety in math-related situations	Yes
Harari *et al*., 2013	The Mathematics Anxiety Scale for Young Children – questions derived from MARS-E (Suinn *et al*., 1988); the Mathematics Anxiety Questionnaire (Wigfield & Meece, 1988) consists of 12 items measuring numerical confidence (e.g., "*Figuring out if I have enough money to buy cookies and a drink is fun*"), worry (e.g., "*I get nervous about making a mistake in math*") and negative reactions (e.g., "*Math gives me a stomachache*").	Anxiety about failure and anxiety in math-related situations	Numerical confidence and negative reactions were related to achievement; worry was not.
Jameson, 2013	The Children's Anxiety in Math Scale consists of 16 items measuring general math anxiety (e.g., "*Thinking about working on math in class makes me feel. . .*"), math performance anxiety (e.g., "*If I have to add up numbers on the blackboard in front of the class, I feel. . .*") and math error anxiety (e.g., "*When the teacher gives the class a math problem I don't understand, I feel. . .*").	Anxiety about failure and anxiety in math-related situations	Yes, but the relationship between the the two types of anxiety is not examined separately.
Ramirez *et al*., 2013	The Child Math Anxiety Questionnaire (CMAQ; Ramirez *et al*., 2013), adapted from MARS-E., asked children how they feel when they have to solve a math task or problem (e.g., "*There are 13 ducks in the water, there are 6 ducks on land, how many ducks are there in all?*") or when they are in math-related situations ("*being called by teacher to explain a math problem on the board*").	Anxiety in math-related situations	Only for children with high working memory
Vucovic *et al*., 2013	Items adapted from MARS-E (Suinn *et al*., 1988) and the Mathematics Anxiety Questionnaire (Wigfield & Meece, 1988): 12 items assessing negative reactions and worry, items with positive valence (e.g., "*I like being called on in math*") and negative valence ("*I get nervous about making a mistake in math").*	Anxiety about failure and anxiety in math-related situations	Yes, but the relationship between the dimensions is not examined separately.

Table 2.
Descriptive Statistics of Observed Variables

	Gender		Grade			
	Girls	Boys	2	3	4	5
Study variables	*M* (*sd*)	*M* (*sd*)	*M* (*sd*)	*M* (*sd*)	*M* (*sd*)	*M* (*sd*)
Math anxiety						
How anxious or calm would you be if you were unable to do something in mathematics? (MA1)[1]	2.95 (1.09)	2.94 (1.17)	2.83 (1.23)	2.97 (1.14)	3.05 (1.15)	2.84 (1.01)
How anxious or calm would you be if you were unable to do a mental calculation task? (MA2) [1]	3.09 (1.10)	3.03 (1.19)	3.14 (1.33)	3.05 (1.18)	3.13 (1.16)	2.93 (0.98)
How anxious or calm would you be if you were unable to do mathematics homework? (MA3)[1]	3.08 (1.17)	3.01 (1.26)	3.08 (1.39)	3.00 (1.22)	3.09 (1.21)	3.02 (1.10)
I get anxious when I have to answer the teacher's questions in math class. (MA4) [2]	2.72 (2.05)	2.39 (1.98)	2.71 (2.27)	2.71 (2.13)	2.46 (1.89)	2.32 (1.79)
I get anxious when I start doing math. (MA5)[2]	1.98 (1.73)	1.75 (1.52)	2.16 (2.00)	1.99 (1.78)	1.82 (1.54)	1.53 (1.13)
I feel tension when I have to do math. (MA6) [2]	1.94 (1.60)	1.82 (1.60)	2.18 (1.99)	2.00 (1.70)	1.79 (1.47)	1.63 (1.25)
Basic arithmetic skills						
Addition Fluency Test score (ARI1) (observed min 0; max 101)	32.73 (13.15)	35.27 (15.47)	22.55 (9.00)	28.82 (9.90)	36.74 (13.18)	46.00 (15.24)
Subtraction Fluency Test score (ARI2) (observed min 2; max 87)	27.92 (11.57)	29.46 (13.69)	17.88 (8.41)	25.79 (9.49)	30.89 (11.85)	37.24 (14.01)
The three-minute Basic Arithmetic Test score (ARI3) (observed min 0; max 27)	14.74 (4.84)	15.16 (5.31)	9.88 (4.27)	14.00 (4.54)	15.86 (4.36)	18.49 (4.13)

Note. [1]scale from 1 to 5. [2]scale from 1 to 7.

Table 3.
Spearman Correlations between the Observed Variables at All Grade Levels

Variable	MA1	MA2	MA3	MA4	MA5	MA6	ARI1	ARI2
Grade 2								
MA1	1							
MA2	.62**	1						
MA3	.57**	.64**	1					
MA4	.23**	.27**	.25**	1				
MA5	.18*	.26*	.27**	.43**	1			
MA6	.10	.17*	.22**	.41**	.58**	1		
ARI1	−.09	−.10	−.07	−.10	−.16*	−.15	1	
ARI2	−.09	–.11	−.14	−.16*	−.25**	−.23**	.77**	1
ARI3	−.05	.01	−.06	−.18*	−.25**	−.24**	.66**	.71**
Grade 3								
MA1	1							
MA2	.52**	1						
MA3	.56**	.62**	1					
MA4	.20**	.20**	.18**	1				
MA5	.20**	.16**	.13**	.50**	1			
MA6	.12*	.13**	.10**	.45**	.49**	1		
ARI1	–.10*	-.03	-.06	-.08	−.11**	−.06	1	
ARI2	−.20**	−.10*	−.17**	−.15**	−.16**	−.07	.73**	1
ARI3	−.15**	−.11*	−.15**	−.15**	−.20**	−.14**	.64**	.74**
Grade 4								
MA1	1							
MA2	.62**	1						
MA3	.62**	.62**	1					
MA4	.20**	.27**	.24**	1				
MA5	.17**	.18**	.23**	.49**	1			
MA6	.17**	.19**	.20**	.44**	.53**	1		
ARI1	−.12*	−.14**	−.14*	−.24**	−.19**	−.16**	1	
ARI2	−.16**	−.21**	−.16**	−.23**	−.22**	−.17**	.82**	1
ARI3	−.16**	−.19**	−.16**	−.25**	−.20**	−.12*	.70**	.73**
Grade 5								
MA1	1							
MA2	.65**	1						
MA3	.57**	.57**	1					
MA4	.27**	.24**	.21**	1				
MA5	.26**	.19**	.23**	.38**	1			
MA6	.24**	.11*	.14*	.42**	.52**	1		
ARI1	−.05	−.14**	−.11	−.25**	−.09	−.05	1	
ARI2	−.14*	−.18**	−.15*	−.23**	−.11	−.13	.80**	1
ARI3	−.18**	−.22**	−.21**	−.20**	−.14*	−.08	.68**	.76**

Note. MA1, MA2, MA3, MA4, MA5, MA6 = math anxiety items; ARI1, ARI2, ARI3 = scores of arithmetic measures .
**p* < .05, ***p* < .01, ****p* < .001.

Table 4.

Spearman Correlations between the Observed Variables in Girls and Boys. Correlations for girls are presented above the diagonal, and correlations for boys are presented below the diagonal.

Girls Boys	MA1	MA2	MA3	MA4	MA5	MA6	ARI1	ARI2	MA1
MA1	–	.62**	.59**	.21**	.21**	.20**	-.14**	-.14**	-.16**
MA2	.57**	–	.61**	.24**	.21**	.20**	-.15**	-.17**	-.18**
MA3	.57**	.61**	–	.22**	.23**	.22**	-.16**	-.17**	-.20**
MA4	.24**	.23**	.20**	–	.44**	.41**	-.09*	-.12**	-.13**
MA5	.18**	.17**	.18**	.48**	–	.53**	-.20**	-.22**	-.23**
MA6	.12**	.11**	.10*	.45**	.52**	–	-.13**	-.13**	-.13**
ARI1	-.04	-.05	-.02	-.18**	-.11**	-.11**	–	.84**	.78**
ARI2	-.12**	-.11**	-.10*	-.19**	-.15**	-.13**	.83**	–	.81**
ARI3	-.10*	-.10*	-.08*	-.18**	-.17**	-.14**	.75**	.81**	–

Note. MA1, MA2, MA3, MA4, MA5, MA6 = math anxiety items; ARI1, ARI2, ARI3 = scores of arithmetic measures.

**p* < .05, ***p* < .01, ****p* < .001.

Table 5.
The Proportions of Participants Reporting Anxiety among Girls and Boys and Different Grade Levels: χ² Test with Adjusted Standardized Residuals

		Gender			Grade				
Math anxiety item	All %	Girls %	Boys %	χ^2 (*df*)	2 %	3 %	4 %	5 %	χ^2 (*df*)
How anxious or calm would you be if you were unable to do something in mathematics? (MA1)[1]	27.44	28.40	26.48	0.60 (1)	24.27 n.s	26.16 n.s.	33.78 3.2	23.16 n.s.	11.34* (3)
How anxious or calm would you be if you were unable to do a mental calculation task? (MA2)[1]	33.51	34.58	32.63	0.55 (1)	39.53 n.s.	33.26 n.s.	37.90 2.1	24.47 -3.6	16.38** (3)
How anxious or calm would you be if you were unable to do mathematics homework? (MA3)[1]	33.85	34.96	32.78	0.68 (1)	35.26 n.s.	32.52 n.s.	36.39 n.s.	31.80 n.s.	2.11 (3)
I get anxious when I have to answer the teacher's questions in math class. (MA4)[2]	18.99	21.04	17.18	3.04* (1)	25.44 2.3	22.05 2.0	16.16 n.s.	14.08 -2.4	13.60** (3)
I get anxious when I start doing math. (MA5) [2]	9.23	10.66	8.04	2.55 (1)	17.16 3.8	11.41 n.s.	7.54 n.s.	3.51 -3.8	27.40*** (3)
I feel tension when I have to do math. (MA6)[2]	8.81	8.82	8.78	0.00 (1)	15.38 3.3	10.44 n.s.	7.20 n.s.	4.24 -3.1	19.15*** (3)

Note. Statistically significant adjusted standardized residuals (absolute value > 1.96) reported below the percentages of the participants on each grade level. **p* < .05, ***p* < .01, ****p* < .001. Reporting anxiety = [1]responding with an anxious or very anxious pictorial face; [2]responding by "mostly true" or "true".

Table 6.
Invariance Comparison for the Math Anxiety Model

Model	Model $\chi^2(df)$	χ^2 difference test	
		$\chi^2(df)$	p
Invariance comparison between genders			
Unconstrained model	26.12 (16)	–	–
Tresholds of observed variables set to be equal	39.84 (26)	13.68 (4)	.19
Factor loadings and tresholds of observed variables set to be equal	40.84 (30)	1.82 (4)	.77
Mean of anxiety about failure factor, factor loadings and tresholds set to be equal	36.51 (31)	.71 (1)	.40
Means of both anxiety factors, factor loadings and tresholds set to be equal	46.87 (32)	8.42 (1)	.00
Factor variances, means, loadings and tresholds of observed varibles set to be equal	52.12 (34)	4.49 (2)	.11
Factor covariance, variances, means, loadings and tresholds of observed variables set to be equal	50.70 (35)	.64 (1)	.42
Invariance comparison between grade levels			
Unconstrained model	46.54 (32)	–	–
Tresholds of observed variables set to be equal	91.01 (68)	47.93 (36)	.09
Factor loadings and tresholds of observed variables set to be equal	106.44 (74)	13.45 (12)	.34
Mean of anxiety about failure factor, factor loadings and tresholds set to be equal	101.65 (77)	4.36 (3)	.22
Means of both anxiety factors, factor loadings and tresholds set to be equal	104.99 (80)	3.77 (3)	.29
Variance of anxiety about failure factor, means of both anxiety factors, factor loadings and tresholds set to be equal	139.84 (83)	17.02 (3)	.00
Factor variances, means, loadings and tresholds of observed varibles set to be equal	175.64 (86)	23.17 (3)	.00
Factor covariance, variances, means, loadings and tresholds of observed variables set to be equal	167.63 (89)	1.51 (3)	.68

Note. χ^2 difference test = model compared to previous, less constrained model.

Table 7.
Invariance Comparison for the Basic Arithmetic Skills Model

Model	Model fit indices		χ² difference test		
	$\chi^2(df)$	*sc*	$\chi^2(df)$	*sc*	*p*
Invariance comparison between genders					
Unconstrained model	0.00 (0)	1.00	–	–	–
Factor loadings set to be equal	1.86 (2)	1.16	1.86 (2)	1.16	.39
Factor loadings and intercepts of observed variables set to be equal	7.19 (4)	1.06	5.69 (2)	.96	.06
Invariance comparison between grade levels					
Unconstrained model	0.00 (0)	1.00	–	–	–
Factor loadings set to be equal	8.11 (6)	1.14	8.11 (6)	1.14	.23

Note. *sc* = scaling correction; χ^2 difference test = model compared to previous, less constrained model.

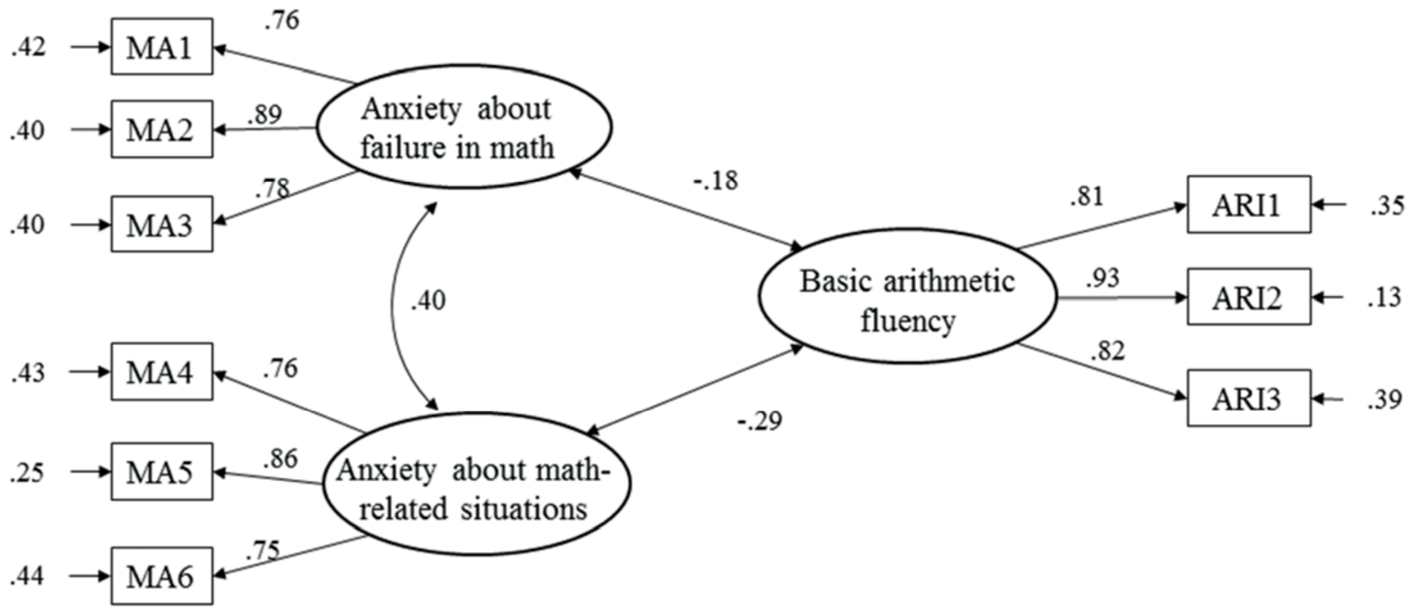

Figure 1. Model linking the two dimensions of math anxiety and achievement. All estimates are standardized. All paths $p < .05$; fit statistics: χ^2 (24) = 51.71, $p = .001$; RMSEA = .03 CFI = .99; TLI = .99

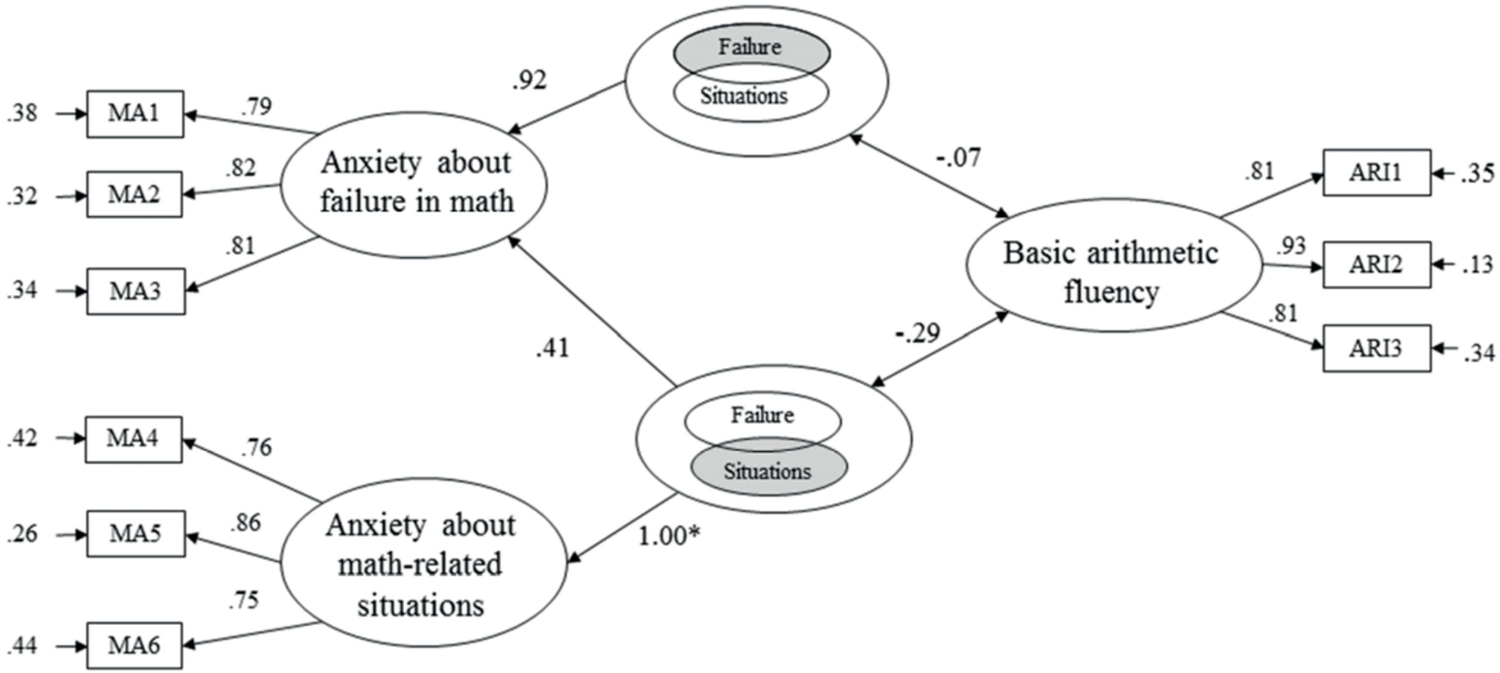

Figure 2. Model for unique variance of Worry. All estimates are standardized. Failure = Anxiety about failure in math; Situations = Anxiety about math-related situations. All paths $p < .05$; fit statistics: χ^2 (24) = 49.14, $p = .002$; RMSEA = .03 CFI = 1.00; TLI = .99

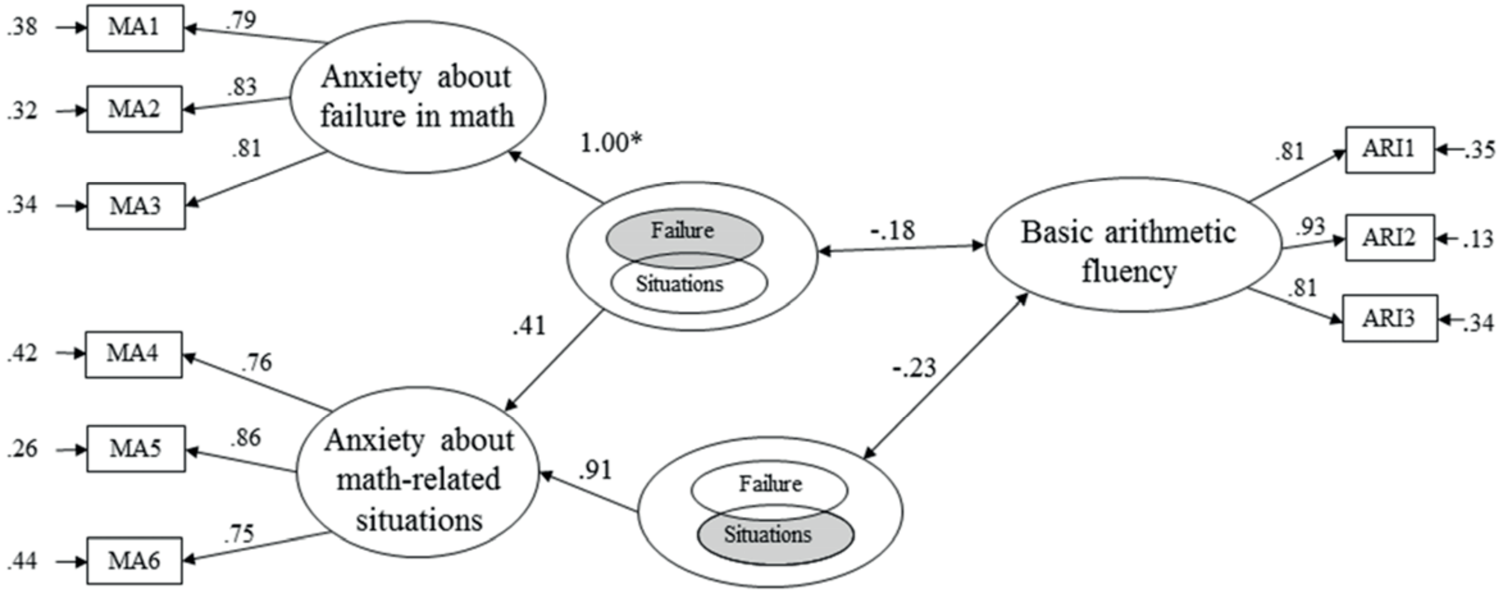

Figure 3. Model for unique variance of Negative affective reactions. Failure = Anxiety about failure in math; Situations = Anxiety about math-related situations. All estimates are standardized. All paths $p < .05$; fit statistics: χ^2 (24) = 49.14, p = .002; RMSEA =.30; CFI =1.00; TLI=.99

II

DEVELOPMENT OF MATH ANXIETY AND ITS LONGITUDINAL RELATIONSHIPS WITH ARITHMETIC ACHIEVEMENT AMONG PRIMARY SCHOOL CHILDREN

by

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Development of Math Anxiety and Its Longitudinal Relationships with Arithmetic Achievement among Primary School Children

Abstract

The aim of this study is to examine the development of two separable aspects of math anxiety, anxiety about math-related situations and anxiety about failure in math, and their cross-lagged relationship with arithmetic achievement. The mean level of anxiety about math-related situations decreased among second, third, and fourth graders, and the level of anxiety about failure in math declined among third, fourth, and fifth graders. The rank-order of individuals was more stable in arithmetic achievement than in either aspect of math anxiety. Arithmetic achievement predicted later anxiety about failure in math, but neither aspect of math anxiety predicted later achievement. The results underline the importance of paying attention to math anxiety because anxiety about math-related situations seems to be as stable in primary school as it is in secondary school students. It is important to provide sufficient educational support and take into account affective factors related to learning from the beginning of schooling.

Keywords: Math anxiety; mathematical skills; primary school; longitudinal study

1. Introduction

1.1 Math anxiety

Math anxiety is most commonly defined as feelings of nervousness and tension interfering with manipulating numbers and solving mathematical problems “in a wide variety of ordinary life and academic situations” (Richardson & Suinn, 1972). Even in childhood, math anxiety has been found to be a unique construct, separate from both test anxiety and general anxiety (Carey, Hill, Devine, & Szücs, 2017). Knowledge of the development of math anxiety during school is limited: whether the average level of math anxiety varies in different grade levels, how stable math anxiety is during school years, and whether stability is affected by age. Moreover, there is a lack of research about the causal relations between math anxiety and math achievement—which one influences the other and whether the relation is reciprocal. Among adolescents and adults, math anxiety has been found to be related to achievement (Hembree, 1990; Richardson & Suinn, 1972), but among primary school students, previous findings about the relationships have been contradictory (Authors, 2017). Longitudinal studies on math anxiety are scarce, and knowledge of the developmental aspects of math anxiety is needed for effective targeting of early interventions.

In our previous, cross-sectional study we investigated the prevalence of math anxiety and its relation with arithmetic skills among primary school children (Authors, 2017). Literacy review revealed that some studies have operationalized math anxiety as being *unable to do something* in mathematics (Dowker, Bennet, & Smith, 2012; Haase et al., 2012; Krinzinger, Kaufmann, & Wilmess, 2009; Thomas & Dowker, 2000). In our study, this aspect of math anxiety is defined as *anxiety about failure in mathematics* (Authors, 2017). On the contrary, other studies have stressed operationalization anxiety in various math-related situations without emphasizing the expected outcomes, successes, or failures (Vucovic, Kieffer, Bailey, & Harari, 2013; Wu, Barth, Amin, Malcarne, & Menon, 2012). This aspect has been defined as *anxiety about math-related situations* (Authors, 2017). Interestingly, contradictory findings seem to be related to the aspect of math anxiety measured. The results of our study confirmed the hypotheses raised from previous literature and showed that these two ways of operationalizing shed light on two separable but related (correlation .40) aspects of math anxiety, and these aspects were differently related to mathematical achievement (Authors, 2017). However, because our first study was cross-sectional, we couldn't examine development or longitudinal relationships. The aim of the present study is to shed light on the development of these two aspects of math anxiety among primary school children over the course of a school year as well as the longitudinal relationship between aspects of math anxiety and math achievement.

1.2 The development of math anxiety

The limited understanding of the development of math anxiety among primary school students results, at least partly, from the paucity of studies focusing on this age group and from the incoherency of the findings. There are a few studies investigating the development of the level of math anxiety longitudinally (Krinzinger et al., 2009; Ma & Xu, 2004) and some investigating differences between several age groups cross-sectionally (Gierl & Bisanz, 1995; Gunderson, Park, Maloney, Beilock, & Levine, 2018; Authors, 2017). Use of different methodological approaches might explain some of the incoherency in the earlier findings and hinder the formation of a lucid understanding of the development of math anxiety. The methodological diversity concerns not only the above-mentioned operationalization of math anxiety but also the approach chosen in examining stability and change in anxiety over time. The approaches to investigate stability and change in math anxiety have varied from the stability of, or change in, the average level of math anxiety (i.e., *mean level change*; Krinzinger et al., 2009) to the stability of, or change in, the relative position of the individuals within a group over time (i.e., *rank-order stability*; Krinzinger et al., 2009; Ma & Xu, 2004) by analyzing stability coefficients of math anxiety between different time points.

The results of the previous studies concerning the development of math anxiety during primary school years are somewhat contradictory. One reason for this might be that they have measured different aspects of math anxiety. Krinzinger et al. (2009) assessed the mean level of *anxiety about failure* longitudinally from first to third grade and found that the level increased over time. Thus far, to our knowledge, the development of *anxiety about math-related situations* has not been studied longitudinally in primary school, but the knowledge about the mean level change is based on cross-sectional studies comparing students in different grade levels. Gierl and Bisanz (1995) found no differences between third and sixth graders in the level of math anxiety in problem-solving situations, but the mean level of math anxiety concerning test situations was higher among older children than younger. Authors (2017) compared the prevalence of anxiety about failure and anxiety about math-related situations in grade levels 2 to 5. There were no differences in the prevalence of anxiety about failure between children at different grade levels, but anxiety about math-related situations was more common among younger students compared with older students. The latter result was in line with the results of Gunderson et al. (2018) who found that the level of anxiety about math-related situations was lower among second than among first graders.

Besides the mean-level of math anxiety, Krinzinger et al. (2009) investigated the anxiety about failure in mathematics also from the perspective of rank order stability. They found lower stability for anxiety (one-year stability coefficients from .49 to .60) than for achievement (one-year stability coefficients from .79 to .91). To our knowledge, anxiety about math-related situations has not been investigated from the perspective of *rank-order stability* among primary school children. Ma and Xu (2004) examined the development of anxiety about math-related situations from seventh to twelfth grade using this approach. They found that math anxiety remained relatively stable from grade 8 onward (one-year stability coefficients were slightly below .60), although not as stable as achievement in mathematics (one-year stability coefficients were over .90). Although the mean-level change approach provides information about the development of math anxiety at *the group level*, by investigating the rank-order stability we get knowledge of the stability of math anxiety at *the individual level* within the group—in other words, whether the same students report anxiety over time.

These two approaches are complementary, and both approaches are needed in order to get a clearer picture of the development of anxiety. It is possible to find decreasing or increasing average levels of anxiety over time, but stable rank-order would reveal that individuals maintain their relative position within a group with respect to their anxiety level. Similarly, it is possible to find low stability in rank-order, indicating individual changes in math anxiety while the anxiety at the group level remains constant. However, these two approaches are rarely used in the same study. More research with a repeated-measures design, taking into account both perspectives as well as different ways of operationalizing math anxiety, is needed in order to better understand the development of math anxiety during primary school.

1.3 Association between math anxiety and achievement

Recent studies on math anxiety suggest that it is related to performance in the primary school years (Cargnelutti, Tomasetto, & Passolunghi, 2017; Carey, Devine, Hill, & Szucs, 2017; Devine, Fawcett, Szücs, & Dowker, 2012; Ramirez, Gunderson, Levine, & Beilock, 2013; Ramirez, Chang, Maloney, Levine, & Beilock, 2016; Authors, 2017; Wu et al., 2012). However, there are also studies questioning this relationship (Devine, Hill, Carey, & Szücs, 2018; Dowker, Bennett, & Smith, 2012; Haase et al., 2012; Hill et al., 2016; Krinzinger et al., 2007; Krinzinger et al., 2009; Thomas & Dowker, 2000; Wood et al., 2012). The inconclusive results of previous studies may be understood considering the varying operationalizations of math anxiety (Authors, 2017). Most of the studies that did not find a relationship between math anxiety and math performance among primary school children operationalized math anxiety as anxiety about failure in mathematics (Dowker et al., 2012; Haase et al., 2012; Krinzinger et al., 2007; Krinzinger et al., 2009; Thomas & Dowker, 2000; Wood et al., 2012). However, studies that operationalized math anxiety as anxiety in math-related situations in general have usually revealed the relationship (Cargnelutti et al., 2017; Harari, Vukovic, & Bailey, 2013; Jameson, 2013; Vucovic et al., 2013; Wu et al., 2012; Wu, Willcutt, Escovar, & Menon, 2014). When the two operationalizations were examined together, it was found that anxiety about failure in math is more common among primary school children, but anxiety about math-related situations in general is directly and more strongly related to performance in mathematics (Authors, 2017). However, the existence of the relationship between math anxiety and achievement cannot be fully explained by the operationalization of math anxiety. Hill et al. (2017), who investigated anxiety about math-related situations, did not find the relationship between anxiety and achievement among primary school students, but they found it among secondary students. Also, Devine et al. (2018) assessed anxiety about math-related situations of primary and secondary school students and found that nearly 80% of highly math-anxious students had typical or high performance in math, questioning the link between math anxiety and achievement.

Even if anxiety about math-related situations has been found to be more strongly related to achievement than anxiety about failure among primary school children (Authors, 2017), the causal relationships between the aspects of math anxiety and math achievement remain unclear. To shed light on the contradictory findings of the relationship between math anxiety and achievement, three competing models have been suggested (Carey, Hill, Devine, & Szücs, 2016). First, the model with the causal direction from high math anxiety to poor math performance is called the *debilitating anxiety model* (Carey et al., 2016). Based on a meta-analysis, Hembree (1990) claimed that math anxiety would weaken math performance, but he did not find any evidence suggesting that poor performance would increase anxiety. This model is supported by the finding that math anxiety seems to cause an “affective drop” in performance: math-anxious individuals are likely to underperform every time they have to do math in a timed setting (Ashcraft & Moore, 2009). There are also some studies among first and second graders with results supporting the debilitating anxiety model. Cargnelutti et al. (2017) found an indirect effect of math anxiety in grade 2 on achievement in grade 3. In a study by Vucovic et al. (2013), anxiety about math-related situations in second grade was found to predict skill development in math, but because anxiety was not assessed longitudinally, strong conclusions about the causal relations could not be made. Besides, Ramirez et al. (2016) studied math anxiety of first and second graders and found that especially children with high working memory are likely to underperform when they experience high math anxiety.

The second model, *deficit theory* (i.e. poor math performance elicits math anxiety; Carey et al., 2016), is supported by a study among junior and senior high school students by Ma and Xu (2004) indicating that prior low math performance predicts later high math anxiety, but prior high mathematics anxiety hardly predicts later low achievement. Furthermore, studies have shown that primary school children with math learning disabilities report more anxiety than their typically achieving peers (Passolunghi, 2011; Rubinsten & Tannock, 2010; Wu et al., 2014), giving support to this model.

Carey et al. (2016) as well as Foley et al. (2017), in their reviews based on previous studies, suggest that one reason for the conflicting results of previous research supporting either deficit theory or debilitating anxiety model might be that the studies actually shed light on different aspects of a bidirectional relationship. In this third model, *reciprocal theory*, math anxiety and achievement influence one another in a vicious circle (Carey et al., 2016). Carey, Devine et al. (2017) investigated math anxiety with latent profile analysis. Based on their results, it seems that some individuals might develop math anxiety as a result of poor performance and some only because of their predisposition to anxiety generally. However, math anxiety also seemed to lower performance, to some degree, regardless of why it had developed. Therefore the researchers suggest that math anxiety and achievement affect each other reciprocally. Also Gunderson et al. (2018) found reciprocal cross-lagged relations between math anxiety and achievement of first and second graders. Even though the relations were reciprocal, the impact of initial achievement on later anxiety was stronger than the effect of anxiety predicting later achievement. They state that children who achieve lower in math and lack some of the math concepts foundational for later development when they start school are more likely to develop math anxiety but also that a higher level of math anxiety is more likely to lead to poorer achievement over time.

Previous longitudinal studies among primary school children have usually focused on relatively young students from first to third grade and have not taken into account different aspects of math anxiety. Longitudinal research taking into account both anxiety about math-related situations and anxiety about failure in math is needed before conclusions concerning the causal directions of the relationship between math anxiety and achievement can be made. More research about the causal relations is needed, especially in primary school when math anxiety and basic math skills are just developing.

2. The present study

The aim of the present study is to examine the development of primary school students' math anxiety and its relationship with arithmetic achievement longitudinally during one school year. This study extends our previous work examining the two types of math anxiety: anxiety about failure in math and anxiety about math-related situations in general (Authors, 2017), by investigating the development of these two aspects of math anxiety and their longitudinal relationship with achievement.

The first aim was to study the development of these two aspects of math anxiety, during one school year, among primary school children from second to fifth grade. The development was studied from two perspectives, mean-level change and rank-order stability, in order to examine development on two levels, at the group level and at the level of individuals within the group. We examined whether there was any change in the mean levels of either anxiety about math-related situations or anxiety about failure in math during a school year at any grade level. Based on the previous, mostly cross-sectional research (Gierl & Bisanz, 1995; Gunderson, Park, Maloney, Beilock, & Levine, 2018; Authors, 2017), we hypothesized that the level of anxiety about math-related situations would decrease during a school year and that the level of anxiety about failure would stay the same or even increase. This could be due to children getting used to studying math during primary school, which would decrease the anxiety about math-related situations but would not affect the fear of failure (Authors, 2017). We also wanted to learn how stable the rank-order of the individuals was in these aspects of math anxiety. Based on the previous research (Ma & Xu, 2004), we hypothesized that the rank-order of the aspects of math anxiety would be less stable than the rank-order of arithmetic achievement. This might reflect the different nature of math anxiety and arithmetic skills: individual differences in arithmetic skills tend to be stable, whereas there seems to be more fluctuation in the level of math anxiety.

Second, we aimed to investigate the longitudinal relationships between the two aspects of math anxiety and arithmetic achievement. We hypothesized that anxiety about math related situations and anxiety about failure in math would predict each other. Further, we hypothesized that we would find a reciprocal relationship between math anxiety and achievement, in students with lower achievement are more likely to develop math anxiety and higher level of math anxiety is more likely to lead to poorer achievement over time. (Carey et al., 2016).

3. Method

3.1 Participants and procedure

This research is based on data from a longitudinal study on the development of self-beliefs and academic skills of primary school aged children. The participants were from 20 Finnish schools, situated in urban and semi-urban areas in central Finland. The participating schools were recruited via basic education municipality officials. The participating special education teachers recruited volunteering classroom teachers of grade levels 2 to 5 at their schools. Participation was voluntary, and written consent was obtained from the participants' guardians. The research procedure was evaluated by the ethical committee of the university. The participants of the present study were 1,321 children (47.84% girls). In the beginning of the follow-up, 178 of the children were second graders (13.47%; M = 8.35 years; SD = 0.32), 475 (35.96%) third graders (M = 9.34 years; SD = 0.31), 383 (29.00%) fourth graders (M = 10.40 years; SD = 0.35), and 285 (21.57%) fifth graders (M = 11.39 years; SD = 0.36).

The data for this study were collected at two time points: November 2013 (time point 1, or T1) and September 2014 (T2). The assessments were carried out and supervised by trained research assistants in group situations in the classroom during the school day. The items were read aloud for the students who then responded on answer sheets. The assessment was structured in a way so that none of the math anxiety questions were presented immediately after the basic arithmetic skills tasks.

Complete data for the measures of math anxiety and basic arithmetic skills in both time points were available for 73.9% of the sample. The highest percentage of missing data (13%

of the participants) was obtained for items of arithmetic achievement and items of anxiety in math-related situations in T2, mainly due to school absences.

3.2 Measures

3.2.1 Math anxiety

Math anxiety was assessed at the two time points with a questionnaire comprised of six items. Three of the items were from the Finnish adaptation (Authors, 2017) of the Math Anxiety Questionnaire (MAQ; Thomas & Dowker, 2000). The format of the MAQ questions was "How anxious or calm would you be if you were unable to do…," and students were to respond regarding "something in mathematics" (MA1), "a mental calculation task" (MA2), and "math homework" (MA3). The two first questions were from the original MAQ, and the third was included for the Finnish version (Authors, 2017). As in the original MAQ, these three items were to be rated on a 5-point scale with pictures of faces depicting various emotions, from *very anxious* (rated as 5) to *very calm* (rated as 1).

The last three math anxiety items (Authors, 2017) were adopted from a subscale that had been initially designed for assessing sources of self-efficacy, based closely on the ideas of Usher and Pajares (2008). These items, "I get anxious when I have to answer the teacher's questions in math class" (MA4), "I get anxious when I start doing math" (MA5), and "I feel tension when I have to do math" (MA6), were rated on a 7-point scale (1 = *false*, 2–3 = *mostly false*, 4 = *neither true nor false*, 5–6 = *mostly true*, 7 = *true*). The anxiety questionnaire items loaded on two factors (for details, see Authors, 2017): the items MA1 through MA3 loaded on one factor, named Anxiety about Failure in Mathematics, and the items MA4 through MA6 on another factor, named Anxiety about Math-Related Situations. The model with two factors was significantly better than the model in which all the math anxiety items were loaded on one factor. Cronbach's alpha for items of the Anxiety about

Math-Related Situations factor was .71 and for the items of the Anxiety about Failure in Math was .82.

3.2.2 Basic arithmetic skills

Basic arithmetic skills were assessed at two time points with three time-limited paper-and-pencil group tests. The first two tests, the two-minute addition fluency test (Author, 2010a) and the two-minute subtraction fluency test (Author, 2010b), consisted of 120 items. All the addends in the addition test and all the results in the subtraction test were smaller than 10. The third test, the three-minute basic arithmetic test (Aunola & Räsänen, 2007), consisted of 30 items assessing addition, subtraction, division, and multiplication skills. The scores for the basic arithmetic skills tests were standardized at both time points within each grade level. Cronbach's alpha for the basic arithmetic skills items was .92.

3.3 Statistical analysis

The analyses were conducted using Mplus software, version 7.3 (Muthén & Muthén, 1998–2017). The full information maximum likelihood (FIML) with robust standard errors and scale-corrected chi-square test values were estimated. The FIML uses all information in the data without imputing missing values. First, a measurement model with latent factors for anxiety in math-related situations, anxiety about failure in math, and arithmetic achievement at both time points was constructed. For interpreting the latent means and correlations across grade levels at different time points, strong invariance was required, i.e. the factor loadings and intercepts of observed variables should be invariant over time and in different grade levels (Van de Schoot, Lugtig, & Hox, 2012). The invariance of the factor loadings and intercepts of observed variables of arithmetic and math anxiety across time and grade levels was tested by comparing the root mean square error of approximation (RMSEA; Steiger, 1990) values of the nested models (parameters freely estimated versus parameters constrained to be equal in all grade levels/time points). A small difference between the RMSEA values of the nested models indicates that the models fit the data as well; therefore, the tested parameters can be set equal between grade levels and time points (MacCallum, Browne, & Vai; 2006). The invariance was tested using the procedure of MacCallum et al. (2006) by comparing the RMSEA values of the most freely estimated and the most constrained models. According to MacCallum et al. (2006), the non-central value is calculated, and the test value of nested models is compared to correspondent non-central chi-square distribution to get a *p*-value to reject the null hypotheses of small difference. The chi-square difference test (Satorra & Bentler, 2001) was not used for testing measurement invariance because this test is overly sensitive to small differences in the loadings and intercepts in the data with a large number of participants. The goodness-of-fit of the final measurement model was evaluated using a chi-square test, RMSEA (Steiger, 1990), the comparative fit index (CFI; Bentler, 1990), and the Tucker-Lewis index (TLI; Hu & Bentler, 1999). For a good model fit, the *p*-value of the chi-square test should be greater than .05, the RMSEA less than .06, the CFI and the TLI greater than .95, and the standardized root mean residual (SRMR) less than .08 (Hu & Bentler, 1999).

Second, the change in, or stability of, the mean levels of the math anxiety factors from T1 to T2 was examined in each grade level. The mean of the intercepts of the observed variables of each factor was constrained to be zero, and then the equality of the factor means in the two time points was tested using the Wald Test of Parameter Constraints (Muthén & Muthén, 1998–2017).

Next, a model with stability effects of the math anxiety factors and the arithmetic achievement factor, as well as concurrent associations and cross-lagged relationships between the three factors in T1 and T2, was constructed. In the final model, only statistically significant paths were presented (see Figure 3). The goodness-of-fit of the model was evaluated using the chi-square test, RMSEA, CFI, TLI, and SRMR.

Finally, the longitudinal relationships between math anxiety factors and achievement were examined. To investigate if there was any difference in the cross-lagged effects across the grade levels, the cross-lagged relationships were compared using a multi-group approach and the Wald Test of Parameter Constraints.

4. Results

4.1 Invariance of math anxiety measure over time and across grade levels

The invariance test (p = .32) indicated small differences between the RMSEA values of the freely estimated model (RMSEA = .05) and the model with most constraints (the factor loadings and intercepts over time and across the grade levels; RMSEA = .06; see Table 1). Thus, the measures of math anxiety and achievement were assumed to be invariant across time. The fit indices for the measurement model with factor loadings and intercepts constrained to be equal over time and across all grade levels were $\chi^2(564) = 1320.27$, $p <$ .001, RMSEA = .06, CFI = .92, TLI = .91, and SRMR =.06.

4.2 The mean-level change in math anxiety

The means of the Anxiety about Math-Related Situations factor are presented in Figure 1. The Wald Test of Parameter Constraints (Table 2) revealed that, during a school year, the level of anxiety about math-related situations declined significantly among second to fourth graders, and the level of anxiety about failure in math declined significantly among third to fifth graders.

4.3 Rank-order stability

The rank-order stabilities (standardized regression coefficients) of the math anxiety and achievement factors, from T1 to T2, are presented in Figure 3. There were no differences between the grade levels in the regression coefficients ($\chi^2(9) = 15.65$, p = .07).

4.4 Cross-lagged relationships between math anxiety and achievement

The cross-lagged model for anxiety about math-related situations, anxiety about failure in mathematics, and arithmetic achievement is presented in Figure 3. The results showed that high anxiety about math-related situations at T1 predicted high anxiety about failure at T2, and low arithmetic achievement at T1 predicted high anxiety about failure in math at T2. Neither arithmetic achievement nor anxiety about failure predicted anxiety about math-related situations, and neither of the two math anxiety factors at T1 predicted arithmetic achievement at T2 when controlling for T1. There were no grade-level differences in the cross-lagged ($\chi^2(18) = 26.07$, $p = .10$) relationships between the math anxiety factors and achievement.

5. Discussion

5.1 General discussion

This study investigated change in math anxiety among primary school children and examined relations between math anxiety and math fluency measured at the beginning and the end of the school year using a cross-lagged design. The development of math anxiety during one school year was examined from two perspectives of stability or change: the mean level of anxiety and the rank-order of individuals. Two aspects of math anxiety—anxiety about math-related situations in general and anxiety about failure in math—were assessed to shed light on the controversies of previous findings.

When the development of math anxiety during a school year was examined, the results showed that, as hypothesized, the average level of anxiety about math-related situations decreased among second, third, and fourth graders but stayed virtually the same among fifth graders. In anxiety about failure in math, we expected that there would be no change or that the level of anxiety would even increase. However, there was no change among second graders, but among third, fourth, and fifth graders the level of this aspect of math anxiety declined as well. The rank-order of the individuals was a bit more stable in anxiety in math-related situations in general (.51) than in anxiety about failure in math (.33). As we hypothesized, the rank-order of participants remained more stable in the arithmetic achievement (.91) than in the two aspects of math anxiety.

We hypothesized that we would find reciprocal relationships between the two aspects of math anxiety and arithmetic achievement. However, the results for the cross-lagged relationships between math anxiety and arithmetic achievement suggest that prior low arithmetic achievement predicts later high anxiety of failure in math, giving support to the deficit theory (Carey et al., 2016). The cross-lagged relationships were similar across grade levels, indicating a similar longitudinal effect from achievement to anxiety in all grade levels from second to fifth.

5.2 The development of math anxiety

In the present study, we used complementary approaches to get a better picture of the development of math anxiety. First, we examined the average level of math anxiety of the whole group of participants (mean-level change/stability) and, second, whether the same students tend to report anxiety over time (the rank-order stability/change). The mean-level results suggest that, on average, primary school students feel less anxious about math during the follow up, including a transition to the next grade level, which opposes the findings of several previous studies (Gierl & Bisanz, 1995; Krinzinger et al., 2009). The mean-level of anxiety about math-related situations decreased among second, third, and fourth graders, and anxiety about failure decreased among third, fourth, and fifth graders during the follow-up. Because the present study was the first longitudinal study among primary school children examining the development of math anxiety and taking into account not only anxiety about failure but also anxiety about math-related situations in general, we do not know whether the decline in these aspects is characteristic of the specific educational context of Finnish schools or a more universal phenomenon.

However, the results for the rank-order stabilities of the two aspects of math anxiety are in line with the previous results. In the present study, the test-retest correlation of anxiety about math-related situations (.51) was close to what Ma and Xu (2004) found among secondary school students (.38 from seventh to eighth grade and .55–.59 from eighth to twelfth grade). It seems that feeling anxious about math-related situations is as stable a phenomenon already in second grade as it is by the end of secondary school. However, as has been previously found concerning anxiety about math-related situations among secondary school students (Ma & Xu, 2004) and anxiety about failure in math among primary school students (Krinzinger et al. 2009), the rank-order in math anxiety aspects was less stable than rank-order in arithmetic achievement.

5.3 Cross-lagged relationships between math anxiety and achievement

In the present study, those participants who were generally anxious about math-related situations were more likely to also be more anxious about failing in math, but prior anxiety about failure did not seem to lead to an increase in more general anxiety about math-related situations. Although arithmetic achievement seems to be cross-sectionally more strongly related to anxiety about math-related situations than to anxiety about failure (Authors, 2017), developmentally, arithmetic achievement has an effect especially on the latter: low achievement predicts higher anxiety about failure in math. The finding about achievement predicting math anxiety is in line with the results of previous research; children with mathematical learning difficulties have been found to be more anxious about mathematics than their typically performing peers (Passolunghi, 2011; Rubinsten & Tannock, 2010; Wu et al., 2014), and mathematical learning difficulties typically manifest as fundamental problems in the development of basic arithmetic skills (Geary, 1993).

The results of the present study about the longitudinal effect of arithmetic achievement on math anxiety provided support for the deficit theory of math anxiety (poor math performance elicits math anxiety; Carey et al., 2016). However, because math anxiety and math achievement were cross-sectionally related, the immediate effect of math anxiety on arithmetic achievement and, thus, the reciprocal relationship, with math anxiety and achievement influencing one another, cannot be ruled out either. If there is an immediate effect of anxiety on achievement, an "affective drop," as Ashcraft and Moore (2009) suggested, it may have been affecting the students' achievement before the age of the participants in the current follow-up. This might explain why the reciprocal relationship has been previously found with cross-lagged modeling among first and second graders (Gunderson et al., 2018), even though longitudinal studies usually give support to the deficit theory (Carey et al. 2016).

5.4 Limitations of the study

The present study has some notable limitations. First, the results suggest that primary school children get less anxious about general math-related situations and that anxiety about failure in math are based on the one year follow-up, including the transition to the next grade level. To compare the development between grade levels, a longer follow-up period is needed. Second, it cannot be assumed that the development of math anxiety would necessarily decline linearly throughout the school years. In Wigfield and Meece's (1988) study, the mean level of math anxiety did not show a consistent linear pattern of change. Among participants from sixth to twelfth grade, ninth graders reported the highest level of anxiety and sixth graders the lowest. In the present study, we focused on a period of time in which the learning environment usually remains relatively stable. In Finland, for example, students' own classroom teachers teach most of the school subjects, math included. Thus, we do not know what happens during transitional points from preschool to primary school or from primary to secondary school, when the structure of everyday school life changes and different school subjects are taught by subject teachers.

Based on the math anxiety measure used in the present study, we separated two aspects of math anxiety. The main difference between these two aspects was that one focused on failure in math, while the other more generally included different kinds of math-related situations without specifying the result (success or failure). Nevertheless, this is only one way to approach the varying operationalizations of math anxiety. Other, to some extent overlapping, operationalizations, for example, focus on the situations that arouse math anxiety (e.g. testing, problem-solving, or social situations; Carey, Hill, et al., 2017; Gierl & Bisanz, 1995; Richardson & Suinn, 1972), the affective and/or cognitive aspects of anxiety (Wigfield & Meece, 1988), or the habitual (trait) and momentary (state) aspects of math anxiety (Goetz, Bieg, Lüdtke, Pekrun, & Hall, 2013). Gierl and Bisanz (1995) found no grade-level differences in math anxiety in problem-solving tasks but a higher level of anxiety about math tests among older students compared with younger students. Correspondingly, the authors suggested that the situations most likely to arouse math anxiety possibly differ across grade levels. Since we did not measure anxiety about math tests, we cannot conclude whether declines occur in all aspects. Further, based on the measure of the present study, we were not able to separate the affective (negative affective reactions) and cognitive (worry about performance) components of math anxiety. Similar to most of the existing research, as Goetz et al. (2013) pointed out, we also focused on trait-like, habitual math anxiety; the assessments of math anxiety and achievement were carried out separately, and we did not measure anxiety in actual problem-solving situations.

The number of math anxiety items was limited on the questionnaire: both aspects of math anxiety were measured with three items only. However, scales with three or even just one item have been found to be adequate for measuring academic anxieties, including math anxiety (Gogol et al., 2014; Núñez-Peña, Guilera, & Suárez-Pellicioni, 2014). Besides, general or test anxiety was not assessed in this study. Even if math anxiety has been found to be a unique construct, even among children (Carey, Hill, et al. 2017), it is also highly correlated with test anxiety (Betz, 1978). It can also be considered a limitation that, of the many subskills of mathematics (see, e.g., Dowker 2005), we assessed only basic arithmetic skills. Further, tapping the actual skills of math-anxious children might be difficult, if the anxiety causes them to underperform. Especially the use of time-limited tests may magnify the effects of anxiety (Faust et al., 1996). However, in arithmetic skills, fluency of basic calculations is essential (Carr, Steiner, Kyser, & Biddlecomb, 2008), and when one aims to measure explicitly arithmetic fluency, time constraints in the assessment cannot be avoided.

5.5. Implications for future research

In future research, more attention should be paid to the complexity of the structure of math anxiety. Since the affective and cognitive dimensions of math anxiety seem to be differently related to achievement (Wigfield & Meece, 1988), the development and the significance of both at different stages of schooling should be studied. The measures of math anxiety should comprise diverse situations (e.g. testing, social, and general problem-solving) to find out whether the mean level change in math anxiety over time is similar in different situations. In addition, the association of math anxiety with a more diverse range of mathematical skills should be examined using tools with and without time limits as well as tasks adapted to the performance level.

The present study is one of the few longitudinal studies investigating math anxiety in primary school. In the future, a longer follow-up period and a focus on school transitions is recommended. In addition, it is possible that the decline in anxiety results from features related to the Finnish school system, such as the extensive part-time special education offered to support struggling learners relatively early without the need to wait for a formal diagnosis of learning disability. For answering this question, longitudinal and cross-cultural research is needed. The present results showing that low achievement predicts later higher math anxiety give support to the observation of Carey et al. (2016) in their review; usually longitudinal studies (Ma & Xu, 2004) provide support for the deficit theory, whereas studies manipulating anxiety levels (Park, Ramirez, & Beilock, 2014) support the debilitating anxiety model. As Carey et al. (2016) pointed out, more research combining these aspects is needed for better understanding of the causal relationships between math anxiety and math achievement.

In the present study we focused on relationships on a group level. However, most of the students with math anxiety are not low-achieving (Devine et al., 2018). Even if low-achieving students seem to be more prone to math anxiety, not all low-achieving students become anxious about mathematics, and furthermore, nearly four of five students with math anxiety are typical or high-achieving. More research with a person-centered approach is needed to explain the relationship between math anxiety and achievement.

The results of the present study underline the importance of paying attention to math anxiety from the beginning of schooling, as anxiety about math-related situations seems to be as stable among second graders as it has been found to be in secondary school students. Integrative approaches in educational support focusing on both the skill development and feelings toward mathematics are needed, especially among children struggling in math. Nevertheless, as the students' rank-order in math anxiety is less stable than in achievement and, therefore, might be easier to affect, interventions targeted at reducing anxiety should be developed and implemented in basic education.

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Table 1
Invariance Comparison for the Measurement Model of Math Anxiety and Arithmetic Achievement in T1 and T2

Constraints over time	Constraints among grade levels	$\chi^2(df)$	*sc*	*RMSEA*
–	–	936.54 (480)	1.11	.054
Factor loadings	–	962.26 (504)	1.11	.052
Factor loadings, intercepts of observed variables	–	1017.130 (528)	1.10	.053
Factor loadings, intercepts of observed variables	Factor loadings	1160.00 (546)	1.12	.058
Factor loadings, intercepts of observed variables	Factor loadings, intercepts of observed variables	1320.27 (564)	1.12	.064

Note: χ^2 difference test = model compared to previous, less constrained model; sc = scaling correction factor; RMSEA = root mean square error of approximation.

Table 2
Wald Test Results Comparing Means of Math Anxiety Factors in T1 and T2

Grade	Anxiety about math-related situations	Anxiety about failure in math
2	10.25**	0.79
3	40.61***	16.38***
4	8.14**	41.99***
5	0.00	5.41*

Note. *$p < .05$, **$p < .01$, ***$p < .001$; df = 1 in all tests.

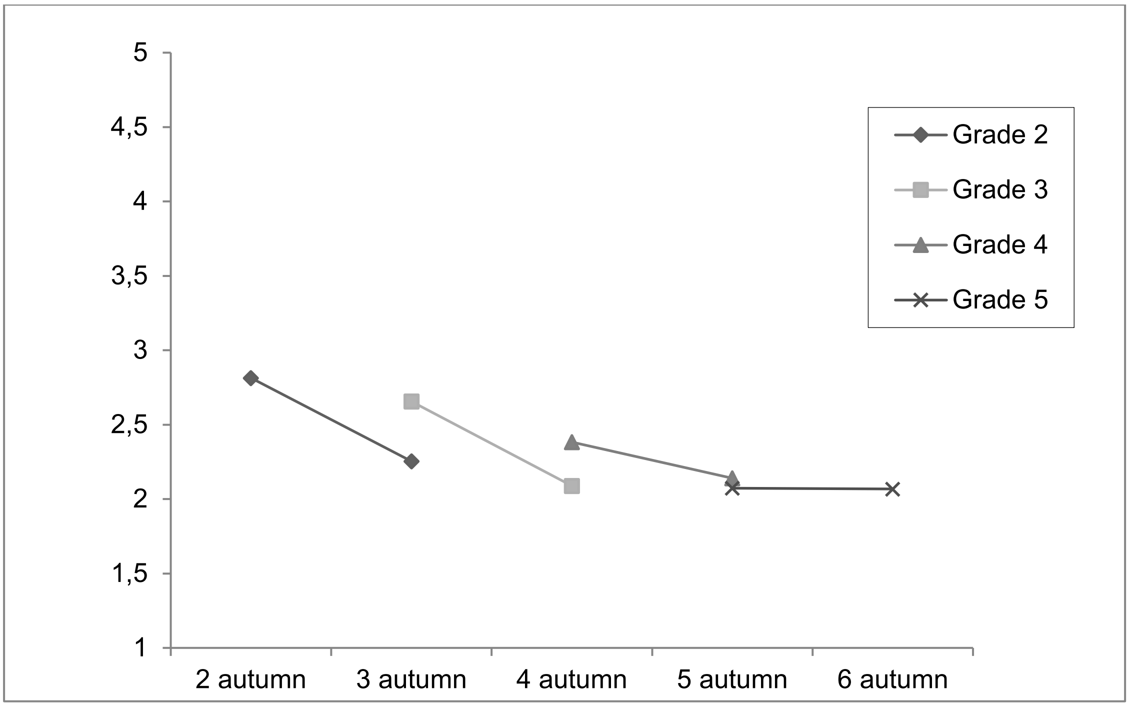

Figure 1. The means of the Anxiety about Math-Related Situations factor.

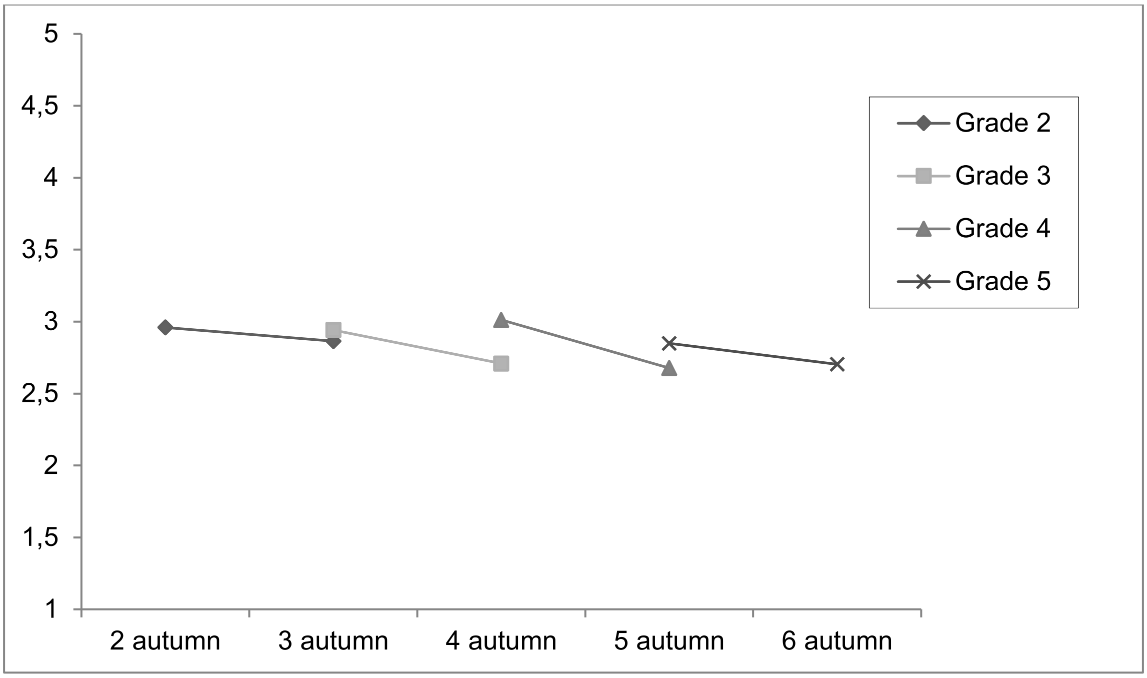

Figure 2. The means of the Anxiety about Failure in Math factor

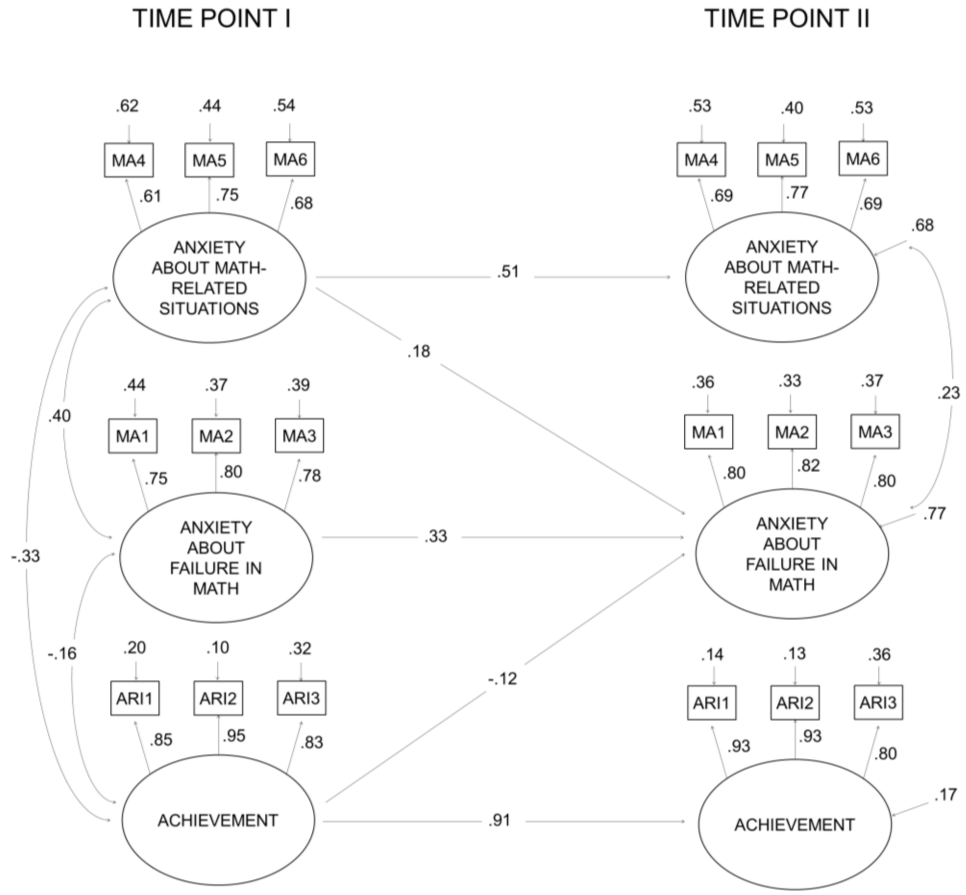

Figure 3. Stability effects of the math anxiety factors and the arithmetic achievement factor, as well as concurrent associations and cross-lagged relationships between anxiety about math-related situations, anxiety about failure, and arithmetic achievement for all participants. All estimates are standardized. All paths $p < .05$; fit statistics for full model: $\chi^2(120) = 493.20$; $p = .001$; RMSEA = .05; CFI = .96; TLI = .95; SRMR =.03.

III

LONGITUDINAL AND SITUATIONAL ASSOCIATIONS BETWEEN MATH ANXIETY AND PERFORMANCE AMONG EARLY ADOLESCENTS

by

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Longitudinal and situational associations between math anxiety and performance among early adolescents

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Abstract

Studies have found math anxiety and achievement to be related from the beginning of formal schooling, but the knowledge regarding the direction of the relationship is vague. The purpose of the present study was to study this relationship. We investigated math anxiety from two points of view: trait and state anxiety. In the first substudy, we investigated the longitudinal relationship between math anxiety and performance from sixth to seventh grade ($n = 848$) with cross-lagged modeling. In the second substudy, we investigated the situational relationship of anxiety and performance by giving the participants ($n = 149$) challenging and nonchallenging math tasks adapted to their skill level, and then examining the association between anxiety and the performance. The results suggest that math anxiety has a small longitudinal effect on performance: High anxiety in sixth grade predicted low performance in seventh grade. Anxiety also had a situational association with performance: when anxiety was aroused, the participants performed more poorly compared to their skill level. The results adduce the two-fold effect of anxiety on achievement: math anxiety seems to have both a real-time association with performance and a long-term effect on the development of basic arithmetic skills.

KEYWORDS
early adolescence, math anxiety, math performance

INTRODUCTION

The relationship between math anxiety and performance among sixth and seventh graders

Math anxiety is usually defined as tension and anxiety when manipulating numbers and solving mathematical problems.[1] It has been suggested that even if math anxiety is not an actual disability, it can function as one as a result of its negative personal, educational, and cognitive consequences.[2] It is related to lower math achievement among children from the beginning of primary school[3–8] as well as among adolescents and adults.[9,10] The correlations of math anxiety and achievement have been similar among children and adults: For example, Sorvo *et al.*[8] found a correlation of –0.29 between math anxiety and performance among primary school children, which is approximately the same as reported in the meta-analyses of Hembree[10] (–0.27) and Ma[9] (–0.34) among adolescents and adults, respectively. As for the causality of the relationship, three competing theoretical models have been suggested: the *deficit theory*, which claims that anxiety is a result of poor achievement; the *debilitating anxiety model*, which claims that anxiety debilitates performance; and the *reciprocal theory*, which claims that the two affect each other in a vicious circle.[3] The results of empirical studies concerning the causal relationship between math anxiety and achievement have been contradictory, as different studies give support to different theoretical models.

Theoretical models of the relationship between math anxiety and achievement

According to the *deficit theory*, difficulties in mathematics leading to negative experiences of performance are likely to generate math anxiety in the future.[11] Difficulty in mathematics has been suggested as a plausible risk factor for math anxiety because children with low mathematical skills are more likely to fall behind their peers, receive negative feedback, and develop negative attitudes toward mathematics.[12] This theory is supported by longitudinal studies among primary school children from grades two to six[13] and secondary and high school students from grades 7 to 12, which indicate that prior low achievement predicts later high math anxiety but not the other way around. In accordance, there are studies indicating that children with mathematical learning difficulties report more math anxiety than their typically achieving peers,[14–16] giving some support to the deficit theory.

The *debilitating anxiety model* suggests that math anxiety affects math performance. Ashcraft and his colleagues have suggested that math anxiety causes an “affective drop” in performance. This means that assessing achievement, particularly under timed, high-stakes conditions, rarely reveals the true ability of individuals with math anxiety but underestimates it.[2] Attentional control theory[17] has also been suggested to explain the immediate effect of anxiety on math performance. Corbetta and Shulman[18] have separated two attentional systems: goal-driven processes, influenced by the individual’s current goals, expectations, and knowledge; and stimulus-driven processes, specialized for the perception of unexpected, salient stimuli. In attentional control theory,[19] anxiety is proposed to disrupt the balance between these two attentional systems by enhancing the influence of stimulus-driven processes over goal-driven processes. Thus, task-irrelevant stimuli capture attention more easily, and thereby, shifting attention between and within tasks becomes more difficult.[19]

The debilitating anxiety model is supported by the results of the meta-analysis of Hembree.[10] The findings consistently showed that high math anxiety undermined achievement and that interventions targeted at reducing math anxiety in students with high anxiety can improve their performance to the level of students with low anxiety. Math anxiety in task situations has been found to strain working memory and thus disrupt performance.[20,21] Ashcraft and Kirk[20] noticed that among college students, math anxiety influenced the performance of “dual tasks,” in which working memory is taxed by performing two tasks at once. Their interpretation of this result is that aroused math anxiety reduces the working memory capacity. This notion underlines the importance of paying attention to anxiety, especially in mathematics, which requires executing sequential steps of processing while keeping information of the substages in memory.[20]

It also seems that students with high math anxiety might tend to avoid mathematics. Ashcraft[22] suggests, based on previous findings,[23,24] that individuals with high math anxiety are more likely to speed through the math-related problems in order to minimize the time involved in math, which is likely to increase the number of errors. Besides the situational effect, this avoidance behavior also seems to have long-term effects on math performance. Hembree[10] found that students with high math anxiety are less likely to choose mathematics courses in high school and college.

The *reciprocal theory* suggests that math anxiety and achievement affect each other in a vicious circle.[11] This theory is supported by the study of Gunderson *et al.*[5] in which a reciprocal relationship was found between math anxiety and math achievement of first and second graders. Furthermore, Carey *et al.*[11] have suggested that the conflicting results regarding the direction of longitudinal associations between math anxiety and achievement indirectly support the reciprocal model of math anxiety and achievement.

Depending on the age of participants, previous studies might actually shed light on different aspects of a bidirectional relationship. It is possible that the educational stage might affect the relationship between math anxiety and achievement, since the transitions from one educational stage to another seem to have an effect on math-related attitudes and emotions, including math anxiety. Deieso and Fraser[25] compared Australian primary and secondary school students and found that secondary school students reported less involvement, more negative attitudes toward mathematics, less enjoyment of mathematics, and more math anxiety. Furthermore, the previous longitudinal studies indicate that the developmental pathways of math anxiety might not be linear during primary and secondary school periods. Our previous study[13] suggests that the level of math anxiety might even decline during primary school, whereas according to the meta-analysis of Hembree,[10] the level of math anxiety increases during secondary school, peaking in ninth and tenth grades. Ma and Xu[26] investigated the causal relationship between math anxiety and achievement from 7th to 12th grades and found that math anxiety predicted achievement for boys across the whole period, but for girls only at critical points of educational transition. These previous findings advocate the need for future studies on the causal relationship between math anxiety and achievement during the transitional stage from primary to secondary school.

The views on math anxiety: individual trait and situational state

The conflicting results of the previous studies might be related to the perspective taken on math anxiety and thereby also methodological constraints. Math anxiety, as with emotions in general, can be examined from two points of view: (1) as a habitual, recurring emotion that is typical to some individuals (*trait anxiety*[27] for academic skills; see Pekrun[28]), or (2) as a situation- and time-specific momentary occurrence (*state anxiety*[27,28]). Math anxiety research has typically focused more on anxiety as a trait of an individual than as a situation-specific emotional state.[29]

The mechanisms proposed by the deficit theory (i.e., poor performance causing anxiety) are more likely to be long-term, whereas the debilitating effect of math anxiety suggests more immediate mechanisms (e.g., straining working memory[2]). This could be the reason why results from longitudinal studies[13,26] often support the deficit theory, whereas results from experimental studies[2] often support the debilitating anxiety model.

Carey *et al.*[11] have hypothesized that using both long-term longitudinal and situational designs might be useful for getting a wider picture of the relationship between math anxiety and achievement. In our understanding, this means that for gaining a more comprehensive understanding of the relationship between math anxiety and achievement, math anxiety should be considered not only as an individual's trait, but also as a situation-specific emotional state. If we want to take into account also the point of view of math anxiety as a momentary, situation-specific emotion, besides asking people to respond based on their *typical* or *reoccurring* emotional reactions in different situations, we also need to ask their feelings right there, *in a specific moment*.[27]

To investigate state anxiety and its relationship with performance, we need to create varying task-performing situations with more and less pressure. One way to manipulate the level of pressure is to apply more and less challenging arithmetic tasks, as previous research suggests that the difficulty of the tasks might affect the level of math anxiety[30,31] as well as the relationship between math anxiety and performance.[23,24,32] Ashcraft and Moore[2] state that the performance of college students in basic arithmetic tasks, which they usually perform somewhat automatically, was not affected by anxiety. In the more complex arithmetic tasks, increased levels of math anxiety seemed to result in either slower or less accurate performance.[23,24] However, there is lack of research about the effect of task difficulty among younger students. Especially in primary school, the variance of arithmetic skills is huge,[33] as some students are not able to perform simple addition tasks automatically, whereas other students might experience hardly any challenges in the school math. If we want to investigate state math anxiety in basic education, the design should take into consideration students' wide range of mathematical skills and its impact on the experienced difficulty: a task that is easy for someone might be challenging for someone else. Thus, instead of using same tasks for all, the tasks should be individually adapted based on the student's performance level in order to provide "challenging" and "not challenging" experiences for all.

The present study

The aim of the present study was to shed light on the relationship between math anxiety and achievement from two different perspectives in the two substudies. In the first substudy, we examined the developmental relationships between trait math anxiety and achievement during the transition from primary to lower secondary school (i.e., from sixth to seventh grade). In the second substudy, in order to obtain a more comprehensive picture of the relationships between math anxiety and performance, we examined the situational effect of state math anxiety on performance in challenging and nonchallenging real-time math situations among sixth graders. The situational effect of state math anxiety was examined by giving the participants challenging and nonchallenging arithmetic tasks adapted to their skill level. As far as we know, the situational effects of anxiety on performance have previously been investigated only among adults. Thus, more knowledge about the situational effect is needed, especially among younger students, whose mathematical skills are still developing. Adapting the difficulty of arithmetic tasks according to individual skill level enabled us to assess the math anxiety of all students in challenging and nonchallenging mathematical situations.

The research questions were

1. How are trait math anxiety and math performance longitudinally related across the transition from primary school to lower secondary school? On the basis of previous longitudinal studies and the reciprocal theory, we tentatively hypothesized that lower skills would predict higher math anxiety and that higher math anxiety would predict lower math skills.
2. Is state math anxiety situationally associated with math performance among sixth grade students, and does the possible relation vary depending on task difficulty? On the basis of previous research among adults, we hypothesized that state math anxiety assessed after each task would be related to math performance—students with anxiety feelings in a real-time situation would have lower math performance than expected based on their skill level. The relation would be stronger in challenging than nonchallenging tasks.

STUDY 1

Materials and methods

Participants and procedure

A total of 848 sixth grade students (457 girls and 391 boys, aged 12.58–13.75 years; $M = 12.32$, $SD = 0.36$), participated in study 1, in which students were followed from sixth grade (primary school) to seventh grade (lower secondary school). The students came from 56 school classes, ranging in size between 7 and 30 pupils ($M = 21.1$, $SD = 4.66$). The students were assessed twice: in autumn 2014 (T1; grade six fall) and in spring 2016 (T2; grade seven spring).

A total of 96% of the participants were native Finnish speakers, 2% were bilingual (Finnish and some other language), and 2% of the adolescents had a language other than Finnish as their mother language. The data were collected as part of a larger longitudinal study focusing on individual and environment-related factors that promote students' learning and well-being during the transition from primary school to lower secondary school. The participants were recruited from one larger town (where the sample included about half of the age cohort) and one middle-sized town (where the whole age cohort was included in the sample) in central Finland. Both towns also included semirural areas with smaller schools (for a more detailed description of the sample, its recruitment, and demographic characteristics, please see Refs. 34 and 35). Parents gave informed written consent for their child's participation. The parents were advised to discuss the study with their child to also ensure the child's own willingness to participate. The schools and the teachers of the participating classrooms gave their permission for the data to be collected during school hours. The ethics committee of the university gave their statement for the study, and the research practices and procedures were modified according to its recommendations.

The students' data were collected in the classrooms during regular school hours. The data collection included tests of academic skills as well as questionnaires concerning students' motivation, social relationships, and well-being. The tests and questionnaires were administered by trained research assistants in group assessment sessions. The collection of the data included in this study took place in the fall semester of grade six (late September to early November 2014) and in the spring semester of grade seven (early March to early May 2016).

Measures

Arithmetic performance

Basic arithmetic performance was assessed with the 3-min Basic Arithmetic Test.[36,37] In this time-limited, group-administered paper-and-pencil test, the participant is required to complete as many arithmetic operations as possible within a 3-min time limit. The sixth-grade version of the test consists of 10 additions, 11 subtractions, and 7 tasks, including both additions and subtractions or multiplications or divisions, whereas the seventh grade version of the test consists of 8 additions, 11 subtractions, and 9 tasks, including both additions and subtractions or multiplications or divisions. The score was the total number of correct responses, with the maximum score being 28. The scores were standardized according to the mean and standard deviation of the age group.

Math anxiety questionnaire

The math anxiety of the participants was assessed with three items from the Achievement Emotions Questionnaire,[38] translated into Finnish and adapted for students from grades six to seven (see also Ref. 39). The questionnaire includes items assessing a broad variety of students' academic emotions toward mathematics and literacy in three learning contexts: learning in general, emotions toward classes, and emotions toward exams. In the present study, we were interested in students' anxiety in mathematics, which was measured with the three items concerning mathematics: "Studying makes me anxious/nervous" (MANX1), "Thinking about lessons makes me nervous" (MANX2), and "I am anxious during tests" (MANX3). The responses were given on a 5-point scale (1 = *disagree*; 5 = *agree*). Cronbach's alpha for the math anxiety scale was 0.64 at T1 (factor score reliability = 0.84) and 0.72 at T2 (factor score reliability = 0.87).

Statistical analyses

The analyses to investigate cross-lagged associations of math anxiety and math performance from grade six fall to grade seven spring were carried out in the following steps. First, a measurement model with a latent factor for math anxiety at both time points was constructed. In the measurement model, the latent factors were allowed to correlate with each other. The invariance of the math anxiety measure over time was tested by first constraining factor loadings, then the intercepts, and finally residual variances of observed variables equal over time and comparing the nested models of math anxiety against each other using the Satorra–Bentler scaled χ^2 difference test.[40] A significant χ^2 difference test indicates better fit for the model with fewer degrees of freedom (i.e., fewer constraints).

Second, cross-lagged structural equation models for math anxiety and arithmetic performance were constructed. In these models, factor loadings, intercepts, and the residual variances of the observed variables were constrained to be equal across time to ensure invariance of the measurement across time. In addition, stability paths from grade six math anxiety to grade seven math anxiety and from grade six math performance to grade seven math performance, as well as cross-lagged paths from grade six math anxiety to grade seven math performance and from grade six math performance to grade seven math anxiety, were estimated. Grade six math anxiety and grade six math achievement were allowed to be correlated. Similarly, the residuals of the grade seven math anxiety and grade seven math achievement were allowed to be correlated.

In the final model, only statistically significant paths were presented (Figure 1). To evaluate the overall goodness of fit of the cross-lagged model, the chi-square test, the root mean square error of approximation test (RMSEA),[41] the standardized root mean square error (SRMR),[42] the comparative fit index (CFI),[42] and the Tucker–Lewis index (TLI)[43] were used. For a good model, the p value of χ^2 should be larger than 0.05, the RMSEA less than 0.06, the CFI and TLI greater than 0.90 (acceptable fit) or 0.95 (excellent fit), and the SRMR smaller than 0.08.[43,44]

All the main analyses were conducted using the Mplus program version 7.3.[44] The estimation method used was maximum likelihood with robust standard errors (MLR). In this sample, the proportion of nonresponses in the different variables ranged from 1.52% to 9.42% (M = 5.65%, SD = 3.30%). The parameters of the models were estimated using full-information maximum likelihood estimation with non-normality robust standard errors (maximum likelihood robust, MLR).[44]

Results

The descriptive statistics for the observed variables are reported in Table 1, and the correlations between the observed variables are reported in Table 2. Descriptive statistics indicated that the level of math anxiety slightly increased from T1 to T2 ($\chi^2(9) = 44.84, p < 0.001$).

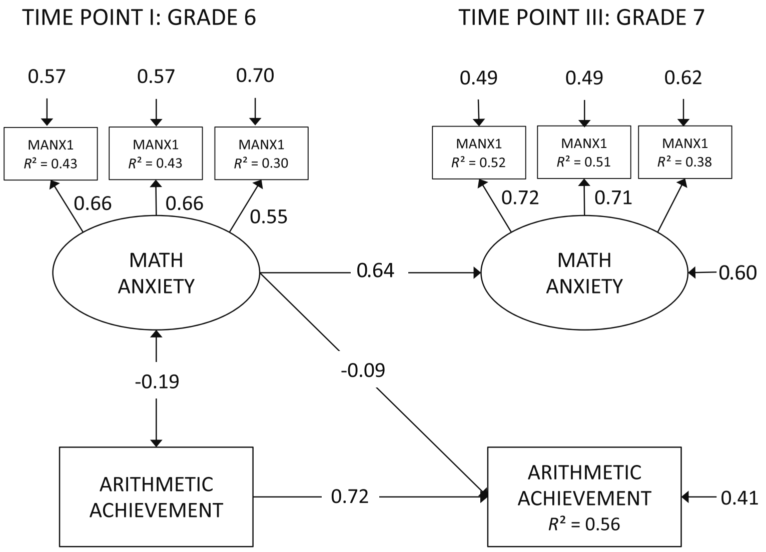

FIGURE 1 Model for the longitudinal relationships between math anxiety and arithmetic achievement. All estimates are standardized. All paths $p < 0.05$; fit statistics: χ^2 (23) = 98.78, $p = 0.001$; RMSEA = 0.06; CFI = 0.94; TLI = 0.93; SRMR = 0.04

TABLE 1 Descriptive statistics of observed math anxiety and achievement variables

Study variables	Time point 1 *M* (*SD*)	Time point 2 *M* (*SD*)	*min*	*max*
Math anxiety				
"Studying makes me anxious/nervous." (MANX1)	1.80 (0.97)	1.94 (1.05)	1	5
"Thinking about lessons makes me nervous." (MANX2)	1.67 (0.97)	1.86 (1.07)	1	5
"I am anxious during tests." (MANX3)	2.10 (1.20)	2.21 (1.20)	1	5
Math achievement				
3-minute Basic Arithmetic Test (ARI)	15.38 (3.55)	17.41 (3.61)	0	28

TABLE 2 Correlations between the observed variables

	Time point 1				Time point 2			
Variable	MANX1	MANX2	MANX3	ARI	MANX1	MANX2	MANX3	ARI
Time point 1								
MANX1	1							
MANX2	0.40**	1						
MANX3	0.37**	0.37**	1					
ARI	−0.16**	−0.08*	−0.10**	1				
Time point 2								
MANX1	0.29**	0.31**	0.18**	−0.10**	1			
MANX2	0.24**	0.36**	0.16**	−0.03	0.53**	1		
MANX3	0.24**	0.28**	0.38**	−0.07*	0.47**	0.40**	1	
ARI	−0.15**	−0.13**	−0.15**	0.74**	−0.15**	−0.12**	−0.08*	1

Note: MANX1, MANX2, MANX3 = math anxiety items; ARI = scores of arithmetic measures.
*$p < 0.05$.
**$p < 0.01$.

TABLE 3 Invariance comparison for the measurement model of math anxiety over time

Model	Model χ^2 (*df*)	χ^2 difference test χ^2 (*df*)	*p*
Unconstrained model	64.00 (8)	–	–
Factor loadings of observed variables set to be equal over time	67.46 (10)	2.49 (2)	0.29
Factor loadings and intercepts of observed variables set to be equal over time	73.47 (12)	2.59 (2)	0.27
Factor loadings, intercepts, and residual variances of observed variables set to be equal over time	75.30 (15)	3.46 (3)	0.33

Note: χ^2 difference test = model compared to previous, less constrained model.

In addition, anxiety was negatively correlated with adolescents' math achievement at both time points.

The measurement model for math anxiety was fully invariant over time (Table 3). The cross-lagged model for math anxiety and achievement is presented in Figure 1. The results showed that even after controlling for previous level of math fluency, high math anxiety at T1 predicted decreased math performance at T2. In turn, math achievement at T1 did not predict subsequent math anxiety at T2.

Additional multigroup analyses were conducted in order to test possible gender differences in the investigated associations. The results of these analyses revealed no significant differences ($p > 0.05$) between girls and boys in the strength of cross-lagged associations between math anxiety and math achievement.

STUDY 2

Materials and methods

Participants and procedure

The participants of study 2 comprised 148 sixth grade students, drawn as a subsample of the overarching longitudinal study's larger community sample of study 1 (see the description of study 1, and see Figure 2 for the sampling procedure). In the fall semester of the sixth grade, the community sample of about 850 students participated in a wider assessment that included an arithmetic group test (the 3-min Basic Arithmetic Test[36,37]). Of the larger sample, 149 students altogether were then selected to participate in individual tests. The sample was nonrandom: 83 of the students scored below the 16th percentile in the arithmetic test and 66 of the participants scored above 16th percentile. Selecting both adolescents with (below the 16th percentile) and without difficulties (scoring above 16th percentile) in arithmetic fluency for a subsample used in the study 2 was part of the sampling procedure of the broader study of which one aim was to investigate learning difficulties. These two groups were matched according to gender distribution and general cognitive ability. The latter was done using the Raven Standard Progressive Matrices test,[45] which consists of diagrams with one part missing, increasing in difficulty. Participants were asked to select the correct part completing each design. In the present study, a shortened version including half of the items (alternating) was used (see also Ref. 46). Responses were scored as correct or incorrect with the maximum score of 30 ($\alpha = 0.81$).

The individual assessments were carried out during the sixth grade spring semester. The assessments consisted of challenging and nonchallenging achievement tasks carried out with a computer, and also short questionnaires filled in before and after each task (for procedure of individual assessments and experiment, see also Refs. 45 and 47). Trained assistants carried out the experiment during regular school hours in a camper van equipped with a built-in ambulatory lab, including two computers (a presentation computer with a touchscreen and a measurement computer). Of all the individual tests, in the present study, we focus on the two arithmetic tasks: challenging and nonchallenging, and questionnaire items assessing state math anxiety after each task (the procedure illustrated in Figure 2).

Measures

Arithmetical achievement in challenging and nonchallenging arithmetic tasks

The challenging and nonchallenging arithmetic tasks were arithmetic tasks with a 4-min time limit, both consisting of a maximum of 40 items adopted from the 3-min Basic Arithmetic test.[36,37] For ensuring both challenging and nonchallenging conditions to as many participants as possible, the participants were divided into three different skill levels based on their previous performance in the basic arithmetic test (low performance = lowest quartile; medium performance = between lowest and highest quartiles; and high performance = highest quartile). The arithmetic test items were divided into six difficulty levels (1 = easiest; 6 = most difficult), based on the previous data from sixth grade fall assessment. The challenging and nonchallenging tasks for all three skill levels were then composed of the test items as described in Table 4. The tasks were different between the three skill levels, but the participants within each skill level received similar tasks.

The tasks lasted for 4 min each. All the students did two arithmetic tasks—one easy task and one difficult task—but the order of the task was counterbalanced between the students (Figure 2). Students did not receive any information about the difficulty before the upcoming task. The students made twice as many errors in the challenging task (40.3%; $SD = 24.7$) compared to the nonchallenging (18.4%; $SD = 15.5$), which indicates successful adaptation of the difficulty levels. For more

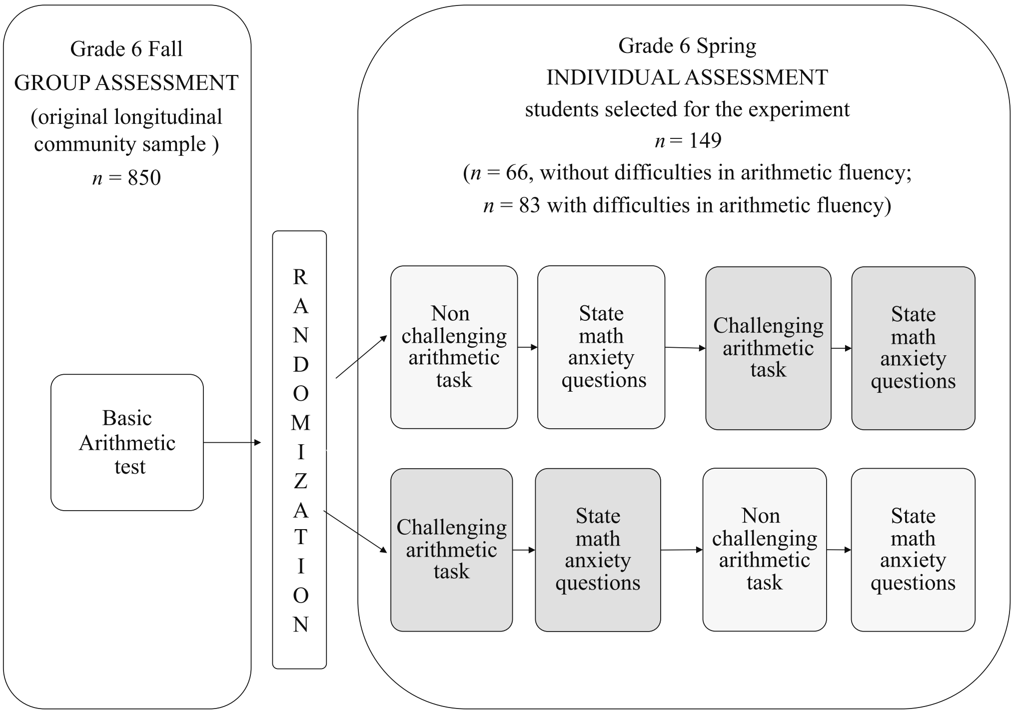

FIGURE 2 The procedure of study 2

TABLE 4 Adaptation of the items in the challenging and nonchallenging arithmetic tasks for three skill levels

	Task					
	Low performance		Medium performance		High performance	
	Nonchallenging	Challenging	Nonchallenging	Challenging	Nonchallenging	Challenging
Item difficulty levels	1–2	3–4	2–3	4–5	3–4	5–6

information about the performance of students on different skill levels in the arithmetic tasks, see Table 5.

Students' performance in these achievement tasks was measured as the number of correct answers, the general mean reaction time, the mean reaction time for correct answers, and the percentage of incorrect answers.

State math anxiety in the challenging and nonchallenging situations

State math anxiety was assessed with three items of a questionnaire immediately after each arithmetic task (easy and difficult), as part of a wider questionnaire, The Emotions in Achievement Situations scale,[48] which was adapted on the basis of the Achievement Emotions scale (AEQ)[38] and the Positive and Negative Affect Scale (PANAS).[49] The participants were asked how they felt during the task and they responded on a 5-point scale (1 = *disagree*; 5 = *agree*). The items assessing state math anxiety were: "*I was nervous/restless*," "*I was panicky/anxious*," and "*I was worried about how well I can do the task*." Cronbach's alpha for the scale was 0.64 in the easy task and 0.64 in the difficult task, and the factor score reliabilities were 0.92 for the easy tasks and 0.92 for the difficult tasks. For the analyses, we calculated the sum scores of state math anxiety separately for challenging and nonchallenging tasks (Table 6).

Statistical analysis

The analyses of study 2 were conducted using IBM SPSS Statistics (version 22). First, math anxiety sum scores were used for grouping the participants based on their reported state math anxiety arousal separately in challenging and nonchallenging task-performing situations. The same criterion for math anxiety was used in both easy and difficult tasks, since the items for measuring anxiety were the same for both tasks. The upper quartile for math anxiety sum score (i.e., approximately one and half standard deviation above the mean) in the nonchallenging task was 6 and for the challenging task was 7; the stricter one of them (7) was used as the criterion. Participants with

TABLE 5 Descriptive statistics of arithmetic achievement and general ability variables for the three skill levels

	Skill level		
	Low performance	**Medium performance**	**High performance**
	***M* (*SD*)**	***M* (*SD*)**	***M* (*SD*)**
Grade 6 Fall			
Basic Arithmetic Test	−1.40 (0.52)	0.06 (0.30)	1.09 (0.41)
Raven Standard Progressive Matrices Test – shortened version	−0.43 (0.88)	−0.20 (0.81)	−0.41 (0.96)
Grade 6 Spring – individual assessment			
Error rate			
Nonchallenging task	21.14% (17.25)	15.65% (12.14)	12.11% (10.99)
Challenging task	41.16% (25.29)	35.19% (24.08)	48.83% (21.39)
Sum of correct answers			
Nonchallenging task	17.14 (6.00)	20.22 (5.03)	19.39 (4.53)
Challenging task	8.16 (3.74)	8.38 (4.67)	5.33 (2.43)

Note: The means of correct answers for Basic Arithmetic Test and Raven Standard Progressive Matrices Test are standardized within the community sample ($n = 850$).

TABLE 6 Math anxiety scores in nonchallenging and challenging arithmetic tasks

Arithmetic task	*M* (*SD*)	Observed min	Observed max
Nonchallenging	5.21 (2.06)	3	12
Challenging	5.80 (2.36)	3	15

anxiety sum scores of 3–6 in a task were categorized as reporting "no math anxiety arousal," whereas participants with anxiety sum scores of 7–15 in a task were categorized as reporting "math anxiety arousal." Based on this categorization, the participants were divided into four groups: 1 = no anxiety arousal in either of the tasks (sum score of 3–6 in both tasks; $n = 97$); 2 = anxiety arousal in easy tasks (sum score of 7–12 in the easy tasks and 3–6 in the difficult tasks; $n = 5$); 3 = anxiety arousal in the difficult tasks (sum score of 3–6 in the easy tasks and 7–12 in the difficult tasks; $n = 23$); and 4 = anxiety arousal in both tasks (sum score of 7–12 in both tasks; $n = 23$). Because of its small size, group 2 was left out of the analyses. One of the participants who did not respond to math anxiety items at all was also excluded from the analyses. One-way analysis of variance (ANOVA) indicated that there was no mean-level difference between the anxiety groups in their performance in the previous autumn arithmetic group test (part of study 1) ($F(3,144) = 2.48$, $p = 0.06$, $\eta^2 = 0.12$).

The analyses were then accomplished by conducting two sets of repeated measures ANOVAs, with the scores of arithmetic performance (the sum score of correct answers and the mean reaction time in general) as dependent variables, anxiety group as a between-subjects factor, and the difficulty of the task (nonchallenging/challenging) as the within-subject factor. Before the analyses, we tested equality of variances between groups, and Levene's test showed that the assumption of equality of variances was met.

As follow-up analyses to examine whether the effect in the mean reaction time could be explained by differences in reaction time specifically for either correct or incorrect answers, we then conducted two more sets of repeated ANOVAs with reaction time for correct and incorrect answers separately as dependent variables, anxiety group as a between-subjects factor, and the difficulty of the task (nonchallenging/challenging) as the within-subject factor.

To make sure that the results were not biased because of the task adaptation (participants in different performance levels getting different tasks), we then reconducted the analyses with performance scores standardized separately within the three performance levels (low, medium, and high). Consequently, each student's standardized performance score represents the student's performance in relation to average performance in their own skill level in the assigned task that was either challenging or nonchallenging.

Finally, we conducted two sets of repeated ANOVAs *separately for every anxiety group*, with the standardized scores of sum of correct answers and the overall mean reaction time as dependent variables and the difficulty of the task as within-subject factor. Using standardized scores in these analyses enables examining whether participants' performance differed from their expected performance level when state math anxiety occurred.

Results

Repeated measures ANOVAs revealed a main effect of difficulty of the task (nonchallenging/challenging) on both the sum score of correct answers $F(2,140) = 454.27$, $p < 0.01$, $\eta_p^2 = 0.76$ and the overall mean reaction time $F(2,140) = 248.73$, $p < 0.01$, $\eta_p^2 = 0.64$. In addition, the analyses revealed an interaction effect of math anxiety group and the difficulty of the task, for both the sum score of correct answers ($F(2,140) = 4.97$, $p < 0.01$, $\eta_p^2 = 0.07$; Figure 3) and the overall mean reaction time ($F(2,140) = 5.26$, $p < 0.01$, $\eta_p^2 = 0.07$; Figure 4).

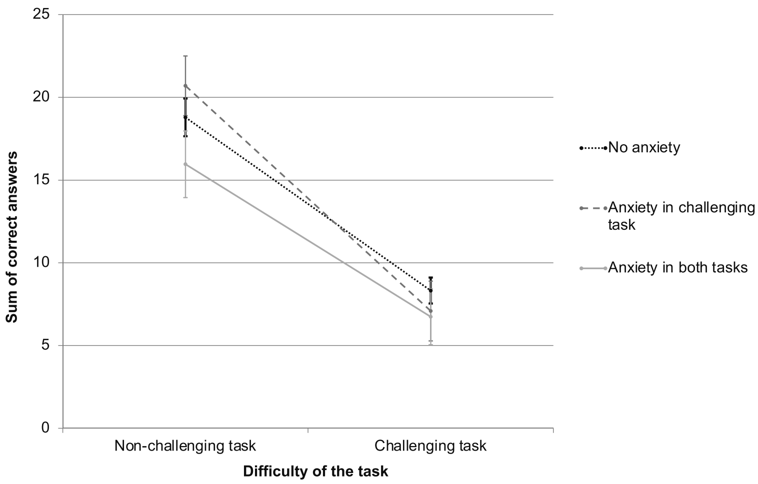

FIGURE 3 Means for the sum of correct answers for the three anxiety groups in nonchallenging and challenging tasks. Note that the scores are standardized within the difficulty level. Error bars represent the 95% confidence interval

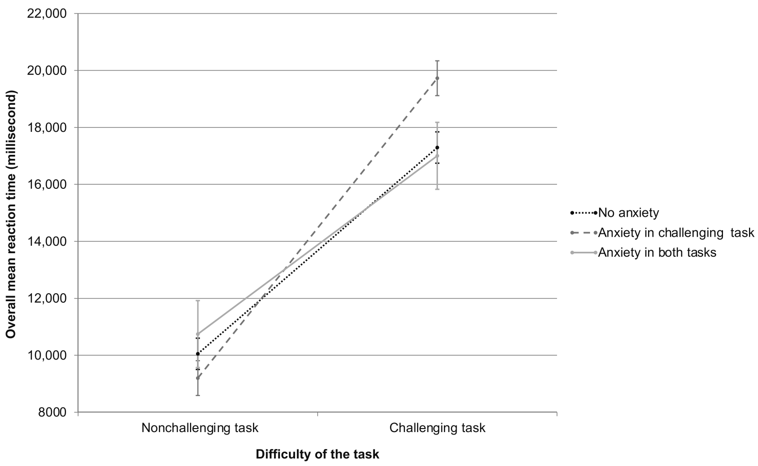

FIGURE 4 Means for the overall mean reaction times for the three anxiety groups in nonchallenging and challenging tasks. Note that the scores are standardized within the difficulty level. Error bars represent the 95% confidence interval

There was no interaction effect of math anxiety group and difficulty of the task for the mean reaction time *in either correct or incorrect answers*, indicating that participants performed slower in the task if they reported anxiety arousal, regardless of whether they had answered correctly.

To make sure that the results about the interaction effect were not biased because of the task adaptation (participants on different performance levels getting different tasks), analyses were then reconducted with performance scores standardized separately within the performance levels. Analyses with standardized scores still revealed the interaction effect of math anxiety group and the difficulty of the task, for both the sum score of correct answers ($F(2,140) = 4.22$, $p = 0.02$, $\eta_p{}^2 = 0.06$) and the overall mean reaction time ($F(2,140) = 6.65$, $p < 0.01$, $\eta_p{}^2 = 0.09$).

Finally, as follow-up analysis, in order to interpret the abovementioned interaction effects, we conducted two sets of repeated ANOVAs (with the standardized scores of sum of correct answers and the overall mean reaction time as dependent variables and the difficulty of the task as within-subject factor) *separately for every anxiety group* (Table 7). The results indicated that the students who reported math anxiety arousal only in the challenging tasks had relatively less correct answers in these tasks and also performed more slowly in them compared to nonchallenging tasks. Among students who either did not report anxiety arousal at all or reported it in both tasks, there were differences in their performance in the two levels of task difficulty.

Additional analyses: controlling trait math anxiety

Additional analyses showed that high trait anxiety was equally related to higher state anxiety during relatively less ($r = 0.35$, $p < 0.001$) and relatively more ($r = 0.39$, $p < 0.001$) challenging math tasks. Adding trait anxiety as a covariate in the analyses of study 2 did not change the results, and trait anxiety as a covariate was not statistically significant.

DISCUSSION

The aim of the present study was to shed light on the relationship between math anxiety and performance. Unlike in majority of previous studies, the relationship was examined from two perspectives: first,

TABLE 7 Results of repeated ANOVAs for the different math anxiety groups

	Standardized scores for sum of correct answers			Standardized scores for overall mean reaction time		
	Nonchallenging task	Challenging task		Nonchallenging task	Challenging task	
Anxiety group	*M* (*SD*)	*M* (*SD*)	*F* (*df*)	*M* (*SD*)	*M* (*SD*)	*F* (*df*)
No anxiety arousal	0.08	0.11	0.08	−0.03	−0.05	0.05
	(0.99)	(0.98)	(1.96)	(1.03)	(1.04)	(1.96)
Anxiety arousal in challenging task only	0.41	−0.20	6.96*	−0.35	0.41	15.75**
	(0.73)	(1.04)	(1.22)	(0.53)	(0.87)	(1.22)
Anxiety arousal in both tasks	−0.42	−0.29	0.44	0.23	−0.11	2.90
	(0.82)	(0.97)	(1.22)	(1.02)	(0.96)	(1.22)

*$p < 0.05$.
**$p < 0.01$.

developmentally focusing on trait anxiety with a longitudinal design, with predicting change in both constructs, when controlling for previous levels; and second, cross-sectionally focusing on the situational effect of state math anxiety on performance in more and less challenging math task situations.

Based on the previous research, we hypothesized (study 1) that we would find a reciprocal relationship between math anxiety and skill development in our longitudinal study (i.e., lower performance in sixth grade would predict higher math anxiety in seventh grade and that higher math anxiety in sixth grade would predict lower math performance in seventh grade, when controlling for the levels of math anxiety and performance from the previous time point). The only longitudinal effect found was a small negative effect of previous math anxiety on later performance. This result suggests that, in addition to a small cross-sectional association at sixth grade, math anxiety uniquely affected skill development over and above skill level from the previous time point (stability correlation of performance was 0.74, $p < 0.001$) during the transition from primary to secondary school. In addition, we found a situational association between math anxiety and math performance (study 2). The association was consistent across the subgroups composed based on their reports of anxiety across the challenging and nonchallenging task situations; when the participants were given easy and difficult arithmetic tasks adapted to their skill level, the students reporting anxiety only in the difficult task performed relatively lower in the difficult than in the easy task, whereas as those reporting similar level of anxiety across situations performed similarly in both tasks. In other words, it seems that arousal of anxiety was related to underperformance.

The results regarding the longitudinal relationship between math anxiety and achievement (study 1) give only partial support for the previous research suggesting a reciprocal relationship between math anxiety and achievement[5] and are contradictory to those of previous longitudinal studies that have found a longitudinal relationship between low performance and high anxiety.[13,26] However, the reciprocal relationship between math anxiety and achievement cannot be completely ruled out based on these results. It is possible that the relationship, or its direction, varies depending on the stage of schooling. In the present study, math anxiety and achievement were examined over the transition stage from primary to secondary school, whereas the previous studies have focused on either primary school children[13] or secondary and high school students.[26] The transitional stage from primary to secondary school has also previously been found to be related to increasing math anxiety, negative changes in students' attitudes toward mathematics, and decreasing enjoyment of mathematics.[25]

The finding that math anxiety longitudinally predicted lower achievement raises the question of the mechanisms via which math anxiety affects the development of arithmetical skills. One explanation might be that if, as has been suggested, anxiety disrupts the attentional system (attentional-control theory[19]) and burdens working memory,[20] as a more habitual trait, it might affect learning situations continuously, and thus disrupt skill learning and fluency development. Also, the avoidance behavior previously noticed as more common among math-anxious individuals[10] might explain the developmental effect; it is plausible that avoidance of math-related situations leads to a smaller amount of exercise which, in turn, results in slower development of mathematical skills.

In study 2, we examined the situational association between math anxiety and performance. In previous research among college students,[23,24] math anxiety has been found to have only a minimal situational effect on simple, single-digit arithmetic problems, but a notable effect on more complex, two-column problems, where individuals with high math anxiety made more errors and had slower performance. In the present study, the participants were primary school students with a large interindividual variation of mathematical skill levels. Thus, instead of categorizing arithmetic tasks as generally simple and complex, we aimed to provide all participants individually nonchallenging and challenging tasks, relative to their skill level. All the groups reacted faster and had more correct answers in the nonchallenging task compared to the challenging task, which indicates successful adaptation of the difficulty level.

Most of the students (66%) did not report anxiety at all in either of the tasks, whereas about 16% reported at least some levels of anxiety in both tasks and 16% only in the difficult task. Only few students (3%) reported anxiety in the easy task only. Those students reporting anxiety only in the difficult task had less correct answers and performed more slowly, relative to the other groups, in the difficult task compared to the easy task. The result that participants performed better when they did not feel anxious indicates a situational relationship between math anxiety and performance. It seems that, at least for the students reporting anxiety only in the challenging task, the results are in line with previous studies among college students,[23,24] indicating that math anxiety is related to both speed and accuracy of mathematical performance also among sixth graders.

The results of study 1 give support to the debilitating anxiety theory, in which the relationship between math anxiety and performance is explained by the debilitating effect of math anxiety on performance.[11] It is notable that the effect size of a cross-lagged effect from math anxiety to subsequent math achievement was small when controlling for the previous level of math achievement. The relatively small effect size of the cross-lagged effect compared to that of the cross-sectional association between anxiety and achievement partly reflects the high stability of math achievement across time (stability correlation was 0.74, $p < 0.001$), which leaves only little room to predict change. Besides, the cross-sectional correlations between latent factors of math anxiety and math performance were small, that is, –0.19 at T1 and –0.09 at T2. Although Hembree[10] reported somewhat higher average correlation (–0.27) between math anxiety and math performance across 150 studies, the individual studies included in the meta-analyses vary substantially with regard to the magnitude of estimated correlation between math anxiety and performance.

The underlying association between anxiety and performance may be complex and even nonlinear; sometimes, a certain level of anxiety and stress can also signal about the subjective importance of the task and subsequently boost better concentration and better task performance. Hence, it might also be that only particularly high levels of anxiety hinder performance in demanding situations or that there is interindividual variation in the effects of anxiety, meaning that some children are especially vulnerable for detrimental effects of math anxiety. In future studies, it might be useful to measure less stable and maybe more complex math skills—in the present study, we focused on basic arithmetic skills. Besides, since we assessed math anxiety and performance in a 1-year follow-up only, we cannot conclude that prior math anxiety would predict performance through all schooling. More longitudinal studies with longer follow-up periods and measures of math skills—not just basic arithmetical skills but also more complex skills with less stability—are needed to explore the long-term developmental relationships. Moreover, applications of person-centered approaches would be useful for exploring different developmental pathways and possible nonlinear associations between adolescents' math anxiety and performance also.

Unfortunately, causal claims about the situational association between math anxiety and performance cannot be made based on the results of study 2. Since the students reporting anxiety only in the difficult task performed relatively lower in the difficult than in the easy task, compared to their skill level, it seems that anxiety is somehow related to *underperformance*. One explanation for this result is that math anxiety arousal disrupts performance. However, it also might be that students' own estimates of failure or underperformance in challenging tasks causes anxiety arousal. Furthermore, it might be both math anxiety disrupting performance and underperformance arousing anxiety in vicious circle. In the future research, situational study designs should be developed to be able to test this causal relationship explicitly.

There are some other limitations concerning our math anxiety measures that should be noted. In the present study, we investigated math anxiety from two perspectives: trait and state anxiety.[27,28] However, the dimensionality of math anxiety was not considered; math anxiety can be divided into different dimensions based on whether it arises in testing, problem-solving, or social situations.[1,50,51] In both substudies, the math anxiety scale consisted of only three items, which also affected the reliability of the scale. Despite somewhat low Cronbach's alpha (0.64 at the first time point and 0.72 at the second time point), the factor score scale reliability of math anxiety was nevertheless high (0.84 at the first time point and 0.87 at the second time point), and the interitem correlations of anxiety items ranged from 0.37 to 0.40 ($p < 0.001$) at time 1 and from 0.40 to 0.57 ($p < 0.001$) at time 2. Three items have also previously been found satisfactory for measuring math anxiety and other academic anxieties.[52,53] Furthermore, general anxiety that has been found to be highly correlated with math anxiety[54] was not controlled for in the present study. However, the results of the study of Carey *et al.*[50] suggest that math anxiety is a unique construct, separate from both test anxiety and general anxiety. Finally, in study 2, we used quite lenient cutoff criteria (upper quartile, i.e., approximately one and half standard deviation above the mean) for dividing the participants into math anxiety groups. Future studies with tighter cutoff scores for math anxiety are needed in order to shed light on the mechanisms, especially among severely anxious adolescents.

The results suggest that the relationship between math anxiety and performance is two-fold: math anxiety is both situationally and longitudinally related to math performance. Math anxiety was viewed from two perspectives—as an individual trait (trait anxiety)[27,28] and as an emotional state (state anxiety)[27,28]—in order to get a wider and more complete picture of the relationship between math anxiety and performance. Based on the results of additional analyses, the two views are somehow related. Nevertheless, controlling for trait anxiety did not change the situational relation between math anxiety and performance; therefore, it seems that the situational effect of math anxiety was a result of a situational emotional state rather than just a permanent tendency to feel anxious about mathematics. However, in future research, different study designs would be needed to explore the relationship between the two views more deeply, as well as the causal directions in the relationship between situational math anxiety and performance.

CONCLUSIONS

Some practical implications can be proposed based on these results. In the school, teachers should be increasingly aware of math anxiety and its consequences. The results of the present study should be taken into consideration in two ways. First, teachers should pay specific attention to the students who continuously seem to become anxious in situations related to mathematics, because math anxiety, as an individual trait, seems to have a longitudinal effect on the development of mathematical skills. Second, in effective math instruction, arousal of stress and anxiety should be minimized. Since math anxiety has a situational effect on performance, the students learn less efficiently when feeling anxious. Additionally, the students should be made more aware of the effect of emotions on both learning and performing.

The results of the present study, along with previous research, underline the complex relationship between math anxiety and performance. They adduce the two-fold relationship between anxiety and achievement: math anxiety seems to have both a real-time association with performance when occurring and a long-term effect on the development of basic arithmetic skills. In future, for gaining more comprehensive understanding, the research should take into account both perspectives: math anxiety as a situational state and as an individual trait, especially when investigating the mechanisms behind the relationship between math anxiety and achievement.

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AUTHOR CONTRIBUTIONS

R.S. analyzed and interpreted the data and drafted the manuscript. N.K. designed and coordinated the study and participated in the interpration of the data and drafting the manuscript. T.K., T.A., H.V., and M.A. participated in the interpration of the data and the results and drafting the manuscript. T.A. partipated in the design and coordination of the study and revising the intellectual content of the manuscript.

COMPETING INTERESTS

The authors declare no competing interests.

PEER REVIEW

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