

**"I Can't Do Math." The Experience of Math Anxiety and Math Related Intrusive
Thoughts in Men and Women**

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THE EXPERIENCE OF MATH RELATED INTRUSIVE THOUGHTS

ABSTRACT

**“I Can’t Do Math.” The Experience of Math Anxiety and Math Related Intrusive Thoughts
in Men and Women****Geneviève Trudel****University of Ottawa, 2024**

The underrepresentation of women in science, technology, engineering, and math (STEM) fields is a well-recognized concern and is often attributed to the importance of mathematics within STEM disciplines. Math anxiety has been suggested to be more prevalent among women which could potentially act as a barrier to their pursuit of STEM careers. This dissertation's primary objective was to gain a better understanding of gender differences in math anxiety. Study 1 aimed to identify whether math anxiety may mediate the relation between gender and math performance in a sample of undergraduate students ($N = 389$). Results revealed that women reported higher math anxiety and exhibited lower math performance compared to men. Moreover, math anxiety partially mediated the association between gender and math performance. Researchers have also primarily focused on the cognitive interference model to explain the link between math anxiety and math performance. This account posits that intrusive thoughts experienced by individuals with math anxiety disrupt the working memory processes necessary for successful math performance. Thus, Study 2 and Study 3 focused on the gender differences in the frequency and types of intrusive thoughts experienced during math tasks. In Study 2 we found that among a sample of 309 undergraduate students, math anxiety significantly predicted the frequency of intrusive thoughts, while gender was not a predictor. The most common intrusive thoughts were related to making mistakes, previous math experiences, and problem-solving methods. Study 3 ($N = 437$) aimed to examine whether intrusive thoughts

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differed based on the working memory demand of the task. Results indicated that women and higher math anxious individuals experienced more intrusive thoughts. Additionally, higher working memory demand tasks elicited more intrusive thoughts. The most common intrusive thoughts were related to making mistakes, previous math experiences, and time pressure.

Overall, this dissertation contributes valuable insights into the complex relation between gender differences, math anxiety, math performance, and intrusive thoughts during math tasks.

Understanding these factors is essential to finding effective interventions for math anxiety which could potentially help address the underrepresentation of women in STEM fields.

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DEDICATION

To my mother who has always gone above and beyond to support me in every pursuit, especially my deepest aspiration of becoming a psychologist. Your unwavering belief in me, relentless encouragement and enduring support have been a driving force behind my journey.

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CONTRIBUTION OF AUTHORS

This dissertation is comprised of a multiple-article format including three articles. The research in all articles was approved by the University of Ottawa's Research Ethics Board. For the first article, *Understanding Gender Disparities in Math Performance: The Role of Math Anxiety*, Véronic Delage, honours student, contributed to the methodological design, data collection, and data cleaning while Fraulein Retanal, the laboratory coordinator, contributed to the data collection and the data cleaning. For the second article, *Understanding Intrusive Thoughts in Math Tasks and The Role of Gender and Math Anxiety*, Dr. Denis Cousineau contributed to the statistics. For the third study, *Math Anxiety, Gender, and Intrusive Thoughts: A study Exploring Working Memory Demand*, both Dr. Simon Beaudry and Dr. Cousineau contributed to the statistics.

For all three articles, Geneviève Trudel's contributions included theoretical and methodological formulations, literature review, experimental research design, ethics application, data collection, data cleaning, data analysis, thesis proposal, manuscript preparation, and manuscript revision. Dr. Maloney oversaw the conceptualization of the articles.

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CHAPTER ONE:

GENERAL INTRODUCTION

Emotions are episodic in nature (Ekman, 1992) and can be triggered by events that are external (e.g., encounters with undesirable stimuli) and/or internal (e.g., thoughts, memories, sensations; Scherer, 2000). Popular models of emotions, such as discrete emotion models, describe emotions as eliciting changes in cognition (e.g., attention), judgement (e.g., perception of risk), experience (e.g., recognition of emotion), behaviour (e.g., running away), and physiology (e.g., heart racing; Lench et al., 2011). Together, these encourage a tailored reaction to the specific environmental change that has triggered the emotion (Lench et al., 2011).

Emotions can also motivate an individual to approach or avoid a specific situation. Positive emotions (e.g., happiness) tend to encourage an individual to approach a situation/stimulus whereas other, more negative emotions (e.g., fear and anxiety), tend to encourage avoidance of a situation/stimulus (Bechara et al., 1997; Lench et al., 2011; Phat, 2014).

Fear and anxiety are normal emotional responses that occur when an individual perceives danger or threat (Milne et al., 2019). They are adaptive responses aimed at motivating reactions that will alleviate the uncomfortable emotion (Rosen & Schulkin, 1998). Though there are similarities between fear and anxiety, these emotional reactions are distinct. Fear is defined as a response that immediately prompts protective actions to shield oneself from the imminent danger or life-threatening circumstances (Barlow, 2000). In contrast, anxiety is a sense of apprehension that arises from the anticipation of potentially harmful events, even when the source of the threat is unknown (Barlow, 2000). Our body responds to three primary types of threats: external, internal, and conditioned (McKay et al., 2017). External threats involve dangers stemming from outside forces (e.g., loss of your job; McKay et al., 2017). Internal threats arise from sensations

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within our bodies, such as those associated with danger (e.g., rapid heartbeat, shortness of breath, dizziness), that may be interpreted as threatening despite originating from internal sources (McKay et al., 2017). The third type of threat is conditioned threat, which pertains to objects, situations, or internal experiences that may not inherently pose significant danger but have become associated with the anticipation of harm (McKay et al., 2017). For example, though math may not pose a danger, repeated negative experience in math-related situations can lead to associations of math with feelings of inadequacy, anxiety, and/or embarrassment (e.g., Beilock & Maloney, 2015; Luttenberger et al., 2018). The way individuals perceive threats has long been identified as a key cognitive process in the emergence and maintenance of anxiety and anxiety related disorders (e.g., Butler and Mathews, 1983; Carr, 1974). Threat appraisal is defined as an individual's assessment of both the likelihood and seriousness of a potential negative future event (Carr, 1974). It is suggested that some individuals are more prone to anxiety (anxiety proneness) due to inaccuracies in evaluating the probability and severity of a threat while underestimating one's ability to cope with the threat (Beck et al., 1985 as cited in Milne et al., 2019).

A cognitive behavioural model is often used to conceptualize anxiety and anxiety disorders (Rapee & Heimberg, 1997; Wells, 1999). According to this model, thoughts, feelings, behaviours, and physiology interact together and with the environment to produce and maintain anxiety (Josefowitz & Myran, 2017). This model refers to thoughts as automatic because they happen very quickly and often without conscious awareness (Josefowitz & Myran, 2017). It is normal for individuals to experience an array of automatic thoughts throughout the day, and most are not associated with any strong emotional reactions (e.g., "I wonder if the sun will be out tomorrow?"; Josefowitz & Myran, 2017). However, some automatic thoughts can be associated with a negative feeling of anxiety (e.g., "What if I forgot that I have a math test tomorrow?"). In

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these instances, the thoughts can influence an individual's feelings, physiology, and behaviours (Josefowitz & Myran, 2017). For instance, if an individual has the automatic thought "What if I forgot that I have a math test tomorrow?" they may become anxious and notice physiological symptoms such as a rapid heart rate, difficulties breathing, sweating, and feeling tense. Given the circumstances, the individual will likely be propelled to engage in a certain behaviour such as checking their agenda or studying for the test. With chronic anxiety and/or anxiety disorders, individuals consistently misinterpret situations as being threatening (McKay et al., 2017). To alleviate the anxiety experienced, individuals may engage in safety behaviours, defined as actions designed to shield them from threats (McKay et al., 2017). There are two types of safety behaviours: avoidant and approach. Avoidant safety behaviors involve actions or strategies aimed at avoiding or reducing anxiety-inducing situations (e.g., I feel anxious that I may have forgotten that I have a math test tomorrow so I will avoid it and go play videogames to distract myself). In contrast, approach safety behaviors entail actively confronting anxiety-provoking situations while employing strategies to prevent or minimize the feared outcome (e.g., I am anxious that I may have forgotten the math test so I will check my agenda a few times per day, ask friends, and email my teacher).

What Contributes to Anxiety?

Anxiety is a complex psychological phenomenon influenced by various factors, including biological predispositions, past experiences, and individual gender differences. While these factors play significant roles in the development and manifestation of anxiety disorders, the etiology of anxiety is complex and not fully understood.

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Biological Factors

Genetic factors seem to play an important role in the development of anxiety disorders with a portion of its variance being explained by genetics (Franić et al., 2010; Van Houten et al., 2013). Some evidence suggests that individuals with family members who have an anxiety disorder have an increased likelihood of experiencing anxiety themselves (Hettema et al., 2005). While specific genes have been identified as contributing to anxiety (e.g., BDNF), anxiety disorders are not solely determined by a single gene but rather multiple genes interacting together (Tocchetto et al., 2011). Some of these genes also impact neurotransmitters (e.g., serotonin, norepinephrine, GABA), which play a pivotal role in the development of anxiety disorders (Chan et al., 2023). Furthermore, alterations in brain activity, such as irregularities in cerebral blood flow and metabolism can also precipitate anxiety (Bonne et al., 2003).

Past Experiences

Traumatic life events including but not limited to sexual, physical, and emotional violence and neglect, significantly heighten an individual's susceptibility to anxiety disorders (e.g., Chen et al., 2010; Fernandes and Osório, 2015). While everyone is at risk of traumatic events, evidence suggests that traumatic experiences appear to be more prevalent among girls and women compared to men (e.g., Stoltenborgh et al., 2011) increasing their vulnerability to anxiety disorders.

Gender

Women are approximately twice as likely to develop anxiety disorders than men (Wittchen et al., 2011; Remes et al., 2016). This difference often starts around the age of six and remains constant across the life span (Beesdo et al., 2009; Costello et al., 2011; Wittchen et al., 2011; Steel et al., 2014). Anxiety disorders seem to also be more chronic and disabling for women

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leading to more severe symptoms of anxiety as well as more somatic complaints than men (McLean et al., 2011). Some researchers suggest that women may have a more sensitized hypothalamic-pituitary-adrenal (HPA) axis (i.e., a system that regulates the stress response system) than men (Kudielka and Kirschbaum, 2005; Goel et al., 2014). As such, this increases their adrenal reactivity and cortisol levels making them more vulnerable to anxiety disorders (Kudielka and Kirschbaum, 2005; Goel et al., 2014; Hallers-Haalboom et al., 2020).

Additionally, there seem to be sociocultural and psychological factors that influence the difference in anxiety occurrence between men and women. For instance, women are more prone to worry, interpret threats as more unpredictable, and perceive symptoms of anxiety as more dangerous than men (McLean & Anderson, 2009; Nolen-Hoeksema, 2012). These differences may be in part related to women's need for affiliation, which refers to an inclination to seek closeness and engage in interdependent relationships (Drescher and Schultheiss, 2016). Though an adaptive response, if the attempt to affiliate is not reciprocated or results in negative outcomes, it can ultimately lead to an increased stress reaction (Taylor, 2006). Researchers have also found that women are more likely to comply with other's desires and have difficulty with assertiveness which, again, increases their vulnerability to anxiety (Hallers-Haalboom et al., 2020). This tendency could partly result from interactions between parents, typically mothers, and daughters, which emphasizes the importance of affiliation and interpersonal closeness, while interactions with boys may prioritize assertiveness and dominance (McLean and Anderson, 2009). Additionally, in a study by Khan and Khan (2020) they identified factors such as loneliness, experiences of bullying, physical abuse, and strained relationships with parents and peers to increase the likelihood of developing an anxiety disorder. They also found that these

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factors had a more pronounced effect on girls, exacerbating the onset and progression of anxiety symptoms as compared with boys.

What are the Consequences of Anxiety?

Left untreated, anxiety may have an array of negative consequences such as comorbid psychopathologies, health consequences, and diminished performance on cognitively demanding tasks, to name a few. Anxiety and anxiety disorders are highly comorbid with other psychopathologies, especially mood disorders and other anxiety disorders. For example, individuals with generalized anxiety disorder (a disorder characterized by excessive and persistent worry) often are also diagnosed with another anxiety disorder and a depressive disorder (APA, 2022). Additionally, the comorbidity between panic disorder and major depressive disorder ranges from 10% to 65% (APA, 2022). Anxiety disorders also increase the risk that individuals may engage in unhealthy behaviours such as nicotine use, physical inactivity, and alcohol use, which subsequently increases the risk of chronic health conditions including but not limited to diabetes, asthma, and cardiovascular disease (Sawchuk et al., 2011). Left untreated, anxiety can lead to individuals taking more days off from work resulting in negative economic consequences and higher rates of unemployment among individuals who struggle with anxiety disorders (Kasper, 2006). Moreover, anxiety also impairs performance on more cognitively demanding tasks (Eysenk & Calvo, 1992; this is further discussed in the section Working Memory). This phenomenon is prevalent in cognitively demanding tasks like mathematics, which may lead to challenges encountered in this domain.

Math Anxiety

Math anxiety is the feeling of fear, tension and apprehension experienced towards math or the prospect of completing math related tasks (Ashcraft, 2002; Hembree, 1990). Math anxiety

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shares many commonalities with other types of anxiety, but it is different from both general anxiety (Hembree, 1990; Hill et al., 2016) and test anxiety (Kazelskis et al., 2000; Ashcraft, 2002). General anxiety (often divided into both state and trait anxiety) refers to the likelihood of an individual worrying about events, behaviours, and personal abilities (Hill et al., 2016). Trait anxiety refers to an individual's typical and more stable feelings of anxiety whereas state anxiety refers to momentary anxiety levels given the circumstances (Spielberger, 2010). Despite being conceptually different from math anxiety, general anxiety shares a moderate correlation with math anxiety (Hembree, 1990; Hill et al., 2016) and math anxiety is often influenced by general anxiety levels (Hill, 2016). Test anxiety refers to anxiety that arises when an individual is faced with an academic test and can be experienced in other domains than math (Kazelskis et al., 2000). Similarly to general anxiety, test anxiety shares moderate correlations with math anxiety (Hembree, 1990).

Math anxiety is not considered a diagnosable disorder recognized by the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, Text Revision (DSM-V-TR; American Psychiatric Association, 2022); however some researchers refer to it as a genuine phobia (Kunwar, 2020; Nnamdi Obikeze, 2019). When engaging with mathematics, those with higher levels of math anxiety can have an array of negative responses, ranging from mild reactions such as slight frustrations to severe reactions containing both emotional and physiological disruptions (e.g., bursting into tears; Ashcraft & Moore, 2009).

Math anxiety is believed to be multidimensional, and the items used within a scale influences the component of math anxiety measured (Barroso et al., 2021). Through the years, researchers have uncovered various components of math anxiety, including math test anxiety (Gierl & Bisanz, 1995), numerical processing anxiety (Wu et al., 2012), math problem-solving anxiety

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(Gierl & Bisanz, 1995), and math error anxiety (Ganley & McGraw, 2016). Given the overlap between these dimensions (Barroso et al., 2021), some researchers only distinguish between two components of math anxiety, 1) math evaluation anxiety, which refers to anxiety that arises when studying for or completing a math evaluation and 2) math learning anxiety, which is the anxiety that arises when an individual is faced with situations related to math learning (i.e., math classes; Hopko et al., 2003). Others, especially those using a cognitive behavioral approach, describe two dimensions to math anxiety, that is, the affective dimension and the cognitive dimension (Bicer et al., 2020). The affective dimension refers to the emotional component of math anxiety, that includes the physical reactions, the feelings of tensions, and overall nervousness. The cognitive dimension relates to the negative thoughts, beliefs, and expectations towards a math situation (see Bicer et al., 2020 for review). It remains unclear however which dimensions of math anxiety are measured using which scale (Namkung et al., 2019) and, for this reason, most researchers do not distinguish between dimensions of math anxiety in their research.

Math anxiety is also seen around the world (Foley et al., 2017). Across 39 countries, 31% of 15-year-old students reported “that they get very nervous doing mathematics problems” (OECD, 2015, p. 2). Math anxiety also starts young. Children as young as first grade report experiencing various levels of math anxiety (Ramirez et al., 2016; Szczygieł & Pieronkiewicz, 2022). This anxiety peaks in adolescence, around 9th and 10th grade when math is believed to become more complex (Hembree, 1990). Individuals are then believed to maintain this level of math anxiety into adulthood (Donelle et al., 2007). Not only is math anxiety seen around the globe, but it is also quite common within North America.

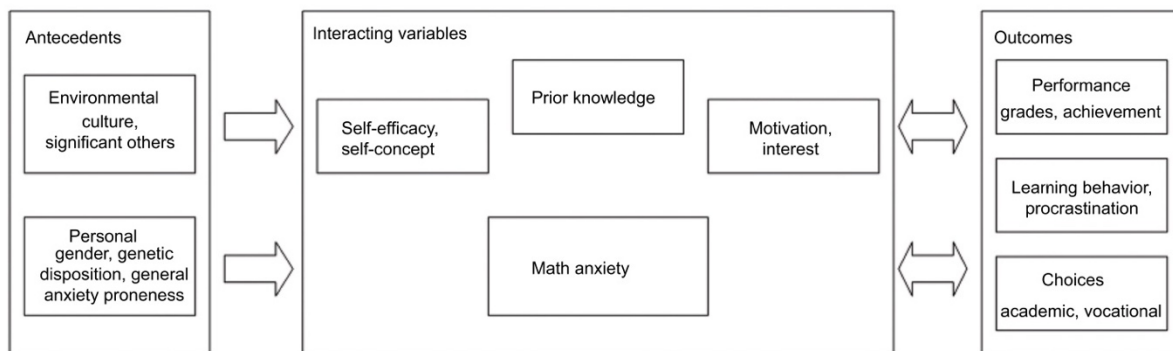
Lutterburger and colleagues (2018) have proposed a framework to conceptualize math anxiety and its effects. Their framework (visually represented in Figure 1) illustrates antecedents,

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interacting variables and outcomes of math anxiety. Among antecedents, they highlight that math anxiety can be influenced by environmental factors such as culture and messages conveyed by parents, as well as by genetic predispositions, general anxiety proneness, and gender.

Additionally, they outline variables that interact with math anxiety such as self-efficacy, prior knowledge of math, and motivation/interest for math. Together, these variables influence the outcome of math anxiety which relate to performance, learning behaviours, and academic choices. The different components of this framework will be unpacked throughout the general introduction.

Figure 1. Math Anxiety Framework



Note. Figure from Lutterberger et al., 2018

Why do some people develop math anxiety?

The antecedents of math anxiety have been a subject of interest for years and many researchers have proposed theories of its origins. Although there are certain genetic and environmental factors that are common to all types of anxieties, it is agreed that there are also specific genetic and environmental influences that contribute specifically to math anxiety (Malanchini, et al., 2017; Wang et al., 2014).

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Culture

There is evidence to suggest that culture seems to influence math anxiety. For instance, using data from 15-year-old students across several countries (Program for International Student Assessment; PISA), Fan and colleagues (2019) compared profiles of math anxiety among 15-year-old students. By comparing students from the United States, Korea, and Finland, they identified that Korean students appeared to have overall more math anxiety. However, among students who reported experiencing math anxiety, those from the United States reported the highest levels of math anxiety compared to math anxious students from Korea and Finland. Fan and colleagues (2019) hypothesized that various factors may influence these findings such as gender stereotypes, as well as teacher and parent expectations.

Significant Others

There is further compelling evidence suggesting that the foundations of math anxiety are often present in early childhood (Beilock & Maloney, 2015). A study by Soni and Kumari (2017) revealed that parents with higher math anxiety tended to have children who were themselves more math anxious and had lower performance in math. The study highlighted how parents' attitudes towards math could impact their communication about the subject, potentially contributing to the development of math anxiety in their children. Maloney and colleagues (2015) suggested that parents with higher math anxiety who often helped their children with math homework had children who themselves developed math anxiety and had lower math achievement. When higher math anxious parents refrained from helping their children in math, however, there seemed to be no negative consequences on the child's math anxiety. It seems that by helping their children in math, there may be the opportunity for a higher math anxious parent to express their frustration and strong dislike for math to their child (Beilock & Maloney, 2015).

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Children can internalize these beliefs resulting in lower motivation to complete math, reduced efforts in math, and eventually increased math anxiety and lower math performance (Beilock & Maloney, 2015). This can lead to a harmful cycle where math anxiety lowers performance in math tasks, leading individuals to avoid math, thereby increasing their anxiety about the subject even further (Beilock & Maloney, 2015).

Another important role model in children's lives is their schoolteacher. Unfortunately, teachers who have math anxiety themselves can convey negative math attitudes to their students (Maloney & Beilock, 2012; Schaeffer et al., 2020). According to Beilock et al. (2009), girls seem to be most affected by teachers' math anxiety. In fact, girls in classes with female teachers (in Canada, about 84% of elementary school teachers identify as female; Statistics Canada, 2014) who have higher math anxiety, often learned less math during the school year (Beilock, Gunderson, Ramirez, & Levine, 2009). Schaeffer and colleagues (2020) replicated the study conducted by Beilock et al., 2009 and found evidence that teachers' math anxiety influenced their students' overall math learning over the school year. Specifically, boys and girls equally learned less math when their teacher experienced higher math anxiety than when their teachers were less math anxious.

Genetic predispositions

Emerging evidence also suggests that math anxiety, similar to other types of anxiety, is influenced by genetic factors. Wang and colleagues (2014) investigated math anxiety in sets of adolescent twins and found that 40% of the variation in math anxiety was attributable to genetics. The rest of the variation was accounted for by individual-specific environmental factors.

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Anxiety Proneness

As described above, anxiety proneness, refers to an individual's tendency to perceive stressful situations as threatening (Reiss, 1997). This stable individual difference increases the likelihood of individuals interpreting stressful math tasks as being threatening and therefore increases their vulnerability to math anxiety (Luttenberger et al., 2018). A meta-analysis by Hembree (1990) found that math anxiety and anxiety proneness had positive correlations ranging from $r = .24$ to $r = .54$.

Gender

The evidence on gender differences in math anxiety has been inconsistent at best. Some studies have found math anxiety levels to be similar among men and women (e.g., Haynes et al., 2004; Levy et al., 2021). However, other studies have found women to experience higher levels of math anxiety than men (e.g., Miller & Bichsel, 2004; Else-Quest et al., 2010; Zhang et al., 2019; Xie et al., 2019) such as a study of 761,655 high school students from 68 nations (Stoet et al., 2016). The context in which researchers measure math anxiety also seems to matter. One study's finding suggested that women exhibited higher levels of math anxiety solely in academic environments, whereas no gender differences were observed in non-academic settings (Roick et al., 2013 as cited in Henschel & Roick, 2020). Girls have also been found to experience more math anxiety related to high stake math tasks (e.g., math evaluations), however, in these same situations, there was more variance in the level of math anxiety for boys (Henschel & Roick, 2020).

Much research has been conducted to investigate the reasons why a gender difference may exist in math anxiety. Overall, researchers seem to propose that these differences may be due to reporting bias, uncontrollability perception, and/or stereotype endorsement.

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Reporting bias. Reporting bias happens when individuals respond in a specific way to make themselves seem favorable (Donaldson & Grant-Vallone, 2002). Some researchers propose that the apparent gender difference in math anxiety may not necessarily reflect an actual disparity in experienced anxiety. Instead, it is suggested that women are simply more likely to report experiencing anxiety than men (Ashcraft, 2002). Math is often perceived as being a male domain field (Heilman, 1983; Makarova et al., 2019; Deiglmayr et al., 2019). Therefore, men may hide their math anxiety to cater to this widely held belief (Xie et al., 2019). Alternatively, Goertz and colleagues (2013) suggested that women may report higher levels of math anxiety because of their belief that they have low competencies in math. This may drive them to perceive and report higher levels of math anxiety than what they truly experience.

Uncontrollability perception. Another explanation for the gender difference in math anxiety is uncontrollability perception. Generally, stress emerges in situations which have previously proven to be unpredictable (Zirk-Sadowski et al., 2014). Thus, the uncontrollability perception arises in situations where individuals become anxious as a result of feeling that they have little to no control (Zirk-Sadowski et al., 2014). In these situations, individuals can sometimes experience learned helplessness (i.e., a condition where an individual suffers from feeling powerless) which leads to an accelerated deterioration of performance (Seligman & Maier, 1967). In their study, Zirk-Sadowski and colleagues (2014) found uncontrollability perception to be one of the causes of math anxiety. Specifically, they found that women have lower perceptions of control when learning math and that this mediated the relation between gender and math anxiety.

Stereotype endorsement. Another body of literature suggests that stereotype endorsement may influence the gender differences in math anxiety. A stereotype is defined as the belief that a

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particular group has specific characteristics and/or engages in specific behaviors (Beeghly, 2015). For years, men have been believed to be naturally better at math than women. Although this stereotype is less prominent today, it is being observed in educational settings (Jao & Radakovic, 2017). Furthermore, among a sample of adults from Ontario, Canada, approximately one-third of the participants held the belief that boys possess superior mathematical abilities compared to girls (Jao & Radakovic, 2017). Within this same sample, a significant proportion of the participants believed that parents are more inclined to perceive their sons as being better at math than their daughters. Women who internalize this stereotype may form a distorted perception of their mathematical abilities (Bonnot & Croizet, 2011) which could contribute to higher levels of anxiety. Bieg and colleagues (2015) found that women who endorse the stereotype that math is a gendered domain often experience higher levels of math anxiety whereas men who endorse this stereotype often have lower levels of math anxiety.

What influences math anxiety?

Self-Efficacy and Self-Concept

Within the context of mathematics, self-efficacy refers to an individual's perception that through their own actions and efforts they can be successful in math (OECD, 2012). Self-efficacy is also closely related to self-concept which refers to an individual's perception of competence within math (Marsh & Scalas 2011). Both high self-efficacy and self-concept in math have been identified as protective factors against math anxiety and to be positively correlated with performance in the PISA studies (OECD, 2012). Self-efficacy, self-concept and math anxiety seem to share a reciprocal relationship (Luttenberger et al., 2018). For instance, increases in math performance tends to be associated with increased self-concept and lower math anxiety (Marsh & Scalas, 2011; Marsh, et al., 2013; Kaskens et al., 2020).

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Prior Knowledge

Research also indicates that inadequate math skills can trigger math anxiety, which in turn may lead individuals to avoid math-related tasks, resulting in missed opportunities to improve their math skills (Carey et al., 2016). Consequently, individuals with higher levels of math anxiety may represent and/or process numbers differently than individuals with lower levels of math anxiety (Maloney et al., 2010; Maloney et al., 2011; Beilock & Maloney, 2015).

Specifically, in a study by Maloney and colleagues (2010), higher and lower math anxious undergraduate students were shown one to nine squares and asked to identify the number of squares presented. When participants were presented with one to four squares, higher and lower math anxious individuals performed similarly. However, when participants were presented with five or more squares, those with higher math anxiety were slower and made considerably more mistakes. Thus, when individuals with higher math anxiety are subitizing (usually identifying one to four objects, which does not require counting) there is no relation with their performance. When individuals are required to count (when five or more objects are presented) however, individuals with higher levels of math anxiety have more difficulty. Counting is considered a foundational skill which is required for higher level math (e.g., Geary, 1993). Thus, those with higher math anxiety may lack the necessary skills to grasp the essential concepts required in more advanced math.

Individuals who are higher in math anxiety also have more difficulty comparing the magnitude of two numbers than their lower math anxious counterparts. Numerical magnitudes are believed to be mentally represented on a mental number line (which is like a mental ruler). This number line is believed to help us conceptualize and efficiently process the difference in magnitude between numbers (Dehaene, 2011). The closer numbers are to one another (e.g., two

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and three) the closer their location is on our mental number line. Importantly, Maloney and colleagues (2011) found that individuals with higher math anxiety were slower at identifying which number was the largest when presented with two numbers. This suggests that individuals who have higher levels of math anxiety also have a less accurate representation of numbers (Maloney et al., 2011). This is an important consideration given that, much like counting, mental number lines are believed to be a foundational concept required to be able to understand and perform more advanced math (Beilock & Maloney, 2015)

Motivation and Interest

Motivation can be defined as internal and/or external factors that drive, direct, and sustain an individual's behaviour towards achieving a goal or outcome (Locke, 2023). Students who are more highly motivated in a specific subject tend to dedicate more time and effort to learning the subject and use more effective learning strategies (Macher et al., 2015). Research with children and adults has identified a negative correlation between math anxiety and performance in individuals with lower motivation, indicating that lower motivation combined with higher math anxiety may contribute to poorer math performance (Wang et al., 2015). However, these same researchers have found a non-linear relation for those with higher levels of math anxiety. It is possible that for students who are highly motivated in math, a moderate degree of math anxiety may push them to study more and more effectively resulting in beneficial effects.

What are the Consequences of Math Anxiety?

Poor Math Performance

Through the years, there has also been much interest in understanding the outcomes of math anxiety. One of its most explored and consistent outcomes is its relation to poor math performance (e.g., Ashcraft et al., 2007; Carey et al., 2016; Pellizzoni et al., 2022).

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Math anxiety and math achievement have been found to have a small-to-moderate negative correlation in populations of various ages (Barroso et al., 2021). The relation between math anxiety and math achievement is most often investigated using mental arithmetic. However, there is some evidence to suggest that math anxiety does not affect all types of math to the same extent (e.g., Vukovic et al., 2013). Specifically, the level of difficulty involved in the math task seems to play an integral role in math anxiety and therefore its link to lower math performance (Ching, 2017).

Three prevailing theories have been brought forth to explain the relation between math anxiety and math performance: the deficit theory (Eysenk & Calvo, 1992), the reciprocal theory (Ashcraft & Krause, 2007), and the cognitive interference theory (Carey et al., 2016).

The *deficit theory* suggests that poor math performance may be caused by lower math skills, which in turn can lead to math anxiety (Barroso et al., 2021). According to this perspective, lower skills in basic number processing lead to negative encounters, which ultimately leads to math anxiety (Barroso et al., 2021). Some evidence suggests that adults with math anxiety demonstrate slower performance in numerical and spatial tasks (Maloney et al., 2010) and are less precise in their understanding of numerical magnitudes (Núñez-Peña & Suárez-Pellicioni, 2014). Should this theory be true, Namkung and colleagues (2019) hypothesized that among a sample of students of varying ages, the relation between math anxiety and math performance would be weaker for younger children compared to adolescents. Specifically, they believed that younger children would likely have experienced fewer instances of poor math performance resulting in fewer negative memories. However, in their meta-analysis they found no differences in the strength of the relation between math anxiety and math performance between elementary

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and high school students (Namkung et al., 2019). This suggests that the other theories may better explain the link between math anxiety and math performance.

The *cognitive interference theory* proposes that math anxiety leads to poor math achievement (Ashcraft & Kirk, 2001; Barroso et al., 2021; Ramirez et al., 2018). The interference occurs in three critical key phases of a math problem solving task: preprocessing, processing, and recalling information leading to lower math achievement (Carey et al., 2016). During the preprocessing phase, math anxiety leads students to avoid math situations due to low motivation, low enjoyment, and low confidence in math, resulting in less opportunity to learn math and subsequently lower math achievement (Hembree, 1990). Interference at the processing and recall level results from intrusive thoughts which use up the working memory load necessary for completing and recalling math information (Carey et al., 2016).

The *reciprocal theory* proposes a bidirectional relationship between math anxiety and math performance (Coddling et al., 2023). The theory integrates both the deficit theory and the cognitive interference theory by suggesting that while poor performance can trigger math anxiety, math anxiety can also contribute to poor math performance. (Carey et al., 2016). The emotional state of math anxiety may also hinder attention, motivation and self-regulation when doing a math task which subsequently leads to poor math performance (Pekrun, 2006). Together, these influence perceptions and beliefs about math performance (Namkung et al., 2019).

Math Learning and Academic/Vocational Choices

Another consequence of math anxiety is that many individuals do not feel comfortable using mathematical skills and therefore avoid careers requiring such skills (Levy et al., 2021). Consequently, there is currently a lack of individuals qualified to work in careers requiring skills in science, technology, engineering, and mathematics (STEM; Franz-Odendaal et al., 2016).

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Individuals with math anxiety have also been found to have less enjoyment of math, lower motivation for math, and less confidence in math (Hembree, 1990). This relation has important implications when considering educational choices and career outcomes. For example, in their study, Espino and colleagues (2017) found that math anxiety in Grade 11 students significantly influenced the likelihood that these students would enroll in math courses for the subsequent year. Making this early academic choice limited their career options for the future and therefore their likelihood of occupying a career in STEM during adulthood (Ahmed, 2018). Further studies by Levy and colleagues (2021) found this trend to specifically affect women whereby math anxiety was predictive of interest in STEM careers for women but not for men. Despite a recent uptake in research related to the consequences of the gender gap in STEM, gender inequalities in STEM remain the same (Casad et al., 2021). In 2016, women made up 34% of STEM bachelor's degree holders and only 23% of science and technology workers among Canadians aged 25 to 64 years (Wall, 2019). Numbers are comparable in the United States (Trapani & Hale, 2019). People have investigated the reasons why men seem to be more drawn to STEM careers than women with one of the factors being its necessity for mathematics and math achievement (Levy et al., 2021).

Gender Differences and Math Achievement

The literature on gender and math achievement, similarly to the gender and math anxiety literature, presents inconsistencies. Some studies have reported lower mathematical performance among women compared to men (e.g., Else-Quest et al., 2010; Pirls et al., 2019; Delage et al., 2021). However, other studies have found similar scores in mathematics for both men and women (e.g., Miller & Bichsel, 2004; Lindberg et al., 2010; Pina et al., 2021).

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For example, in a meta-analysis which encompassed a sample of 1,286,350 individuals worldwide, Lindberg and colleagues concluded that there was no significant difference in mathematical performance between men and women (Lindberg et al., 2010). They further concluded that observed gender disparity can likely be attributed to factors that would be inherently unrelated to mathematical ability. However, according to the 2019 results from the Trends in International Mathematics and Science Study (TIMSS), it was found that among 64 participating countries, approximately half of them observed significant gender differences in math performance, with boys consistently outperforming girls (Pirls et al., 2019). For example, they observed gender discrepancies in Finland, Italy, Japan, Sweden but no gender differences in math performance in the United States and Canada. Similar patterns were also observed with the Programme for International Students Assessment (PISA) which collected data across 65 participating countries and found that, on average, 15-year-old boys outperformed girls, in mathematics (OECD, 2019). These gender differences are often first observed in elementary school and appear to increase during high school and adulthood (Reilly et al., 2017).

A wide array of skills is also encompassed in mathematics such as number sense, arithmetic knowledge, fluency in calculation, and proficiency in mathematical problem-solving (van de Weijer-Bergsma et al., 2022). Large scales studies such as PISA (OECD, 2015) and TIMSS (Pirls et al., 2019) often rely on mathematical word problem-solving tasks (van de Weijer-Bergsma et al., 2022). However, when looking more specifically at math strands, it appears that gender differences vary depending on the specific strand of math completed. Using a sample of elementary school students, van de Weijer-Bergsma and colleagues (2022) aimed to identify performance differences between boys and girls. They found that boys showed higher overall levels of math fluency (i.e., tests of standard addition, subtraction, multiplication, division) than

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girls. However, they did not find any gender differences for overall math problem solving (i.e., contextual math problems such as money, time, proportions). In both Canada and the United States, boys were found to outperform girls on assessments of numbers (i.e., number expressions, simple equations, number relationships, fractions, and decimals), measurement and geometry, and data (i.e., reading, interpreting, and representing data; Mullis et al., 2020). As such, in Study 1 and 2, mathematical skills will be assessed using a variety of mathematical strands. The difficulty of the task is also believed to influence this trend whereby boys demonstrated superior performance on more challenging items, whereas girls exhibited better performance on easier items (Bielinski & Davison, 2001).

As stated above, math performance can also be influenced by math anxiety (e.g., Ashcraft et al., 2007; Carey et al., 2016; Pellizzoni et al., 2022). As such, some researchers have investigated whether gender may moderate the relation between math anxiety and math achievement. For example, Miller and Bichsel (2004) investigated this question and found that the relation between math anxiety and math performance was moderated by gender. Later, Barroso and colleagues (2021) tried to replicate these findings, but to no avail. Rather, they found a similar association between math anxiety and math achievement for both men and women. It is possible however, that though gender may not moderate this relation, math anxiety may rather mediate the relation between gender and math performance. However, no studies to our knowledge have previously investigated this question. As such, Study 1 of this dissertation investigated this issue.

Working Memory

Working memory refers to a mental workspace which allows people to control, regulate, manipulate, and retain important information to complete a demanding cognitive task (e.g., mentally completing complex mathematical equations; Miyake & Shah, 1999). Working memory

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is said to be important in mathematics as this subject often entails holding on to partial information while mentally manipulating new information to arrive to a solution (Raghubar et al., 2010).

The link between working memory and math competence has been widely investigated and, repeatedly, working memory has been found to relate to various types of math performance (e.g., problem solving, calculations; Peng et al., 2016). The way the task is presented also seems to matter. For example, math problems (i.e., contextual math problems that are written out) seem to use up more working memory resources than math fluency questions (i.e., simply calculating math facts quickly; Miller & Bichsel, 2004). This was hypothesized to be, because solving written math problems involves mentally constructing a representation of the problem, keeping track of the relevant numbers, and organizing them correctly according to the necessary steps.

Ashcraft and Kirk (2001) investigated this relation further and predicted that working memory was an important factor influencing math performance especially in those with higher math anxiety. They compared higher and lower math anxious individuals' performance on two-column addition problems involving carry operations (i.e., high working memory additions). While doing these additions, participants were also asked to maintain a 2-letter string or a 6 letter-string in memory. Individuals with higher levels of math anxiety produced significantly more mistakes when asked to maintain a 6-letter string in memory than those with lower levels of math anxiety. It was concluded that individuals with higher math anxiety were likely to experience worries which disrupted the working memory resources necessary for the completion of this task.

The cognitive interference theory (as described in the Math Anxiety and Math Achievement section) states that math anxiety causes a reduction in cognitive resources necessary for the

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completion of mathematics (Ramirez et al., 2018). Specifically, working memory seems to be disrupted by intrusive thoughts and rumination when anxiety is present (Eysenck & Calvo, 1992). Despite this disruption being a common understanding within the math anxiety literature, the nature of these intrusive thoughts remains unclear and was the focus of Study 2.

Additionally, given that math is particularly working memory demanding (Ashcraft, 1992), it follows that experiencing math anxiety during a math task causes one to perform at a level below that of which they would otherwise be capable (Ashcraft & Kirk, 2001; Maloney & Beilock, 2012). As such, Study 3 will focus on the relation between intrusive thoughts and the working memory demand of a math task.

Intrusive Thoughts

Intrusive thoughts, defined as “repeated, unbidden memories, thoughts, and images of a stressor” (Lepore et al., 2000, p. 500) are distinct from worry (i.e., defined as verbal thoughts related to a possible outcome or consequence; Wilson, 2010) and are believed to increase one’s worry (Gross & Eifert, 1990).

Although intrusive thoughts are among the common underpinnings of our understanding of the link between math anxiety and math performance, very few studies have explored the nature of these intrusive thoughts. One of the few studies which has investigated these thoughts was conducted by Hunt and colleagues in 2014. In their study, they looked at the frequency and the types of intrusive thoughts experienced by those with math anxiety. More specifically, by modifying the Cognitive Intrusions Questionnaire (CIQ) developed by Freeston and colleagues in 1991 (English translation by Freeston in 1994), to be more specific to mathematics (CIQ-M), they created 8 categories of math-related intrusive thoughts (i.e., making mistakes, time pressure, method of problem solving, what people might think, panicking, previous math experiences,

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physical changes, and non-task-related). They found that those with higher math anxiety experienced more frequent intrusive thoughts of each type, except for method of problem solving. However, given that women are not only more vulnerable to experiencing math anxiety but also more likely to experience intrusive thoughts, it is unclear whether these results may differ when considering gender. As such, Study 2 and Study 3 of this dissertation explored this question.

Statement of the Problem

Math anxiety is a prevalent phenomenon that has been associated, in some literature, with a higher prevalence among women and is believed to result in fewer women pursuing careers in STEM fields (Ahmed, 2018; Levy et al., 2021). Furthermore, researchers have previously linked math anxiety to decreased math performance (e.g., Ashcraft et al., 2007; Carey et al., 2016; Pellizzoni et al., 2022) using the cognitive interference theory. Specifically, they highlighted that intrusive thoughts may be the culprit for reduced performance in those with math anxiety (Eysenck & Calvo, 1992). However, research on these intrusive thoughts has been limited which hinders the implementation of targeted interventions tailored to the most prevalent types of intrusive thoughts.

This dissertation aims to examine the relation between gender and math anxiety. We explored whether gender operates as a mediator in the association between math anxiety and math performance, suggesting that women's lower math performance may be partly attributable to their higher levels of math anxiety. Additionally, we investigated the frequency and types of intrusive thoughts experienced by both men and women during math tasks as well as while completing higher and lower working memory demanding math. Through these investigations, we hope to enhance our understanding of the intricacies of math anxiety experienced by men and

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women. We anticipate that these findings will provide valuable guidance for the development of future interventions aimed at mitigating the potential gender gap in math performance and promoting equitable opportunities in STEM careers.

Current Studies

The primary aim of this dissertation was to develop a better understanding of the gender differences in math anxiety. Study 1 was designed to clarify the presence of a gender difference in math anxiety and explore whether math anxiety could partially explain gender disparities in math performance. To do so, undergraduate students ($N = 389$) were invited to the laboratory to complete a one-hour questionnaire where they were asked to report on their math anxiety, their general anxiety and then were asked to complete a math task. We hypothesized that gender differences would be observed in math anxiety and math performance. We also hypothesized that math anxiety would mediate the relation between gender and math performance.

Additionally, though researchers often rely on the cognitive interference theory to explain the relation between math anxiety and poor math performance, limited research has explored the frequency and nature of these thoughts. Therefore, Study 2 investigated the frequency and types of intrusive thoughts experienced by individuals with varying levels of math anxiety. A total of 309 participants completed the study remotely via the Gorilla platform. Participants completed an assessment of math anxiety, followed by a math task, and reported on their intrusive thoughts.

Building upon the findings of Study 2, Study 3 aimed to examine whether the frequency and nature of intrusive thoughts differed based on the working memory demands of a math task. Working memory is crucial in mathematical tasks, and its limited capacity can influence cognitive processes (Beilock & Maloney, 2015; Namkung et al., 2019). A total of 437 undergraduate students participated remotely via the Gorilla platform. Participants were first

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asked to report on their math anxiety and their general anxiety. Next, participants were randomly assigned to start with either a lower working memory demand task or to start with a higher working memory demand task. Every participant completed a working memory task, a measure of intrusive thoughts, a neutralizing task, followed by another working memory task, and a final measure of intrusive thoughts. We hypothesized that both gender and working memory demand would influence the frequency of intrusive thoughts as well as the types of thoughts experienced during the task. Overall, this thesis sought to investigate the presence of a gender difference in math anxiety and explore potential variations in intrusive thoughts between men and women. The findings from these studies are anticipated to contribute valuable insight and a deeper understanding of the experiences of math anxiety for both men and women.

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CHAPTER TWO:

Study 1: Understanding Gender Disparities in Math Performance: The Role of Math Anxiety

Comprehension of numerical concepts and fundamental mathematics skills are essential for many activities of daily living (e.g., managing money, cooking, understanding sport statistics). Familiarity and level of comfort with these concepts and skills are predictive of academic success (Odic et al., 2016), employment opportunities (Ahmed, 2018), income (Wall, 2019), and socioeconomic status (Ritchie & Bates, 2013). Over the last decades, researchers have investigated various factors which contribute to mathematical skills. Among these, emotional factors such as math anxiety have been of utmost importance (e.g., Ashcraft, 2002; Beilock & Maloney, 2015; Hembree, 1990). However, as outlined in the general introduction, there have been diverging results surrounding the question of gender differences in math anxiety (e.g., Xie et al., 2019; Else-Quest et al., 2010; Stoet et al., 2016). A growing body of literature suggests that women suffer from higher levels of math anxiety than men (Betz, 1978; Llabre & Suarez, 1985; Stoet et al., 2016; Xie et al., 2019) while other researchers fail to find such differences (Hyde et al., 2008; Levy et al., 2021). There is also a shortage of women in STEM, as there are fewer women who study and work in these fields than men (Wall, 2019). This is recognized as being detrimental to women, given that STEM occupations are among the highest-paying and fastest-growing professions (Wall, 2019). As described in the general introduction, different theories attempt to explain this possible gender difference.

A different, yet related topic of research pertains to one of the most common outcomes of math anxiety: poor math performance (Ashcraft et al., 2007; Carey et al., 2016; Pellizzoni et al., 2022). While there are some reasons to believe that those who struggle more in math may be most prone to develop math anxiety (e.g., Ramirez et al., 2016 for a review), the consensus is

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that math anxiety contributes to people underperforming in mathematics. Studies have found a negative association between math anxiety and performance on math tasks whereby individuals who experienced more math anxiety performed more poorly on tasks of mathematics (Ashcraft and Moore, 2001; OECD, 2015; Barroso et al., 2021). In an experimental study, Ashcraft and Kirk (2001) explored the relationship between math anxiety and math performance. They compared the performance of individuals with high and low math anxiety on two-column addition problems involving carry operations (i.e., high working memory demanding additions). Participants were also asked to remember either a 2-letter or a 6-letter string during the addition task. They found that those with higher math anxiety had significantly lower math performance when trying to remember a 6-letter string in mind than lower math anxious individuals.

Current Study

For this study, we explored whether we could find a gender difference in math anxiety and in math performance. It was first hypothesized that women would experience higher levels of math anxiety than men (*Hypothesis 1*). Researchers have also previously found that women have lower performance on math achievement measures than men (e.g., Anaya et al., 2022). As such, it was further hypothesized that undergraduate women would have lower performance on an assessment of mathematical skill than undergraduate men (*Hypothesis 2*). Finally, given that math anxiety is believed to elicit mechanisms which use up resources to complete a math task, it was hypothesized that the gender difference in math performance would be mediated by participants' math anxiety (*Hypothesis 3*).

Method

Participants

An a priori power analysis was conducted using G*Power 3.1.9.2 software, which determined that a sample size of 176 participants was needed, with $\alpha = 0.05$ and Power = 0.95.

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To account for the expected exclusion of some participants, we increased the required sample size by approximately 25%. Undergraduate students ($N = 418$) were recruited from a student participation pool at a large research-intensive Canadian university. To be eligible for this study, students were required to be fluent in English. They were allocated one percent toward their final grade for participating in this hour-long study.

Participants were excluded from analyses if they did not consent to the study ($n = 5$), if they did not answer more than 70% of the survey ($n = 5$), if their response times were of 0 ($n = 2$), if they did not provide a gender ($n = 3$), and if they provided the same consecutive answer on reverse coded measures (i.e., State Trait Anxiety Inventory) for more than half of the scale (10 or more items; $n = 14$; Huang et al., 2012). Data were collected from September to December 2019. Of the 389 participants, 274 identified as women and the mean age of participants was 19.2 years ($SD = 2.5$). Most participants' native tongue was English (56.5%) and reported a family income above 50,000\$ per year (64.1%). Among our sample, women reported experiencing higher levels of trait anxiety ($M = 47.22$, $SD = 9.88$) than men ($M = 41.23$, $SD = 9.28$), $t(387) = -5.38$, $p < .001$, $d = .29$.

Measures

Math Test

Participants were asked to complete a short mathematics test composed of a variety of questions. These questions were designed by a math curriculum specialist hired by the research team. Given the influence of different mathematical strands on performance (van de Weijer-Bergsma et al., 2022), we included math questions covering various strands of mathematics as could be observed in standardized testing. Specifically, we included concepts taught in the five strands of mathematics evaluated in fifth to seventh grade by the local provincial mathematic

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curriculum as concepts addressed in these questions are presented early enough in Canadian education that participants should be familiar with these types of questions (i.e., increasing the likelihood of having participants be able to solve the math problems). More specifically, individuals were asked to answer 10 questions in each of the following strands: data management and probability, geometry and spatial sense, number sense and numeration, measurement, and algebra. These questions were designed to be similar to questions that could be present on a provincially standardized math test. Thus, participants were presented with a math problem and were given four potential answers from which to choose. Once the participant had selected their answer, they were automatically directed to the next question. Abstentions from answering a question were treated as incorrect answers. We followed this method as it is the current practice on most academic exams. Please refer to Appendix A for the full math test. In the current sample, Cronbach's alpha was .83.

Math Anxiety

Math anxiety was measured using the nine-item Abbreviated Math Anxiety Scale (AMAS) designed by Hopko et al., in 2003 which can be found in Appendix B. Participants were asked to rate how anxious they felt on a five-point Likert scale ranging from *low anxiety (1)* to *high anxiety (5)* in various situations relevant in mathematics, such as "Listening to a lecture in math class". This measure has been reported by Hopko et al. (2003) to have good to excellent internal consistency ($\alpha = .90$) and test-retest reliability ($r = .85$) and have a Cronbach's alpha of .90. In the current sample, Cronbach's alpha was also .90.

General Anxiety

General anxiety was measured using the trait section of the STAI (Appendix C; Spielberger et al., 1983). This 20-item questionnaire required participants to report on how they

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generally feel. Some items were anxiety-absent (e.g., I am content) while others were anxiety-positive (e.g., I worry too much over something that really doesn't matter). Questions were answered on a 4-point Likert scale ranging from *Not at all (1)* to *Very much so (4)*, and anxiety-absent items were reversed scored. In their study, Spielberger et al., (1983) found this measure to demonstrate high internal consistency ($\alpha = .90$), good test-retest reliability for college-aged students ($r = .73 - r = .86$) and a Cronbach's alpha of .92. In the current sample, Cronbach's alpha was .91.

Socio-demographics

Socio-demographic data were collected, including age, gender, and language proficiency. Socio-demographic questions were either answered with text entry or by selecting one of the provided options. See Appendix D for specific socio-demographic questions.

Procedure

This study was approved by the *Office of Research Ethics and Integrity* and complied with the *Social Sciences and Humanities Research Council* of Canada's guidelines on human testing. Participants were invited to complete an hour-long questionnaire which was administered through Qualtrics in a laboratory on the university's campus. A research assistant was present during the completion of the study to answer any questions. Upon arrival to the laboratory, participants were brought to a testing station that included a computer, a pencil, a piece of paper, and a calculator. Math questions were completed first, followed by the STAI-T, the AMAS, and the socio-demographics questions. Response times and accuracies were recorded for each math question. Only response accuracies were analyzed for this study.

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Data analysis

Occasionally participants failed to provide answers to a few questions on the AMAS and the STAI-T (<5.5%). A Little's Missing Complete at Random (MCAR) test was completed to determine the pattern of missing data. Results indicated that data were MCAR, $\chi^2(147, N = 389) = 137.66, p = 0.70$. Data imputation with expectation maximization (250 iterations) was used to impute missing data. All continuous variables were assessed for normality with Q-Q plots, a review of skewness, kurtosis, and a z-test for normality (Kim, 2013). As math was negatively skewed, a log transformation was carried out to normalize the data using standard parameters (Kim, 2013; Wang et al., 2014).

The data analyses were computed using the PROCESS macro v. 4.2 in SPSS, Model 4. First, independent-sample t-tests were completed to investigate whether gender differences existed for math anxiety and for the scores of the math performance measure. Assumptions of normality, Levene's test for equality of variance ($p \geq .05$), and independence of observation were met. Next, a mediation analysis was conducted to investigate the relation between gender, math anxiety and math performance, controlling for general anxiety. Trait anxiety was controlled for in this analysis as previous studies have found that general anxiety and math anxiety share a moderate correlation (Hill et al. 2016; Mammarella et al. 2018) and we wanted to ensure we were investigating math anxiety specifically. Both the significance and the strength of the mediation model were tested using a bootstrapping method with 5000 iterations. Indirect effects were calculated for each of the 5000 bootstrapped iterations and the 95% interval was determined by computing the indirect effect at the 2.5th and the 97.5th percentile. Assumptions of linearity (assessed by regression plots), normality, independence of residuals (Durbin-Watson =

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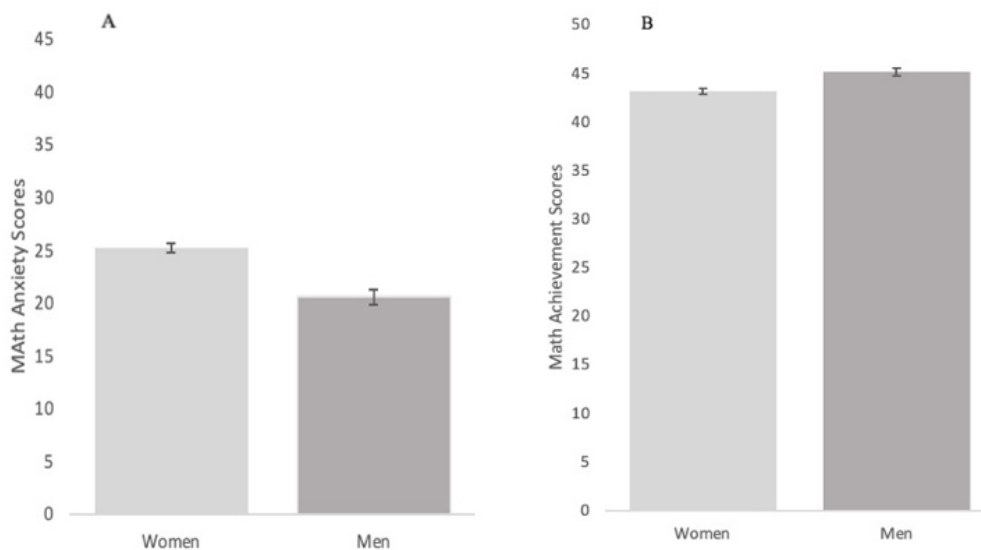
1.87), homoscedasticity of variance (assessed by visual inspection of plots of studentized residuals), and multicollinearity were met.

Results

Comparing the Magnitude of Gender Differences in Math Anxiety and Math Ability

Math anxiety scores ranged from 9 to 45 and as was predicted, women reported higher levels of math anxiety ($M = 25.27$, $SD = 7.67$) than men ($M = 20.59$, $SD = 7.95$), ($t(387) = -5.43$, $p < .001$, Hedge's $g = 0.60$). Additionally, scores on the math task could range from 0 to 50 and, as predicted, men scored higher on the math test ($M = 45.14$, $SD = 4.45$) than women ($M = 43.14$, $SD = 4.95$), ($t(387) = 3.75$, $p < .001$, Hedge's $g = 0.42$). See Figure 2 for a visual depiction.

Figure 2. Gender Differences in the Math Anxiety and Math Achievement Scores



Of note: Figures 1A and 1B show the average levels of math anxiety and math ability broken down by gender. Error bars reflect standard errors.

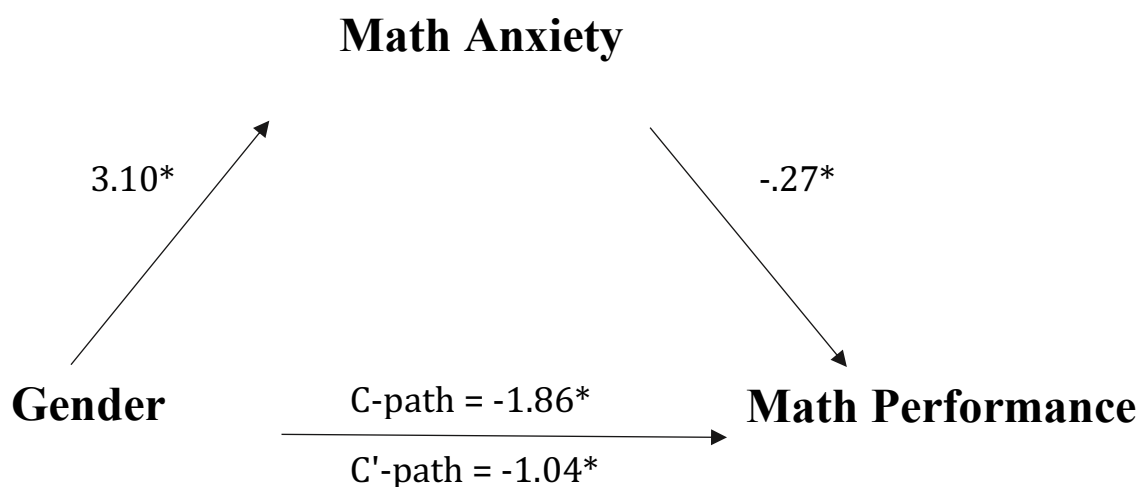
Mediation Analyses

A mediation analysis was conducted to investigate the hypothesis that math anxiety mediates the relation between gender and math performance. General anxiety, measured with the

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STAI-T, was included as a covariate in the analysis to control for anxiety other than that related to math. As illustrated in Figure 3, the results revealed a significant direct effect of gender on math performance, while accounting for MA as a mediator $b = -1.04$, $t(389) = -2.01$, $p = 0.046$. In addition, when math anxiety was added to the model, the total indirect effect was significant as the 95% confidence interval did not include zero (effect = -0.825 , 95% CI $[-1.14, -0.37]$), suggesting that math anxiety mediated the relation between gender and math performance. As such, approximately 44.4% of the effect of gender on math performance is explained by the level of math anxiety of the individual.

Figure 3. Math anxiety as a Mediator of the Relation Between Gender and Math Performance.



* indicates $p < .05$.

Of note: the values provided in this figure are the unstandardized regression coefficients.

Discussion

The present study aimed to explore the gender differences in math anxiety and math performance by testing the following three hypotheses: (1) women would experience higher math anxiety than men, (2) women would have lower performance on an assessment of mathematical skills, and (3) the gender difference in math performance would be mediated by the participant's math anxiety.

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With regards to Hypothesis 1, women in our sample reported higher levels of math anxiety than men. This provides additional evidence that there may in fact be a gender difference in math anxiety such as found by various researchers (Betz, 1978; Llabre & Suarez, 1985; Stoet et al., 2016; Xie et al., 2019). With respect to Hypothesis 2, we also found a statistically significant gender difference between men's and women's math performance whereby men outperformed women on a math task. This finding is in line with previous results from Else-Quest et al. (2010) who also found small gender differences in math achievement. However, these results should be considered within the context of the findings for Hypothesis 3. Specifically, we found that the gender difference in math performance was mediated by participants' math anxiety. In fact, as demonstrated in the results, math anxiety mediated the relation between gender and math performance. Similar to what has been discovered by other researchers, these results suggest that math anxiety hinders one's performance on math tasks (Maloney et al., 2013; Spencer et al., 1999). Additionally, given that the difference in math performance is partially mediated by math anxiety, it suggests that this gender gap might, at least in part, be due to psychological factors rather than men being better in math and therefore outperforming women in math tasks (Jordan et al., 2006; Krinzinger et al., 2012; Krinzinger et al., 2012). This might in part be due to the mechanisms underlying math anxiety. In fact, one of the common explanations for the relation between math anxiety and math performance suggests that math anxiety may lead to a decrease in the cognitive resources required for math achievement (Ramirez et al., 2016). In particular, working memory appears to be disrupted by intrusive thoughts and rumination when anxiety is present (Calvo & Eysenck, 1992). Since math tasks are known to heavily rely on working memory (Ashcraft, 1992), when individuals experience math anxiety in such situations, their

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performance is hindered below what they are capable of achieving (Ashcraft & Kirk, 2001; Maloney & Beilock, 2012; Shi and Liu, 2016).

Implications

Researchers have argued that math anxiety is one of the core factors influencing the lack of women in STEM careers (Beilock & Maloney, 2015; Maloney & Beilock, 2012). The results of this study support the idea of math anxiety being one of the potential culprits of the gender gap in math performance. Therefore, implementing interventions aimed at reducing math anxiety could help women reach their full potential. However, a better understanding of its underlying mechanisms is crucial to be able to suggest and implement proper interventions to reduce or eliminate it. As outlined in the introduction, there is significant research which highlights the role of intrusive thoughts in the relation between math anxiety and math performance. Consequently, the following studies will delve into the examination of intrusive thoughts experienced by men and women during math tasks to try and gather better insight into the experience of math anxiety within these populations.

Limitations

It is important to note that this study has some limitations. One of the largest limitations is that 70% of our sample identified as women. This, paired with the fact that many researchers have found evidence that women are more likely to experience math anxiety than men (e.g., Else-Quest et al., 2010; Miller & Bichsel, 2004; Stoet et al., 2016; Xie et al., 2019; Zhang et al., 2019) limits the generalizability of the findings and could have introduced bias in the statistical analyses. Additionally, this study was limited to individuals who identified as either men or women. As such, this does not accurately represent the broader population, which includes individuals of various gender identities and does not provide information about how math

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anxiety may influence math performance in these populations. Similarly, our sample consisted solely of undergraduate students. Among this sample, most participants were anglophones between the ages of 18 and 22 and were of middle socioeconomic status. As such, it is important to be cautious when trying to extrapolate and generalize the findings of the study herein to other populations. Furthermore, even though participants engaged with the survey within the framework of their courses, the nature of the math task was probably not high-pressure, considering students were rewarded merely for participating rather than for achieving success in the task itself. This could have led to a reduced level of math anxiety compared to a scenario where the task carried more weight, such as being a component of a course evaluation worth a significant portion of the final grade. In such cases, participants may have experienced less math anxiety than they may have if this same math task was presented in the context of a math evaluation. Future research should investigate whether results remain similar if participants complete the study in the context of an evaluation. Moreover, the AMAS and the STAI-T questionnaires were both administered at the end of the study which could have been affected by the math task they had just completed.

Conclusion

The current investigation had the goal of exploring whether math anxiety mediated the relation between gender and math performance among an undergraduate sample from a Canadian university. Our results demonstrated that gender mediated this relation, at least in part. These findings support the need for interventions particularly for women to help them reduce or eliminate their math anxiety and entice them to pursue careers in STEM fields.

CHAPTER THREE:**Study 2: Understanding Intrusive Thoughts in Math Tasks and The Role of Gender and Math Anxiety**

Intrusive thoughts are distressing thoughts, images or memories of a stressor that are experienced repeatedly and can prolong both the emotional and physiological responses to stressful events (Lepore et al., 2000). They are believed to be a normal experience of human consciousness and are experienced in multiple cultures across the world (Clark & Radomsky, 2014). They are also common within both clinical (Langlois et al., 2000) and non-clinical populations (Langlois et al., 2000) and although they seem to play an integral role in math anxiety, they are often studied in the context of Obsessive-Compulsive Disorders (OCD; e.g., Belloch et al., 2016; Seli et al., 2017). In the context of OCD, intrusive thoughts, otherwise called “cognitive intrusions”, “normal obsessions”, and “obsessional thoughts”, are often accompanied by compulsions that are used by the individual to try and reduce the anxiety generated by the intrusive thought (American Psychiatric Association, 2013). It is important to note that intrusive thoughts are experienced by most people (Bouvard et al., 2017) and only develop into obsessions in a fraction of cases (Salkovskis, 1999). In the context of math anxiety, intrusive thoughts do not include the obsessive nature that is often referred to in the OCD literature. Rather, it refers to unwanted thoughts that come to mind abruptly and repeatedly and can cause some level of distress (Wigfield & Meece, 1988). Intrusive thoughts are also most common in individuals with higher levels of math anxiety (Wigfield & Meece, 1988; Hunt et al., 2014).

Women are not only more vulnerable to develop math anxiety (Betz, 1978; Llabre & Suarez, 1985; Stoet et al., 2016), but are also more susceptible to experiencing intrusive thoughts when

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in stressful situations (Lepore et al., 2000; Schmaus et al., 2008; Del Río-Casanova et al., 2021; Arnáez et al., 2021; Thaiposri & Reece, 2022). For example, women have been found to experience more intrusive thoughts compared to men in situations such as the early stages of the COVID-19 pandemic (Del Río-Casanova et al., 2021), when experiencing illness anxiety (Arnáez et al., 2021), and when experiencing an eating disorder (Thaiposri & Reece, 2022).

Intrusive thoughts are also believed to play an integral role in the relation between math anxiety and math performance (Ramirez et al., 2018). In fact, the cognitive interference theory states that math anxiety generates intrusive thoughts which uses working memory resources necessary for the completion of math tasks (Ramirez et al., 2018). For example, Shi and Liu (2016) investigated the relation between intrusive thoughts and math anxiety, looking specifically at working memory. Participants were randomly assigned to one of two conditions (i.e., math-related, and valence-neutral). In the math-related condition, participants were asked to read a sentence related to dysfunctional beliefs about math aloud (e.g., “I feel nervous while working on a math problem”) whereas in the valence-neutral condition, participants were presented with a neutral sentence (e.g., “Each day the sun rises in the east and sets in the west.”). Participants were also asked to complete a working memory task. Math anxious individuals performed worse on the working memory task when math-related sentences were presented, than those with lower math anxiety. However, no differences were found when valence-neutral sentences were presented. Thus, it is believed that when individuals are highly math anxious, they become preoccupied by this anxiety which can act as a “secondary task” and result in the exhaustion of working memory resources necessary for the completion of an arithmetic task (Ashcraft & Krause, 2007). Specifically, when individuals have higher math anxiety, they are trying to do two things at once: 1) solve the math problem and 2) cope with intrusive thoughts

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(Beilock & Maloney, 2015; Ramirez et al., 2018; Barroso et al., 2021). Given the limited nature of working memory, when intrusive thoughts are present, they use up the working memory resources which subsequently influences the individual's ability to solve the math problems and thus diminishes their performance on these tasks (Beilock & Maloney, 2015; Namkung et al., 2019). With thorough investigation, Ashcraft and Faust (1994) found that although individuals with higher math anxiety were slower and less accurate when completing a task of more complex arithmetic problems, this was not believed to be the result of the individual's competence (Ashcraft & Moore, 2009). It was rather believed to be the result of working memory impairment linked to intrusive thoughts (Ashcraft et al., 1992). It remains unclear however whether the frequency and the types of intrusive thoughts vary as a function of the working memory demand of the task at hand.

Surprisingly, although intrusive thoughts are among the common underpinnings of our understanding of the relation between math anxiety and performance, few studies have explored the relation between intrusive thoughts and math anxiety. One of the few studies which has explored the topic was conducted in 2014 by Hunt and colleagues. As per outlined in the general introduction, in their study Hunt and colleagues (2014) outlined 8 categories of math-related intrusive thoughts (i.e., making mistakes, time pressure, method of problem solving, what people might think, panicking, previous math experiences, physical changes, and non-task-related) that may be experienced by those with math anxiety. They found that math anxious individuals endorsed more intrusive thoughts than individuals without math anxiety, especially those related to what people may think, panicking, and physical changes. It is possible that math anxious individuals have poor self-concept about their math ability (OECD, 2012) and therefore fear that others may also perceive and judge their difficulties in math. This may lead to increased intrusive

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thoughts pertaining to what people may think. Anxiety is also physiologically designed to motivate a reaction and leads to physiological changes that prepare an individual to react adequately to a situation (Josefowitz & Myran, 2017). This can often lead to uncomfortable physical sensations (e.g., heart racing, paced breathing) and in extreme cases can lead to panic. Study 1 provides evidence that women experience higher levels of math anxiety than men. Additionally, past studies suggest that women are more susceptible to experiencing intrusive thoughts when in stressful situations (e.g., Lepore et al., 2000; Schmaus et al., 2008; del Río-Casanova et al., 2021; Arnáez et al., 2021; Thaiposri & Reece, 2022). As such, this study aims to further investigate math anxiety and gender differences in both the frequency and the types of intrusive thoughts experienced when doing a math task.

Current Study

This study aims to develop a better understanding of the gender differences of math anxiety by looking at individuals' intrusive thoughts. As such, both the frequency and the types of intrusive thoughts of both gender and level of math anxiety were explored.

Frequency of Intrusive Thoughts

Given that women tend to experience more intrusive thoughts than men (e.g., Lepore et al., 2000; Del Río-Casanova et al., 2021; Arnáez et al., 2021; Thaiposri & Reece, 2022), it was first hypothesized that women in the current sample would report more intrusive thoughts than men (*Hypothesis 1*). Additionally, given that math anxiety has been found to be positively correlated with the frequency of intrusive thoughts (Hunt et al., 2014), it was hypothesized that those with higher math anxiety would experience more intrusive thoughts than those with lower math anxiety (*Hypothesis 2*). Furthermore, it was hypothesized that women with higher math anxiety

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would experience more intrusive thoughts than men with comparable levels of math anxiety (*Hypothesis 3*).

Types of Thoughts

Hypothesis 4 posits that women would experience more intrusive thoughts of each of the seven types of intrusive thoughts compared to men (*Hypothesis 4*). Additionally, in light of the previous findings by Hunt and colleagues (2014), it was hypothesized that higher math anxious individuals would experience more intrusive thoughts of each of the seven types with the most prevalent being those related to what people might think, panicking, and physical changes (*Hypothesis 5*; Hunt et al., 2014). Additionally, for years, women have been stereotyped as being “worse in math” than men (Bieg et al., 2015; Cargnelutti et al., 2017; Steffens & Jelenec, 2011; Jao & Radakovic, 2017) which may have led to increased math anxiety in women. As such, it was also hypothesized that higher math anxious women would experience more intrusive thoughts of each of the seven types compared to higher math anxious men with the most prevalent thoughts being those that may relate to the fear of confirming the social stereotype of being bad at math (i.e., making mistakes, method of problem solving, and what people may think; *Hypothesis 6*).

Categories of Thoughts

For the purpose of this dissertation, the seven different types of intrusive thoughts proposed by Hunt and colleagues (2014) were divided into three broader categories 1) thoughts related to math ability (i.e., making mistakes, previous math experience, and method of problem solving), 2) thoughts related to the circumstances of the task (i.e., time pressure and what people may think), and 3) thoughts related to the physiological response to the task (i.e., panicking and physical changes; see Table 1).

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Given the prevalent social stereotype that women have difficulty with math (Bieg et al., 2015; Cargnelutti et al., 2017; Steffens & Jelenec, 2011), we wondered if the most prevalent category of thoughts experienced by women would relate to their math ability. On the other hand, because men are often stereotyped as being good in math tasks, it was hypothesized that their fear may be most related to concerns about circumstances of the task that may make it more difficult (Cvencek et al., 2011; Maloney et al., 2013; *Research Question 1*).

Table 1. *Categories of Intrusive Thoughts*

Category 1: Math ability	Category 2: Circumstances of the task	Category 3: Physiological reactions
Making mistakes	Time pressure	Panicking
Previous math experience	What people may think	Physical changes
Method of problem solving		

Methods

Participants

Prior to data collection, an a priori power analysis was conducted using G*Power 3.1.9.2 ($\alpha = 0.05$, Power = 0.95) revealed a required sample size of 280 participants. We increase the sample size required by approximately 25% (estimating that this would be the percentage of participants excluded). Thus, 368 undergraduate students from a Canadian university were recruited from an undergraduate student research pool which was designed to allow students following introductory level courses to earn up to four percent of their final course grade by participating in research. Students who participated in this one-hour long study were allocated one percent towards their final grade, as per institutional guidelines.

Procedure

Participants were asked to complete a pre-screen questionnaire when registering to the pool. They also had to complete the Single-Item Math Anxiety (SIMA; see description of measure

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below) among the pre-screen questions and provide their gender. With these data we could ensure similar number of participants (i.e., low math anxious men, low math anxious women, high math anxious men, high math anxious women). Students were required to be fluent in written English and to identify as either a man or a woman to be eligible for the study. Only eligible students were able to view the study on their student research portal.

Some participants were excluded from analyses for various reasons. First, they were excluded if they provided an invalid verification ID or did not complete the survey ($n = 14$) as this made it impossible to retrieve their pre-screen data. Additionally, those who provided inconsistent scores on the SIMA and the AMAS ($n = 24$; e.g., report low math anxiety on the SIMA and high math anxiety on the AMAS) were deemed to provide inconsistent math anxiety scores and were excluded from further analyses. To calculate inconsistencies, we determined the equivalent scores between the SIMA and the AMAS (with equivalent score on the AMAS being a 4-point increase for every 1-point increment on the SIMA). To give more leniency to participants, we divided the AMAS into three levels of math anxiety (scores under 21 were considered low, scores between 22 and 33 were considered medium, and scores above 34 were considered high) and determined that a participant's scores needed to change by 12-points (or 3 points for the SIMA) to change levels of math anxiety. Participants whose AMAS scores were plus or minus 12 from the expected scores based on the SIMA were excluded from further analyses. For example, if a participant reported a score of 5 on the SIMA, their equivalent score on the AMAS would be of 25; we would therefore include them if they reported scores ranging from 13 to 37. Participants who incorrectly answered two or more attention check questions ($n = 18$; e.g., "Please select 2") or who provided long string of identical answers ($n = 3$; Huang et al., 2012) were excluded for lack of attention during the tasks. The final sample size ($N = 309$)

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provided sufficient power for our post-hoc power analysis [$\alpha = 0.05$, Power = 0.87]. Data was collected from April 2021 to July 2022.

Of the 309 participants, 166 identified as women. Generally women in our sample reported experiencing higher levels of math anxiety ($M = 28.12$, $SD = 7.17$) than men ($M = 24.24$, $SD = 6.64$), $t(307) = -4.90$, $p = <.001$, $d = .56$. Women also reported experiencing higher levels of trait anxiety ($M = 50.43$, $SD = 11.70$) than men ($M = 47.21$, $SD = 10.72$), $t(307) = -2.51$, $p = .013$, $d = .29$. Women also exhibited lower math performance ($M = 40.2$, $SD = 7.82$) than men ($M = 42.75$, $SD = 6.58$), $t(307) = -2.97$, $p = .003$, $d = 0.34$. The mean age of participants was 19.7 years ($SD = 3.7$). Participants in the sample reported being registered in a range of faculties: Health Sciences (24.3%), Science (24.3%), Social Sciences (21.4%), Business Management (15.5%), Arts (7.4%), Engineering (4.2%), Medicine (1.3%), Education (<1%), and Other (1%). Most participants reported their native tongue to be English (61%) whereas others reported French (13.6%), Mandarin (7.1%), Arabic (5.4%), or other languages (12.9%). Most participants also reported a family income above 75,000\$ per year (59.5%). All participants were included in analyses.

Measures

Note that the measures of math anxiety, general anxiety, math skill and socio-demographics were identical to those used in Study 1. As such, only the measures new to Study 2 are detailed here.

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Math Anxiety.

Prior to the study, math anxiety was assessed using The Single-Item Math Anxiety scale (SIMA) designed by Núñez-Peña and colleagues (2014). Individuals were asked “*On a scale from 1 to 10, how math anxious are you?*” where 1 represents *not anxious* and 10 *very anxious*. Núñez-Peña, Guilera and Suárez-Pellicioni (2014) found that the SIMA is correlated at .95 with the Shortened Math Anxiety Rating Scale (sMARS; another measure of math anxiety), rendering the minimum reliability estimate of the SIMA .70. Additionally, this measure was deemed valid as it had adequate test-retest reliability ($r = .81$).

Intrusive Thoughts.

Intrusive thoughts were measured using the Cognitive Intrusions Questionnaire for Maths (CIQM) which is a version that was modified by Hunt et al., (2014) from the original Cognitive Intrusions Questionnaire (CIQ) developed by Freeston et al., 1991 (English translation by Freeston, 1994). The CIQ is a common measure used to assess an individual’s intrusive thoughts after a specific task. Only the first part of this measure was used for data analyses and required participants to identify which type of intrusive thoughts they experienced during the math task as well as the frequency of their intrusive thoughts. In their study, Hunt and colleagues (2014) modified this section of the measure to include a list of thoughts that would be relevant to math. Among the types of thoughts included in their measure are “making mistakes”, “time pressure”, “method of problem solving”, “what people might think”, “panicking”, “previous math experience”, “physical changes”, and “non-task related” (see Appendix E).

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Procedure

This study was approved by the *Office of Research Ethics and Integrity* and complied with the *Social Sciences and Humanities Research Council of Canada's* guidelines on human testing. Students were asked to provide voluntary and informed consent to partake in this study. Interested participants were asked to complete a pre-screen questionnaire to evaluate eligibility. They were told that the study explored how math anxiety may influence thoughts experienced during a math task. Invited participants completed a one-hour questionnaire that was completed remotely using the Gorilla platform. Participants completed the AMAS and the STAI-T, followed by a math task. Once this task was completed, participants were asked to complete the CIQM to evaluate the frequency and the type of intrusive thoughts experienced (Hunt et al., 2014). Last, participants answered the demographic questions. Throughout the questionnaire, there were three attention check questions dispersed in the questionnaire (e.g., “please select 3”) to flag inattention to the task.

Data analysis

Statistical analyses were performed using SPSS version 26 and R version 4.2.2. Occasionally some participants did not provide answers to a few questions on the AMAS and the STAI-T (< 2.5%). A Little's MCAR test was completed to determine the pattern of missing data. Results indicated that data were MCAR, $\chi^2(5072, N = 309) = 5127.22 p = 0.29$. Expectation-maximization with 250 iterations was completed to replace missing values.

A two-way ANOVA was first completed to test for a main effect of gender, a main effect of math anxiety and to see whether there was an interaction between these variables (note that math anxiety was divided into quartiles). Assumptions of linearity (as assessed by regression plots), independence of residuals (Durbin-Watson = 1.85), homoscedasticity (as assessed by

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visual inspection of plots), multicollinearity (tolerance > 0.1), outliers, leverage values, and normality were met.

We also wondered whether each of the seven types of intrusive thoughts experienced by women, higher math anxious individuals and higher math anxious women might differ from those experienced by men, lower math anxious individuals and higher math anxious men. As such, we divided math anxiety into quartiles and completed chi-square tests of homogeneity to explore these questions. To control for multiple comparisons, Bonferroni corrections were completed and the corrected threshold for statistically significant results was determined to be $p \leq 0.002$. An Analysis of Proportions Using Arcsine Transformation (ANOPA) was completed to explore whether proportional differences existed between the types of thoughts experienced for individuals with differing levels of math anxiety (Laurencelle & Cousineau, 2022). Lastly, we explored whether there would be gender differences within the different categories of intrusive thoughts. To do so, we completed a Kruskal-Wallis test using post-hoc Bonferroni corrected Mann Whiney U's to identify group differences. Of note, only a sub-set of the CIQ-M questionnaire was analysed for the study herein (i.e., question 3.1 and 3.9).

Results

Frequency of Intrusive Thoughts

Gender, math anxiety and the frequency of intrusive thoughts

Hypothesis 1 was that there would be a main effect of gender on the frequency of intrusive thoughts. A two-way ANOVA revealed no main effect of gender on the frequency of intrusive thoughts, $F(1, 301) = 2.97, p = .089$ adj. $R^2 = .01$, whereby women experienced a similar frequency of intrusive thoughts ($M = 3.14, SD = 1.19$) as men ($M = 2.68, SD = 1.23$) during the math test. However, for Hypothesis 2, there was a main effect of math anxiety on the frequency

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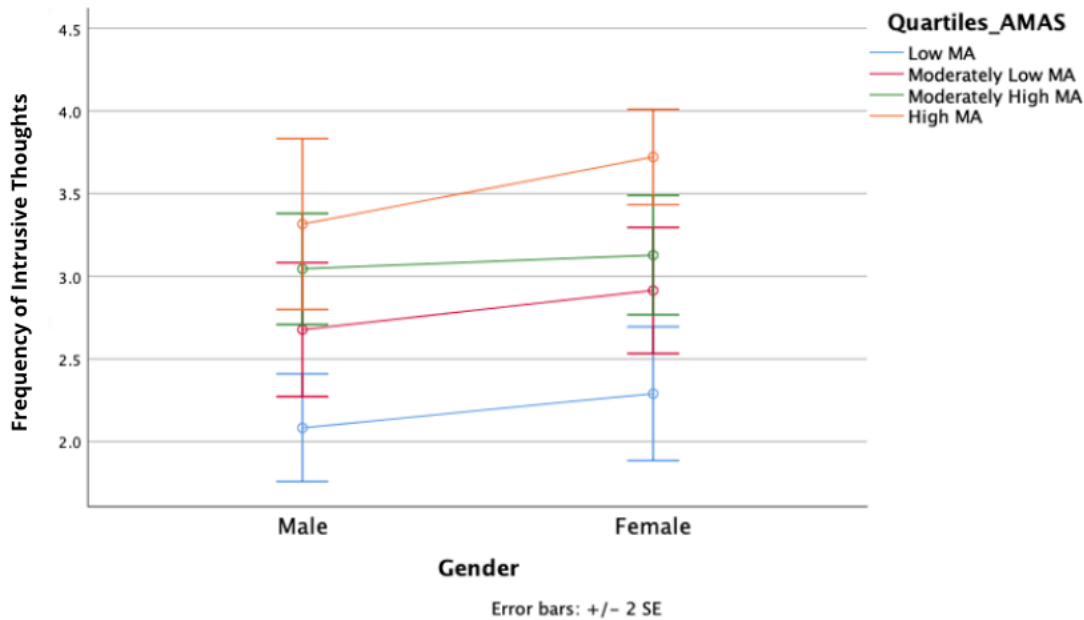
of intrusive thoughts $F(3, 301) = 16.75, p < .001$ adj. $R^2 = .14$, whereby higher math anxious individuals experienced more intrusive thoughts than lower math anxious individuals (see Table 2). With regards to Hypothesis 3, we predicted an interaction between gender and math anxiety whereby higher math anxious women would experience more intrusive thoughts than higher math anxious men. Contrary to our prediction, there were no interactions between gender and math anxiety on frequency of intrusive thoughts $F(3, 301) = 0.24, p = .872$, partial $\eta^2 = .002$ (see Figure 4).

Table 2. *Mean Frequency of Intrusive Thoughts by Level of Math Anxiety.*

	Low Math Anxiety (n = 79)	Moderately Low Math Anxious (n = 66)	Moderately High Math Anxious (n = 84)	High Math Anxious (n = 80)
Mean frequency of intrusive thoughts	2.16 (SD = 1.16)	2.80 (SD = 1.19)	3.09 (SD = 1.16)	3.68 (SD = .99)

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Figure 4. Relation Between Math Anxiety and Gender on the Frequency of Intrusive Thoughts.



Seven Different Types of Intrusive Thoughts

Analyses were also conducted to investigate the types of intrusive thoughts experienced as a function of gender and math anxiety.

Gender and types of intrusive thoughts

Hypothesis 4 was that women would experience more intrusive thoughts of each of the seven types. Chi-squares of homogeneity were conducted to explore this hypothesis. Contrary to what was expected, women experienced significantly more intrusive thoughts related only to making mistakes and panicking compared to men.

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Table 3. Differences in the Types of Intrusive Thoughts for Men and Women

Types of intrusive thoughts	Men (n = 143)	Women (n = 166)	Pearson Chi-Square	P value
Making Mistakes	67.1%	83.1%	10.70	.001*
Previous Math Experience	52.7%	65.1%	5.62	.018
Method of Problem Solving	41.3%	55.4%	6.17	.013
Time Pressure	32.9%	45.2%	4.87	.027
What People Might Think	26.6%	37.3%	4.08	.044
Panicking	15.4%	33.1%	12.93	<.001*
Physical Changes	14.7%	21.7%	2.50	.075
None of the Above	14.0%	4.8%	7.83	.004*

*Indicates statistically significant results at $p \leq .006$ as per Bonferroni's correction.

Of note: the percentages used in this table do not sum up to 100% as they are not mutually exclusive.

Math anxiety and types of intrusive thoughts

Based on the study from Hunt et al., 2014, Hypothesis 5 was that higher math anxious individuals would experience more intrusive thoughts related to what people might think, to panicking, and to physical changes relative to their lower math anxious peers. To test this hypothesis, math anxiety was divided into four quartiles low math anxiety ($n = 79$), moderately low math anxiety ($n = 66$), moderately high math anxiety ($n = 84$), and high math anxiety ($n = 79$). Chi-square tests of homogeneity were conducted to test whether there were differences in the types of intrusive thoughts experienced. Individuals in the fourth quartile (higher math anxious individuals) were more likely to experience intrusive thoughts of each of the seven types (see Table 4). Contrary to what was predicted, the most prevalent intrusive thoughts experienced by higher math anxious individuals were those related to making mistakes, to previous math experience, and to method of problem solving.

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Table 4. Differences in the Types of Intrusive Thoughts for Lower and Higher Math Anxious Individuals.

	Low MA (n = 79)	Medium Low MA (n = 66)	Medium High MA (n= 84)	High MA (n = 80)	Pearson Chi-Square	P value
Making mistakes	57.0%	71.2%	79.8%	93.8%	30.75	<.001*
Previous math experience	34.2%	57.6%	63.1%	80.0%	35.31	<.001*
Method of problem solving	34.2%	47.0%	52.4%	61.3%	12.24	.007
Time pressure	26.6%	36.4%	39.3%	55.0%	13.83	.004
What people may think	11.4%	25.8%	40.5%	50.0%	31.08	<.001*
Physical changes	10.1%	12.1%	16.7%	33.8%	18.02	<.001*
Panicking	6.3%	9.1%	32.1%	48.8%	50.06	<.001*
No intrusive thoughts	25.3%	9.1%	2.4%	0.0%	37.85	<.001*

*Indicates statistically significant results at $p \leq .006$ as per Bonferroni's correction.

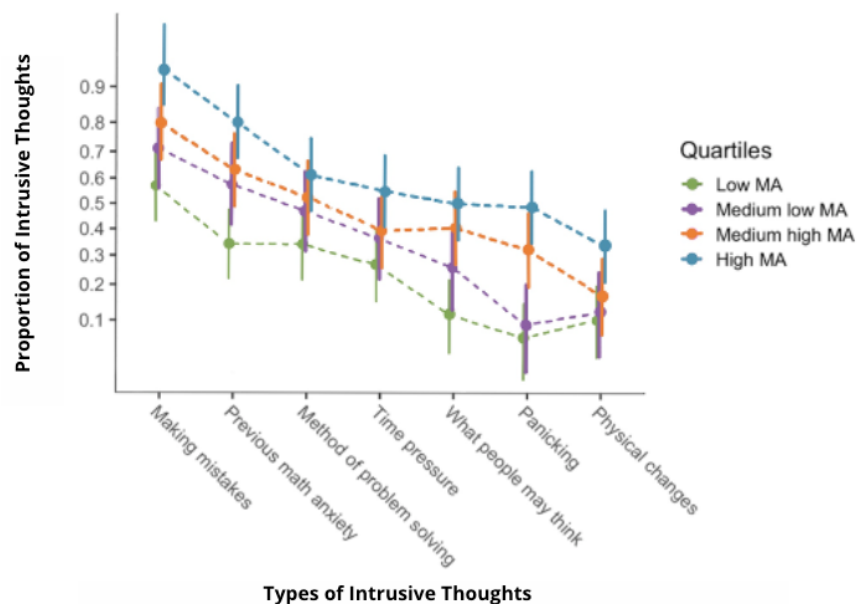
Of note: the percentages used in this table do not sum up to 100% as they are not mutually exclusive.

Next, we completed an ANOVA to investigate if there were proportional differences in the types of thoughts experienced among individuals with varying levels of math anxiety. The ANOVA allows one to explore interactions, main effects, and simple effects in studies that use repeated measures (Laurencelle & Cousineau, 2022). A significant effect of math anxiety $\chi^2(3) = 0.57, p = <.001$, as well as a significant effect of the types of intrusive thoughts $\chi^2(6) = 1.19, p = <.001$ was observed. There were no significant interactions between the level of math anxiety and types of intrusive thoughts experienced $\chi^2(18) = 0.07, p = <.001$ (see Figure 5). Participants with the highest level of math anxiety experienced more intrusive thoughts of every type compared to participants lower in math anxiety. As indicated in Figure 4, the proportional

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difference in the types of intrusive thoughts experienced as a function of math anxiety are similar regardless of the type of intrusive thought.

Figure 5. Differences in the Proportion of Intrusive Thoughts by Level of Math Anxiety.



Gender, math anxiety, and intrusive thoughts

Hypothesis 6 was that higher math anxious women would experience more intrusive thoughts of each of the seven types with the most prevalent thoughts being those related to making mistakes, method of problem solving, and what people may think. Again, AMAS was split by quartile and chi-squares of homogeneity were conducted. Contrary to what was predicted, higher math anxious women did not experience more intrusive thoughts of each of the seven types. As expected, however, the most common types of intrusive thoughts were related to making mistakes, previous math experience and method of problem solving (see Table 5).

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Table 5. *Differences in the Experience of Intrusive Thoughts for Men and Women*

Types of intrusive thoughts	Low Math Anxious Men (n = 48)	Moderately Low Math Anxious Men (n = 31)	Moderately High Math Anxious Men (n = 45)	High Math Anxious Men (n = 19)	Low Math Anxious Women (n = 31)	Moderately Low Math Anxious Women (n = 35)	Moderately High Math Anxious Women (n = 39)	Higher Math Anxious Women (n = 61)	Pearson Chi-Square	P value
Making Mistakes	47.9%	67.7%	77.8%	89.5%	71.0%	74.3%	82.1%	95.1%	37.03	<.001*
Previous Math Experience	31.3%	57.8%	57.8%	84.2%	38.7%	60.0%	69.2%	78.7%	37.25	<.001*
Method of Problem Solving	29.2%	38.7%	44.4%	68.4%	41.9%	54.3%	61.5%	59.0%	18.02	.012
Time Pressure	22.9%	29.0%	42.2%	42.1%	32.0%	42.9%	35.9%	59.0%	17.92	.012
Physical Changes	8.3%	16.1%	15.6%	26.3%	12.9%	8.6%	17.9%	36.1%	19.90	.006*
What People Might Think	4.2%	32.3%	35.6%	52.6%	22.6%	20.0%	46.2%	49.2%	36.28	<.001*
Panicking	4.2%	6.5%	26.7%	31.6%	9.7%	11.4%	38.5%	54.1%	56.06	<.001*
None of the Above	31.3%	12.9%	2.2%	0%	16.1%	5.7%	2.6%	0%	44.11	<.001*

*Indicates statistically significant results at $p \leq .006$ as per Bonferroni's correction.

Of note: the percentages used in this table do not sum up to 100% as they are not mutually exclusive.

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Categories of intrusive thoughts

Lastly, we had a research question that proposed that the most prevalent types of intrusive thoughts experienced by women ($n = 166$) would be those related to their math ability whereas men ($n = 143$) would experience more intrusive thoughts related to the circumstances of the task. A Kruskal-Wallis H test was conducted. The mean ranks of intrusive thoughts scores were statistically significantly different between groups, $\chi^2(1) = 13.278$, $p < .001$. Subsequently, Mann-Whitney U tests were performed with a Bonferroni correction for multiple comparisons. Women experienced more intrusive thoughts related to their math ability $U = 14606.00$, $z = 3.64$, $p < .001$, the circumstances of the task $U = 13899.00$, $z = 2.82$, $p = .005$ and physiological responses to the task $U = 13769.00$, $z = 2.94$, $p = .003$ (see Table 6 for means). As hypothesized, the most prevalent category of intrusive thoughts experienced by women was related to their math ability ($M = 2.04$, $SD = .96$). However, contrary to hypotheses, the most prevalent category of intrusive thoughts in men was also thoughts related to their math ability ($M = 1.60$, $SD = 1.05$).

Table 6. Means of Intrusive Thoughts by Categories of Thoughts for Men and Women

Categories of intrusive thoughts	Men	Women
Math Abilities	1.60 ($SD = 1.05$)	2.04 ($SD = .96$)
Circumstances of the task	.59 ($SD = .67$)	.83 ($SD = .73$)
Physiological response	.30 ($SD = .56$)	.55 ($SD = .75$)

Discussion

In the first part of this study, we tested three hypotheses related to the frequency of intrusive thoughts, whereby we hypothesized that (1) women would report more intrusive thoughts than men, (2) higher math anxious individuals would report more intrusive thoughts

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than lower math anxious individuals, and (3) higher math anxious women would experience more intrusive thoughts than higher math anxious men.

For Hypothesis 1, we failed to find a main effect of gender on the frequency of intrusive thoughts. This result is inconsistent with previous research that has found that women are generally more likely to experience intrusive thoughts than men (Arnáez et al., 2021; Del Río-Casanova et al., 2021; Thaiposri & Reece, 2022). With respect to Hypothesis 2, we found that individuals with higher math anxiety experienced more intrusive thoughts than those with lower math anxiety. This was consistent with previous findings by Hunt et al. (2014) who found math anxiety to strongly correlate with the frequency of intrusive thoughts. The results from Hypothesis 3 indicated no interaction between math anxiety and gender suggesting that the frequency of intrusive thoughts was similar for both higher math anxious men and women. This suggests that individuals with similar levels of math anxiety can be expected to have a similar frequency of intrusive thoughts, regardless of their gender. This is contrary to the literature in other fields which suggests that women tend to experience more intrusive thoughts than men (Arnáez et al., 2021; del Río-Casanova et al., 2021; Thaiposri & Reece, 2022). It has been previously reported that women tend to exhibit higher overall anxiety compared to men (Deng et al., 2021; Mohammadi et al., 2020). Consequently, when examining both anxiety and the frequency of intrusive thoughts between genders, one must consider the likely comparison between individuals with higher anxiety levels (often women) and those with lower anxiety levels (often men). This unintentional comparison can lead to the perception that women experience more intrusive thoughts than men. However, this study suggests that within the context of math anxiety, both men and women with similar levels of math anxiety experience no significant difference in the frequency of their intrusive thoughts. Furthermore, it is crucial to

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acknowledge that despite our efforts to include various strands of mathematics in the study, the math task employed may have been insufficiently challenging for the participants. Research suggests that the difficulty level of math tasks can impact the experience of math anxiety (Namkung et al., 2019). Consequently, it is plausible that the relatively easier task utilized in our study may have elicited lower levels of math anxiety, resulting in fewer instances of intrusive thoughts. Consequently, similar frequencies of intrusive thoughts may have been observed for both men and women in our study. Moreover, there is supporting evidence indicating that gender differences in math performance may be influenced by the specific types of math tasks (e.g., van de Weijer-Bergsma et al., 2022). Therefore, certain math strands could potentially lead to higher levels of math anxiety and, consequently, more frequent intrusive thoughts.

In the second part of this study, we investigated the types of intrusive thoughts experienced by participants. Specifically, we hypothesized that (4) women would experience more intrusive thoughts of each of the seven types, (5) higher math anxious individuals would experience more intrusive thoughts of each of the seven types, and (6) higher math anxious women would experience more intrusive thoughts of each of the seven types compared to higher math anxious men.

With regards to Hypothesis 4, we found that men and women did not experience differing types of intrusive thoughts. Rather, the most common types of thoughts experienced by men and women were related to making mistakes, previous math experiences and method of problem solving. Additionally, significantly more women experienced thoughts related to making mistakes and panicking than did men. Given that women are often more likely to be stereotyped as being “bad at math” (Steffens & Jelenec, 2011), it is possible that women in our sample

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experience more intrusive thoughts related to making mistakes in fear that if they made a mistake, they would confirm this social stereotype.

Previous research has also found a higher prevalence of panic disorder (McLean et al., 2011) and somatic symptoms (Atasoy et al., 2022) in women compared to men. As such, it is possible that previous experiences with somatic and panic related symptoms heightened sensitivity toward these symptoms among women in our sample, making them more likely to have intrusive thoughts about panicking than men. Men however were more likely to report experiencing an absence of intrusive thoughts compared to women. On one hand, it is possible that men truly experience little to no intrusive thoughts when completing the math task. On the other hand, previous researchers have suggested that men tend to underreport their levels of math anxiety (Xie et al., 2019). It is possible that the avoidance and/or absence of recognition of their anxiety extends to those of intrusive thoughts leading to an underreporting of their experience.

In line with Hypothesis 5, results from the study herein suggest that higher math anxious individuals experience more intrusive thoughts of every type as compared with their lower math anxious counterparts with the three most common types of thoughts related to making mistakes, previous math experience, and method of problem solving. Additionally, the proportional difference in the experience of intrusive thoughts was similar across levels of math anxiety. Interestingly, this was not completely in line with the results from Hunt and colleagues (2014). In their study, they also found making mistakes and method of problem solving as being the most common types of thoughts. The second most common type of intrusive thoughts reported in their study related to time pressure whereas in ours it was related to previous math experience. It is possible that the type of math completed may influence the types of thoughts experienced. In fact, in their study, Hunt and colleagues asked participants to complete addition and subtraction

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questions with fixation points between trials. This may have induced some sense of time pressure for participants. However, most participants were likely familiar with additions and subtractions therefore reducing intrusive thoughts related to previous math experience. On the contrary, in our study, participants were not presented fixation points and were asked a broader range of math questions stemming from the fifth to seventh grade curriculum. Participants had to have previously learned the math content to be able to answer these questions. This could have increased intrusive thoughts related to previous math experience. When exploring Hypothesis 6, we found that higher math anxious women and higher math anxious men also experienced the same types of intrusive thoughts whereby making mistakes, previous math experiences and method of problem solving were the most common.

Additionally, we had one research question which related to the categories of intrusive thoughts. We wondered if women would experience more intrusive thoughts related to their math ability whereas men would experience more intrusive thoughts related to the circumstances of the task. We found that both men and women in our sample reported experiencing more intrusive thoughts related to their math ability. These results suggest that, for both men and women, math anxiety seems to induce intrusive thoughts related to the math itself (i.e., making mistakes, previous math experience, method of problem solving) rather than other factors that may also contribute to the anxiety such as time pressure, what people may think, panicking and physical changes.

Implications

The findings from the study herein allowed for a more in depth look at the experience of math anxiety for men and women as well as for those with differing levels of math anxiety. In the last decade, there has been a push to explore and implement interventions to help those with

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math anxiety. One well supported intervention is expressive writing which is a clinical technique that encourages individuals to write openly about their feelings towards a stressor (Park et al., 2014). Expressive writing is thought to be helpful because it diminishes intrusive thoughts experienced by participants which ultimately helps increase working memory capacity (Klein & Boals, 2001). There is evidence to suggest that expressive writing tasks are most effective when participants are provided with specific guidelines for their writing (Reinhold et al., 2018). The findings from the study herein could help guide expressive writing interventions by providing participants with more specific instructions (i.e., write freely about fears related to how your previous math experience may influence your success on this task) rather than asking participants to write about a math task generally.

Limitations

The COVID-19 pandemic presented unprecedented challenges for data collection in this study. Conducting the research remotely using the Gorilla platform limited our control over data collection. This likely resulted in participants completing the survey in different environments, potentially influencing their engagement and the study outcomes. While steps were taken to ensure data quality and validity, including the use of attention check questions, it is important to acknowledge that limitations stemming from the remote survey methodology cannot be eliminated. This may have introduced additional variability and potential bias in the data.

Moreover, the exceptional circumstances of the COVID-19 pandemic were known to be stressful for many individuals and could have triggered intrusive thoughts (Del Río-Casanova et al., 2021). Consequently, the reported frequency of intrusive thoughts in this study may be an overestimation compared to non-exceptional times.

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Another limitation of this study is the homogeneity of the participant sample, which was primarily composed of young, anglophone adults from undergraduate programs and with mid-to-high socioeconomic status. Consequently, caution should be exercised when extrapolating the results to more diverse populations and contexts. Future studies should strive to replicate this research to a more heterogeneous sample and by conducting in-person surveys to address these limitations.

Furthermore, it appears that the math task employed in this study was relatively easy for participants, leading to high scores on the task (i.e., most participants had above 80%). This could potentially have influenced the participants' experience of math anxiety, as well as the frequency and types of intrusive thoughts reported. Additionally, the study was completed in a low stakes environment whereby participants were compensated for their participation rather than for their grades. To enhance the validity and generalizability of findings, future research should consider utilizing a more challenging math measure to introduce greater variability in participants' performance and subsequently capture a wider range of experiences in terms of math anxiety and intrusive thoughts. Future studies should also consider exploring whether results may change in a higher stakes environment such as when completing a class evaluation.

The study also lacked clear descriptions regarding the various types of intrusive thoughts. This could potentially have led to varied interpretations among participants. For instance, for thoughts related to past math experiences, some individuals might have construed this to inquire about their prior exposure to the content, while others may have understood it as their positive or negative encounters with math in the past. To address this ambiguity, future studies could encourage participants to elaborate on the specific nature of the prevalent thoughts they experienced. Additionally, qualitative data pertaining to intrusive thoughts would facilitate a

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deeper understanding of how individuals perceive and categorize intrusive thoughts, thereby enhancing the validity and reliability of the findings.

According to the cognitive interference theory, math anxiety leads to intrusive thoughts which uses up working memory necessary for math performance (Eysenck & Calvo, 1992). Considering the high demand for working memory in math tasks (Ashcraft, 1992), it can be inferred that experiencing math anxiety during such tasks leads to performance below one's potential capabilities (Ashcraft & Kirk, 2001; Maloney & Beilock, 2012). A limitation of this study is the absence of differentiation between math questions with higher and lower working memory demands. Consequently, we are unable to provide insights into the influence of working memory demands on intrusive thoughts. Investigating this aspect should be prioritized in future studies and will be the focus of Study 3.

Conclusion

Gender and math anxiety were both shown to be significant predictors of the frequency of intrusive thoughts. However, no interactions were identified between gender, math anxiety and intrusive thoughts whereby both higher math anxious men and women experienced similar frequencies of intrusive thoughts. Additionally, the most common types of intrusive thoughts for men, women, and for higher and lower math anxious individuals were those related to making mistakes, previous math experience, and method of problem solving. These findings provide important insight into both the gender, and math anxiety differences in intrusive thoughts. Future research should investigate the influence of working memory demands on intrusive thoughts experienced during a math task.

CHAPTER FOUR:**Study 3: Math Anxiety, Gender, and Intrusive Thoughts: A study Exploring Working Memory Demand**

Working memory can be defined as a cognitive process that provides a mental workspace for controlling, regulating, manipulating, and retaining crucial information necessary for the completion of complex cognitive tasks, such as solving intricate mathematical equations (Miyake & Shah, 1999). In the realm of mathematics, working memory holds particular importance due to the frequent need to retain partial information while mentally manipulating new information to reach a solution (Raghubar et al., 2010). Ashcraft and Kirk (2001) predicted that working memory was an important factor influencing math performance especially in those with higher math anxiety. They compared higher and lower math anxious individuals' performance on two-column addition problems involving carry operations (i.e., high working memory additions). While doing these additions, participants were also asked to maintain a 2-letter string or a 6 letter-string in memory. Individuals with higher levels of math anxiety produced significantly more mistakes when asked to maintain a 6-letter string in memory than those with lower levels of math anxiety. It was concluded that individuals with higher math anxiety were likely to experience worries which disrupted the working memory resources necessary for the completion of this task.

One of the downfalls of working memory is that it is limited in its nature and can be used up by external and/or internal distractions (Pellizzoni et al., 2022; Shi & Liu, 2016). As outlined in the general introduction, math anxiety can lead to intrusive thoughts and rumination which deplete working memory (Eysenck & Calvo, 1992). Given that math is particularly working memory demanding (Ashcraft, 1992), when individuals have higher math anxiety, they are trying to do two things at once 1) solve the math problem and 2) cope with intrusive thoughts (Beilock

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& Maloney, 2015; Ramirez et al., 2018). Given that intrusive thoughts consume working memory, this influences the individual's ability to maintain and mentally manipulate information such as required with math problems and thus diminishes their performance on math tasks (Beilock & Maloney, 2015; Ashcraft & Kirk, 2001; Maloney & Beilock, 2012). Shi and Liu in 2016 found that math anxious individuals had lower performances on a working memory demanding task when they had been previously presented with anxiety inducing math statements. In line with the cognitive interference theory, they hypothesized that these individuals likely experienced intrusive thoughts which impaired their performance.

In Study 2, our findings did not yield any evidence of gender differences in the frequency and types of intrusive thoughts experienced during the completion of the math task. Nonetheless, we proposed that this outcome could potentially be attributed to both the nature of the math task and its level of difficulty. Previous research has indicated that boys tend to exhibit superior performance on arithmetic tasks compared to girls (Weijer-Bergsma et al., 2022). Therefore, in this study, we modified the math task to specifically focus on arithmetic, with the aim of exploring whether gender differences may become apparent.

Furthermore, it remains unclear whether math tasks with higher demands on working memory versus those with lower demands evoke similar frequencies and types of intrusive thoughts. This requires further investigation to ascertain whether the cognitive load associated with working memory influences the manifestation of intrusive thoughts during math tasks. On one hand, it is possible that higher working memory demanding math (i.e., generally more difficult math) results in more intrusive thoughts which ultimately negatively affect math performance. On the other hand, it is possible that the same types and number of intrusive thoughts are present in both higher and lower working memory math. However, unlike higher

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working memory demanding math, lower working memory demanding math requires fewer working memory resources which may make it manageable for individuals to attend to both the math task and the intrusive thoughts. If this is the case, performance may not be impacted on lower working memory demanding math but only when the math requires more working memory resources than available.

Current Study

In the current study, we measured individuals' experience of intrusive thoughts when completing lower and higher working memory-demanding math tasks to further deepen our understanding of the gender differences in math anxiety. Similar to Study 2, both the frequency and the types of intrusive thoughts were explored as a function of gender and level of math anxiety.

Performance

It was hypothesized that we would find a main effect of working memory demand on performance. In light of the results from Study 1 which identified a gender difference in math performance, we also hypothesized that there would be a main effect of gender on performance. As previously mentioned, for Study 1 and 2 we used a measure that proved to be relatively easy for participants. We still observed gender differences on math performance with men achieving slightly better scores than women, although the differences were not substantial. For the current study, we chose a math measure that involves both low working memory and high working memory arithmetic calculations. Consequently, on the low working memory math task, we anticipated that participants would perform well and therefore scores would be similar between genders. However, considering that tasks requiring higher working memory tend to be inherently more challenging, we hypothesized that scores on the higher working memory math task would

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decrease for both men and women. This led us to predict that there would be no interaction between working memory and gender (*Hypothesis 1*). Similarly, it was also hypothesized that the relation between working memory demand, level of math anxiety, and performance would exhibit a main effect of working memory demand and a main effect of math anxiety. It was also predicted that there would be no interactions between these two variables because again, we anticipated that both higher and lower math anxious individual would perform well on the lower working memory task, and both have reduced performance on the higher working memory math task (*Hypothesis 2*).

Frequency of intrusive thoughts

Prior research has found women to experience more intrusive thoughts than men (Lepore et al., 2000). Moreover, gender differences have been noted in performance on arithmetic tasks (Weijer-Bergsma et al., 2022). Based on these findings, it was hypothesized that we would observe a gender difference in the frequency of intrusive thoughts whereby women would experience more intrusive thoughts than men. Additionally, given that higher working memory tasks tend to be more challenging in nature, we hypothesized that there would be a main effect of working memory on the frequency of intrusive thoughts. However, given that working memory tasks are inherently more challenging, we thought that both men and women may experience more intrusive thoughts when completing the higher working memory task leading to no interaction between gender and working memory (*Hypothesis 3*). It was also hypothesized that when examining the relation between working memory demand, levels of math anxiety and the frequency of intrusive thoughts there would be a main effect of working memory demand and math anxiety. Given that higher math anxious individuals experience more intrusive thoughts than lower math anxious individuals (Wigfield & Meece, 1988; Hunt et al., 2014) and that higher

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working memory tasks are more challenging than lower working memory tasks, it was hypothesized that there would be an interaction between working memory and math anxiety (*Hypothesis 4*).

Types of thoughts

Given the findings from Study 2, it was hypothesized that both men and women would experience the same types of intrusive thoughts when completing a lower and a higher working memory-demanding task (*Hypothesis 5*). It was also hypothesized that higher math anxious men and women would experience more intrusive thoughts of every type compared to their lower math anxious counterparts (*Hypothesis 6*). Further, it was hypothesized that the most common types of intrusive thoughts experienced by both higher math anxious men and women would be those related to making mistakes, previous math experience, and method of problem solving (*Hypothesis 7*). Finally, given that individuals tend to have more difficulty completing higher working memory-demanding tasks, it was hypothesized that individuals would experience more intrusive thoughts of every type when completing a higher working memory-demanding task compared to a lower working memory-demanding task (*Hypothesis 8*).

Methods

Participants

An a priori power analysis was performed utilizing G*Power 3.1.9.2 software, indicating a necessary sample size of 382 participants with $\alpha = 0.05$ and Power = 0.95. We adjusted the required sample size by approximately 25%, considering the anticipated percentage of participants who would be excluded. Over two semester, undergraduate students ($N = 635$) from a Canadian university were recruited via an undergraduate student pool which is designed to allow students following introductory level courses to earn up to four percent of their final

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course grade by participating in research. Students who participated in this 45-minute study were allocated one percent towards their final grade, as per institutional guidelines.

Upon registration to the pool, participants were asked to fill out a pre-screen questionnaire. Among the pre-screen questions, they were asked to complete the Single-Item Math Anxiety (SIMA) and were required to be fluent in written English. Some participants were excluded from analyses for various reasons, including: their data did not register correctly ($n = 39$), providing an invalid verification ID ($n = 2$), or providing inconsistent scores for the SIMA and the AMAS ($n = 29$; i.e., note that this was determined the same way as in Study 2). Participants were also excluded if they incorrectly answered two or more attention check questions ($n = 7$; e.g., “Please select 2”) or provided the same consecutive answer on reverse coded measures (i.e., State Trait Anxiety Inventory) for more than half of the scale ($n = 2$; Huang et al., 2012). Participants who reported using a calculator, a pencil and paper or reported that they did not provide quality data ($n = 119$) were also excluded from analyses as these would have greatly impacted the strain on their working memory. This resulted in a final sample size ($N = 437$) providing sufficient power for our post-hoc power analysis [$\alpha = 0.05$, Power = .97]. Data was collected from May to November 2022.

Of the 437 included participants, 123 participants identified as men, 303 identified as women and 11 individuals identified as another gender (e.g., non-binary, trans, questioning). Women reported higher levels of math anxiety ($M = 27.61$, $SD = 7.20$) than men ($M = 22.85$, $SD = 7.07$), $t(424) = -6.22$, $p = <.001$. The mean age of participants was 19.52 years ($SD = 3.50$) and participants in the sample reported being registered in a range of faculties: Health Sciences (28.1%), Social Sciences (26.1%), Science (23.3%), Business Management (11.0%), Arts (6.9%), Engineering (4.1%), Medicine (<1%), and Education (<1%). Most participants reported

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their native tongue to be English (54.2%) whereas others reported French (20.5%), Arabic (4.3%), Mandarin (3%), or other languages (18%). Most participants also reported a family income above 75,000\$ per year (60.4%).

Measures

Note that the measures of math anxiety, general anxiety, socio-demographic questions were identical to those used in Study 1 and the measure of intrusive thoughts was identical to the one used in Study 2. Therefore, only the measures new to Study 3 are detailed below.

Modular Arithmetic

The math task used was the modular arithmetic task developed by Gauss (1801; as cited in Beilock & Carr, 2005) as it requires knowledge and skill from real-world arithmetic. However, given that modular arithmetic is not often used or taught, this task is advantageous in a study as it is often novel, even to those who have a lot of math experience. Modular arithmetic problems (i.e., represented by the following symbol “ \equiv ”) are completed by judging the accuracy of problems such as “ $62 \equiv 14 \pmod{3}$ ”. To solve the problem, the second number needs to be subtracted from the first number (i.e., $62-14$). Next, the difference is divided by the last number (i.e., $48/3$). If the dividend provides a whole number (i.e., no decimals), then the statement is true, if not, the statement is false. This task was divided into two subsections: questions that were lower in working memory demand and those that were higher in working memory demand. Higher working memory demand questions involved carry-over operations (e.g., $73 \equiv 13$) whereas lower working memory demand questions did not (e.g., $8 \equiv 1$). Carry-over operations are thought to be more working memory demanding as participants need to mentally keep track of the carried-over digits, maintain accuracy in the calculations, and correctly align and place the numbers in the appropriate columns (Ashcraft & Krause, 2007). As such, working memory

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resources are necessary to temporarily store and manipulate the intermediate results during the problem-solving process (Ashcraft & Krause, 2007). To review this task, please refer to Appendix F. Cronbach's alpha for the task within our current sample was of .93.

Procedure

This study was approved by the *Office of Research Ethics and Integrity* and complied with the *Social Sciences and Humanities Research Council of Canada's* guidelines on human testing. Each participant was tested individually through Gorilla on their own device. Interested participants registered for the study through the student research pool and provided voluntary and informed consent. Next, participants were asked to complete questionnaires assessing their level of math anxiety (AMAS) and general anxiety (STAI-T). Participants were then randomly assigned to either a higher or a lower working memory-demanding modular arithmetic task. This study used a within-participants design whereby each participant was exposed to both the higher and lower working memory-demanding tasks. For the working memory task, participants were provided a solution to a modular arithmetic question and were asked to identify whether the question was correctly or incorrectly resolved by pressing "a" for true or "l" for false. Every participant first completed a practice trial which was comprised of four lower working memory demand questions [e.g., $5 \equiv 2 \pmod{3}$] and four higher working memory demand questions [e.g., $62 \equiv 14 \pmod{3}$]. These were presented in a randomized order. Each trial started with a 500ms fixation point at the centre of the screen followed by the question. During the practice trial, participants were presented with a check mark or an X for 1,000ms following the submission of an answer to indicate whether they had correctly resolved the problem. Then, the screen went blank for 1,000ms before they were presented with the next fixation point. Both the higher working memory demand and the lower working memory demand tasks comprised 40 modular

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arithmetic problems which were presented in a random order for each participant. Participants were instructed that the use of calculators, paper, and/or pencils were not permitted. Following the first working memory demanding tasks (i.e., higher and lower working memory demanding tasks), the participants were asked to complete an assessment of the intrusive thoughts they experienced during the task (Hunt et al., 2014). Following the intrusive thoughts questionnaire, and prior to the second working memory demanding task, participants were required to watch a 2:45 second video on rice cultivation to neutralize working memory load and the anxiety from the previous task. Next, participants were asked to complete the subsequent modular arithmetic task followed by another self-reported measure on intrusive thoughts. Finally, participants were asked to answer demographic questions and confirm whether they used a calculator or paper-pencil during their participation.

Data analysis plan.

Statistical analyses were performed using SPSS version 26 and R version 4.2.2. Occasionally some participants did not provide answers to a few questions on the AMAS and the STAI-T (<2%). A Little's Missing Complete at Random (MCAR) test was completed to determine the pattern of missing data. Results indicated that data were MCAR, $\chi^2(4435, N = 437) = 4060.06, p = 1.000$. Expectation-maximization with 250 iterations was completed to replace missing values.

First and foremost, four separate two-way mixed ANOVAs were completed to investigate the first four hypotheses. We tested the assumptions of homogeneity, outliers, and normality of distributions. Next, chi-square tests of homogeneity were completed to investigate the following hypotheses. To control for the increase in Type I error, Bonferroni corrections were manually applied, and statistically significant results were identified as being those with a p value ≤ 0.03 . It

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is important to note that individuals who identified as other than men or women were excluded from analyses regarding questions pertaining to gender. They were included in all other analyses. Of note, both ANOVAs and chi-squares are believed to be robust against unequal group sizes (Blanca et al., 2017; McHugh, 2012). An ANOPA was completed to explore whether proportional differences existed between the types of thoughts experienced during a lower and a higher working memory demand tasks (Laurencelle & Cousineau, 2022).

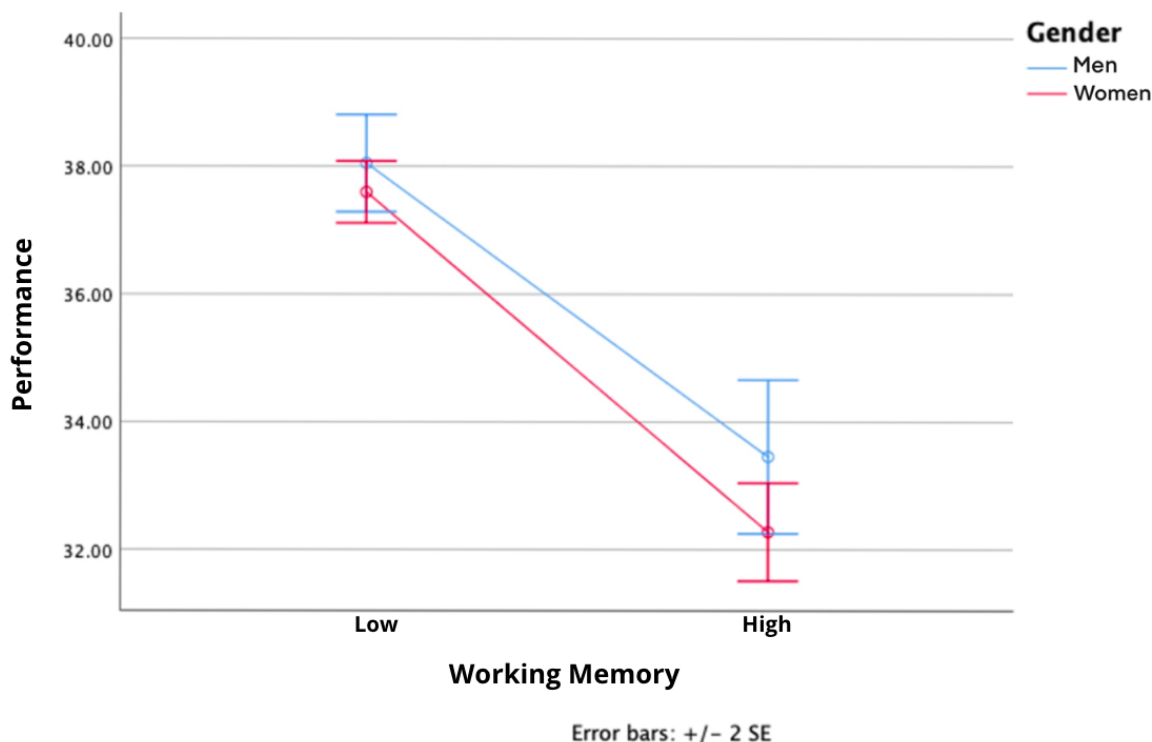
Results

Performance on the task

Performance, Gender, and Working Memory Demand

We first predicted a main effect of gender on performance during the math task. Only individuals who identified as men and women were included in this analysis. Contrary to our expectations, there were no main effects of gender $F(1, 424) = 2.53, p = .11, \eta^2 = .006$ and both men and women had similar scores during the math task (men $M = 71.51, SD = 9.02$; women $M = 69.88, SD = 9.79$). We also hypothesized that there would be a main effect of working memory on performance during the math task. The two-way mixed ANOVA revealed a main effect of working memory demand $F(1, 424) = 259.96, p < .001, \eta^2 = .38$ whereby individuals experienced lower performance when completing a higher working memory demanding task ($M = 32.67, SD = 6.67$) compared to a lower working memory demanding task ($M = 37.69, SD = 4.27$). As hypothesized, there was no interaction between working memory demand and gender, $F(1, 424) = 1.397, p = .238$ (see Figure 6).

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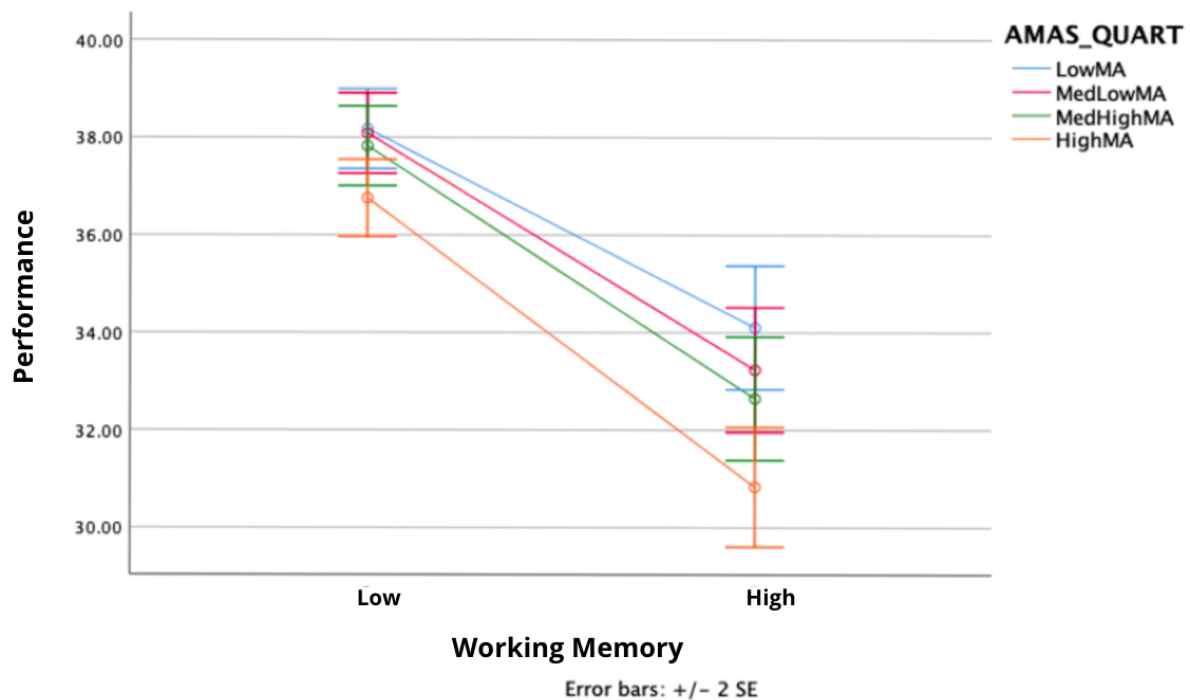
Figure 6. Effects of Gender and Working Memory Demand on Performance.**Performance, Math Anxiety and Working Memory Demand**

Furthermore, we hypothesized that we would observe a main effect of math anxiety on performance during the math task. Math anxiety was divided into quartiles for this analysis. A two-way mixed ANOVA revealed a main effect of level of math anxiety, $F(3,433) = 5.12, p = .002, \eta^2 = .03$ whereby those with higher math anxiety experienced lower scores on both the lower and the higher working memory demand task (see Table 7). As anticipated, we also found a main effect of working memory demand $F(1, 433) = 331.20, p < .001, \eta^2 = .43$ whereby individuals exhibited lower performances when completing a higher working memory demanding task ($M = 32.67, SD = 6.67$) compared to a lower working memory demanding task ($M = 37.69, SD = 4.27$). A two-way mixed ANOVA also revealed no interaction between working memory demand and math anxiety, $F(3, 430) = 1.98, p = .12$ (see Figure 7).

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Table 7. Performance on Working Memory Demand Task by Level of Math Anxiety.

Mean scores	Low Math Anxiety (n = 108)	Moderately Low Math Anxious (n = 106)	Moderately High Math Anxious (n = 108)	High Math Anxious (n = 115)
Lower working memory demand task	38.18 (SD = 3.90)	38.09 (SD = 3.13)	37.82 (SD = 4.09)	36.76 (SD = 5.44)
Higher working memory demand task	34.10 (SD = 6.12)	33.24 (SD = 6.76)	32.65 (SD = 6.83)	30.83 (SD = 6.61)

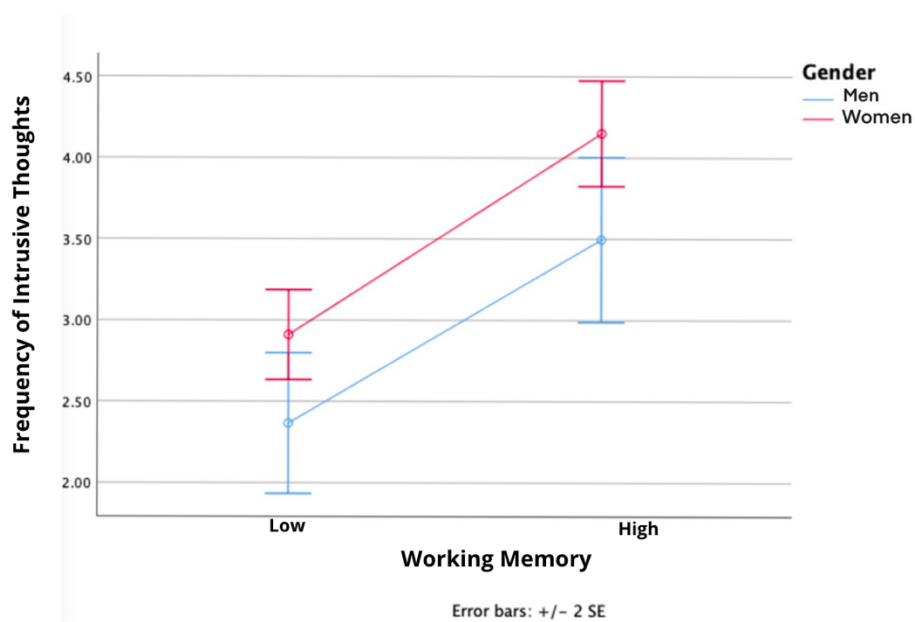
Figure 7. Performance on the Working Memory Demand Tasks for Individuals with Varying Levels of Math Anxiety.**Frequency of Intrusive Thoughts****Gender Difference in the Frequency of Intrusive Thoughts**

It was also hypothesized that there would be a main effect of gender on the frequency of intrusive thoughts. Only individuals who identified as men and women were included in this

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analysis. As predicted, a two-way ANOVA revealed a main effect of gender $F(1, 422) = 5.90, p = .016, \eta^2 = .014$ whereby women ($M = 3.53, SD = .13$) reported experiencing more frequent intrusive thoughts than men ($M = 2.93, SD = .21$). We also predicted a main effect of working memory on the frequency of intrusive thoughts. A main effect of working memory demand was identified $F(1, 422) = 79.97, p < .001, \eta^2 = .16$ whereby individuals experienced more intrusive thoughts when completing a higher working memory demanding task ($M = 3.82, SD = .15$) compared to a lower working memory demanding task ($M = 2.64, SD = .13$). However, we did not predict an interaction between gender and working memory. As hypothesized, a two-way mixed ANOVA revealed no interaction between working memory demand and gender, $F(1, 422) = 0.17, p = .68$ (see Figure 6).

Figure 8. *Effect of Gender and Working Memory Demand on the Frequency of Intrusive Thoughts.*



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Math Anxiety Differences and the Frequency of Intrusive Thoughts

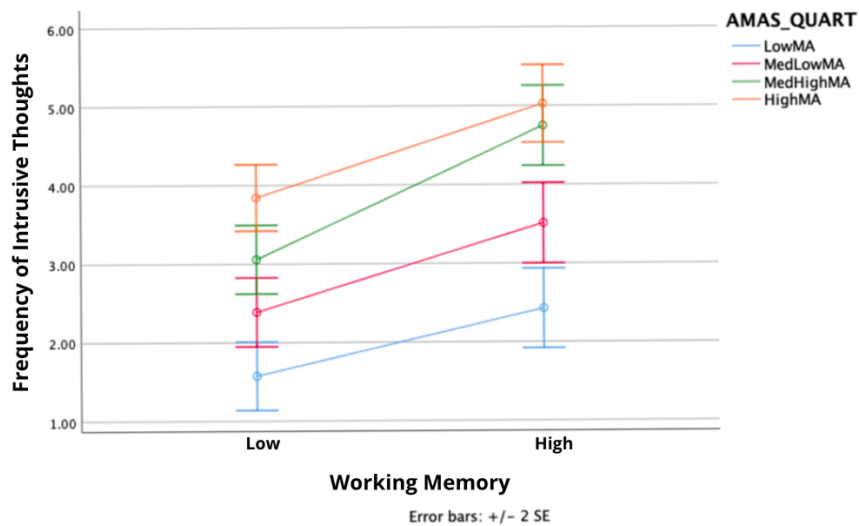
It was further hypothesized that we would observe a main effect of math anxiety on the frequency on intrusive thoughts. As expected, a two-way mixed ANOVA revealed a main effect of level of math anxiety, when divided into quartiles, $F(3,431) = 28.23, p < .001, \eta^2 = .16$. Specifically, individuals with higher math anxiety experienced more frequent intrusive thoughts than lower math anxious individuals (see Table 8). We also hypothesized that we would, again, find a main effect of working memory on the frequency of intrusive thoughts. As predicted, a main effect of working memory demand was identified $F(1, 431) = 105.17, p < .001, \eta^2 = .20$, whereby individuals experienced more intrusive thoughts when completing a higher working memory demanding task compared to a lower working memory demanding task. However, it was expected that there would be an interaction between math anxiety and working memory. The two-way mixed ANOVA revealed no interaction between working memory demand and math anxiety, $F(3, 428) = 2.17, p = .09$ (see Figure 9).

Table 8. *Mean Total Frequency of Intrusive Thoughts by Level of Math Anxiety.*

	Low Math Anxiety (n = 108)	Moderately Low Math Anxious (n = 106)	Moderately High Math Anxious (n = 107)	High Math Anxious (n = 114)
Mean frequency of intrusive thoughts	2.0	2.95	3.9	4.43
	(SD = .20)	(SD = .21)	(SD = .21)	(SD = .20)

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Figure 9. *Effect of Math Anxiety and Working Memory Demand on the Frequency of Intrusive Thoughts.*



Types of Intrusive Thoughts

Gender and the types of intrusive thoughts

It was further hypothesized that both men and women would experience the same types of intrusive thoughts when completing a lower and a higher working memory demanding task. As expected, both men and women experienced mostly the same types of intrusive thoughts with the most common thoughts being related to making mistakes, method of problem solving, and time pressure (see Table 9).

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Table 9. *Differences in the Types of Intrusive Thoughts for Men and Women with Differing Levels of Math Anxiety*

Types of intrusive thoughts	Men - Low working memory math (n = 123)	Women - Low working memory math (n = 303)	Men - High working memory math (n = 123)	Women - High working memory math (n = 303)
Making Mistakes	63.4%	69.6%	74.8%	82.8%
Method of Problem Solving	30.9%	33.0%	56.9%	60.7%
Time Pressure	34.1%	36.9%	46.3%	53.1%
Previous Math Experience	26.8%	25.7%	30.1%	35.0%
What People Might Think	12.2%	18.5%	19.5%	27.7%
Panicking	11.4%	18.8%	22.8%	35.3%
Physical Changes	6.5%	14.9%	11.4%	21.5%
None of the Above	19.5%	17.8%	12.2%	8.9%

Of note: the percentages used in this table do not sum up to 100% as they are not mutually exclusive.

Gender, math anxiety, and intrusive thoughts

Additionally, similarly to the findings from Study 2, it was hypothesized that higher math anxious men and women would experience more intrusive thoughts of every type as compared to their lower math anxious counterparts. Only individuals who identified as men and women were included in this analysis. To explore this question, AMAS was split into quartiles and the number of intrusive thoughts for either the lower working memory demanding or the higher working memory demanding tasks were added. Contrary to this hypothesis, higher math anxious men and higher math anxious women did not experience more intrusive thoughts of every type. In fact, moderately high math anxious men experienced more intrusive thoughts related to method of problem solving, previous math experience, what people may think, and physical changes than higher math anxious men. Moderately high math anxious women also experienced more intrusive thoughts related to making mistakes, method of problem solving, and time pressure

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than higher math anxious women. It was further hypothesized that the most frequent types of thoughts experienced by higher math anxious men and women would be those relating to making mistakes, previous math experience, and method of problem solving. Similarly to the findings from Study 2, the most common type of intrusive thoughts were related to making mistakes and method of problem solving. Unlike Study 2, one of the most common types of intrusive thoughts related to time pressure rather than previous math experience (see Table 10).

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Table 10. *Differences in the Types of Intrusive Thoughts for Men and Women with Differing Levels of Math Anxiety.*

Types of intrusive thoughts	Low Math Anxious Men (n = 46)	Moderately Low Math Anxious Men (n = 35)	Moderately High Math Anxious Men (n = 28)	High Math Anxious Men (n = 14)	Low Math Anxious Women (n = 58)	Moderately Low Math Anxious Women (n = 70)	Moderately High Math Anxious Women (n = 75)	Higher Math Anxious Women (n = 100)	Pearson Chi-Square	P value
Making Mistakes	78.3%	88.6%	92.9%	100.0%	79.3%	85.7%	96.0%	94.0%	20.17	.005*
Method of Problem Solving	52.2%	60.0%	78.6%	64.3%	51.7%	54.3%	78.7%	74.0%	23.73	.001*
Time Pressure	56.5%	31.4%	67.9%	85.7%	34.5%	54.3%	80.0%	71.0%	51.07	<.001*
Previous Math Experience	26.1%	40.0%	64.3%	57.1%	22.4%	35.7%	36.0%	63.0%	41.27	<.001*
What People Might Think	19.6%	14.3%	50.0%	14.3%	15.5%	17.1%	44.0%	44.0%	41.08	<.001*
Panicking	15.2%	28.6%	39.3%	42.9%	13.8%	30.0%	49.3%	60.0%	52.78	<.001*
Physical Changes	2.2%	14.3%	35.7%	7.1%	8.6%	14.3%	36.0%	40.0%	50.18	<.001*
None of the Above	41.3%	25.7%	14.3%	14.3%	36.2%	30.0%	10.7%	18.0%	25.22	.001*

*Indicates statistically significant results at $p \leq .006$ as per Bonferroni's correction.

Of note: the percentages used in this table do not sum up to 100% as they are not mutually exclusive.

Types of Intrusive Thoughts Experienced in High and Low Working Memory Tasks

Finally, eight chi-squares of homogeneity were conducted to explore whether the types of thoughts experienced in a lower and higher working memory demanding task differed. It was hypothesized that individuals would experience more intrusive thoughts of every type when completing a higher working memory demanding task. However, contrary to what was anticipated, the higher working memory task elicited significantly more intrusive thoughts of every type except for previous math experience and physical changes (see Table 11). The most common types of intrusive thoughts for both the lower working memory demanding task and the higher working memory demanding task were those related to making mistakes, method of problem solving, and previous math experience.

Table 11. *Differences in the Types of Intrusive Thoughts Experienced During the Higher and Lower Working Memory Demand Task.*

Intrusive Thoughts	Low working memory task (n=437)	High working memory task (n = 437)	Pearson Chi-Squares	P Value
Making Mistakes	295 (67.5%)	351 (80.3%)	18.61	<.001*
Time pressure	161 (36.9%)	221 (50.6%)	16.74	<.001*
Method of problem solving	140 (32%)	259 (59.3%)	65.30	<.001*
Previous math experience	112 (25.6%)	145 (33.2%)	6.002	.014
Panicking	72 (16.5%)	137 (31.4%)	26.60	<.001*
What people may think	71 (16.2%)	108 (24.7%)	9.62	.002*
Physical changes	54 (12.4%)	83 (19.0%)	7.28	.007
None	82 (18.8%)	44 (10.1%)	13.39	<.001*

*Indicates statistically significant results at $p \leq .006$ as per Bonferroni's correction.

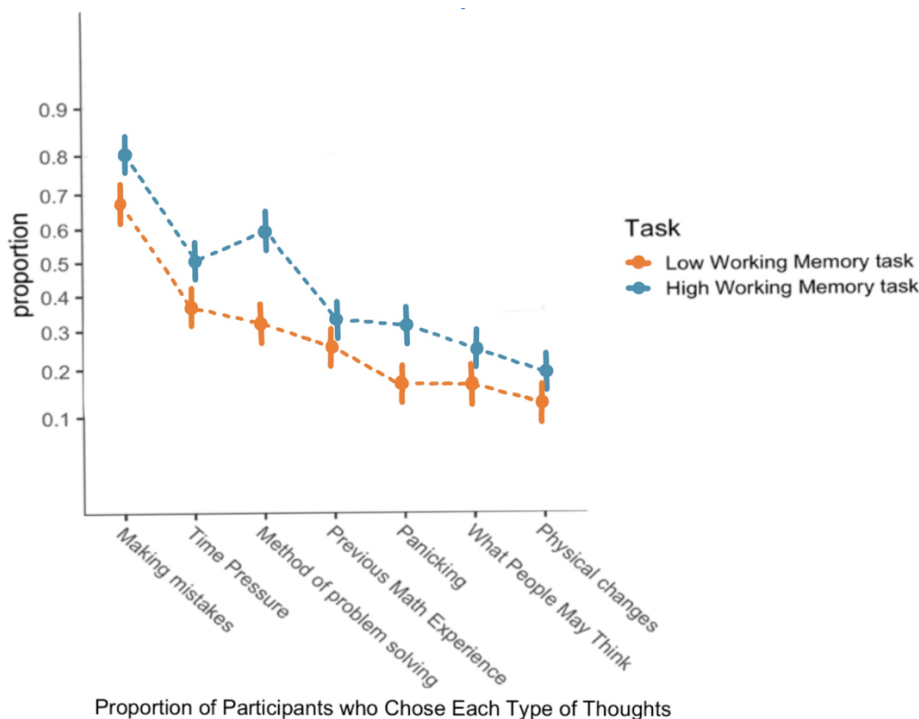
Of note: the percentages used in this table do not sum up to 100% as they are not mutually exclusive.

To explore this question further an ANOVA was completed to explore whether proportional differences existed between the types of thoughts experienced during a lower and a higher working memory demand task. The ANOVA allows the exploration of interactions, main and simple effects in studies which use repeated measures (Laurencelle & Cousineau, 2022). The ANOVA revealed a significant effect of the working memory task $\chi^2(1) = 129.29, p = <.001$, as well as a significant effect of the types of intrusive thoughts $\chi^2(6) = 213.31, p = <.001$.

Additionally, a significant interaction was found between the demand of the working memory task and the types of intrusive thoughts experienced $\chi^2(11) = 213.31, p = <.001$ (see Figure 10).

As can be observed in Figure 10, when completing a higher working memory demand task, participants experienced more intrusive thoughts of every type compared to when they completed a lower working memory demand task. However, compared to other types of intrusive thoughts, there was a significant increase in the proportion of intrusive thoughts related to method of problem solving when individuals participated in a higher working memory task compared to a lower working memory task.

Figure 10. Proportional Differences in the Types of Intrusive Thoughts Experienced in Higher and Lower Working Memory Demand Tasks.



Discussion

We first tested two hypotheses related to performance on the math task where we hypothesized (1) that we would observe that both gender and working memory would individually influence performance on the math task. However, it was predicted that there would be no interaction between gender and working memory demand. Further, we hypothesized (2) that we would observe a main effect of math anxiety and a main effect of working memory demand on performance, but no interaction between these variables.

Contrary to Hypothesis 1, there were no main effects of gender on performance during the math task. As such, both men and women experienced similar scores on both the lower and the higher working memory demanding task. These findings are inconsistent with the results from both Study 1 and Study 2 which indicated a gender difference in math performance. As such, this study adds to the current inconsistencies in the literature. As suggested by Vukovic et

al., 2013, it is possible that the type of math completed influences math anxiety and therefore math performance. However, previous researchers have found gender differences in arithmetic performance (Mullis et al., 2020; van de Weijer-Bergsma et al., 2022), which was the underlying reason why we chose this math task. Interestingly, the arithmetic task resulted in a gender difference in the occurrence of intrusive thoughts but not in math performance. We did however find a main effect of working memory on performance whereby individuals experienced lower performance on the higher working memory demanding math task but not on the lower working memory demanding math task. These results are not surprising considering that the relation between math anxiety and math performance appears to be influenced by the level of difficulty of the math task (i.e., the amount of working memory necessary to complete the task; Namkung et al., 2019). Engaging in more complex mathematical tasks requires a higher utilization of working memory resources. However, considering that working memory is limited in its nature, math tasks that exceed working memory capacities may result in difficulties retaining and mentally manipulating mathematical information (Namkung et al., 2019). Consequently, this can lead to errors and a decline in overall math performance (Namkung et al., 2019).

With regards to Hypothesis 2, we also found a main effect of working memory as well as a main effect of math anxiety on performance. However, there were no interactions between these variables. These results suggest that working memory demand influences performance on the task for both higher and lower math anxious individuals. It is important to note that higher working memory tasks are inherently more challenging for most individuals. Consequently, individuals with lower math anxiety also exhibit a decrease in performance on tasks requiring higher working memory, although the extent of this decrease isn't as substantial compared to individuals with higher math anxiety. Through the lens of the cognitive interference theory, one

could hypothesize that the presence of anxiety may lead to intrusive thoughts which interfere with individuals' working memory (Calvo & Eysenck, 1992). As such, individuals with higher levels of math anxiety would have less working memory resources to attribute to the working memory demanding math tasks regardless of the level of difficulty of the task. This results in worse performance than those with lower math anxiety (Ashcraft & Kirk, 2001; Maloney & Beilock, 2012). Considering that higher math anxious individuals already have limited working memory resources, a more pronounced decline in performance is observed when the task requires higher working memory resources.

Next, we tested two hypotheses related to the frequency of intrusive thoughts, whereby we hypothesized that (3) when examining the relation between working memory demand, gender, and the frequency of intrusive thoughts we would observe a main effect of working memory demand, a main effect of gender but no interaction between these variables. Similarly, hypothesis (4) stated that when examining the relation between working memory demand, levels of math anxiety, and the frequency of intrusive thoughts there would be a main effect of working memory demand and a main effect of math anxiety and an interaction between working memory demand and level of math anxiety.

For Hypothesis 3, as predicted we found a main effect of gender. This result is inconsistent with our findings from Study 2 whereby we found no gender differences in the frequency of intrusive thoughts. However, it is consistent with past literature which states that, under stressful circumstances, women generally experience more intrusive thoughts than men (Arnáez et al., 2021; Del Río-Casanova et al., 2021; Thaiposri & Reece, 2022). It is possible that the type of math completed elicited more math anxiety for women and therefore an increase in the frequency of intrusive thoughts. We also observed a main effect of working memory demand.

This is likely because higher working memory tasks generally generate more math anxiety and subsequently more intrusive thoughts (Carey et al., 2016; Ching, 2017). However, we did not observe any interaction between gender and working memory demand which suggests that women experienced more intrusive thoughts than men, regardless of the working memory demand of the math task.

Regarding Hypothesis 4, our study yielded a significant main effect of math anxiety on the frequency of intrusive thoughts. These findings align with the results obtained in Study 2, where we observed that individuals with higher levels of math anxiety reported more frequent intrusive thoughts compared to those with lower math anxiety. Moreover, these results are consistent with the results from Hunt et al. (2014), which also found math anxiety to be strongly related with the frequency of intrusive thoughts during math tasks. As previously stated in Hypothesis 2, we also found a main effect of working memory. However, we did not observe any interaction between math anxiety and working memory which suggests that higher math anxious individuals experienced more intrusive thoughts during both a lower and a higher working memory demand math task. However, unlike higher working memory-demanding math, lower working memory-demanding math requires fewer working memory resources. This may enable individuals to manage both the math task and the intrusive thoughts simultaneously. In such cases, performance does not seem to be as affected in lower working memory-demanding math tasks, but only when the math requires more working memory resources than readily available.

Finally, we investigated the types of intrusive thoughts experienced by participants. Specifically, we hypothesized (5) that men and women would experience the same types of intrusive thoughts when completing a lower and higher working memory task. We also

hypothesized (6) that higher math anxious individuals would experience more intrusive thoughts of every type, (7) the most common types of thoughts would be related to making mistakes, previous math experience, and method of problem solving, and (8) participants would experience more intrusive thoughts of every type when completing the higher working memory task.

With regards to Hypothesis 5, as expected, both men and women experienced the same types of intrusive thoughts. This was consistent with the findings from Study 2 which found no significant differences in the types of intrusive thoughts experienced during the math task. For Hypothesis 6, we found that, contrary to our hypothesis, higher math anxious men and higher math anxious women did not experience more intrusive thoughts of every type. More specifically, moderately high math anxious men experienced more intrusive thoughts related to method of problem solving, previous math experience, what people may think, and physical changes, than higher math anxious men. Additionally, moderately high math anxious women also experienced more intrusive thoughts related to making mistakes, method of problem solving, and time pressure than higher math anxious women, though some of these differences were negligible. On the contrary, higher math anxious women experienced more intrusive thoughts pertaining to previous math experience, panic, and physical changes. Given that anxiety often leads to physiological changes, it is possible that as anxiety increases, it leads to more physical symptoms and more symptoms of panic increasing these types of intrusive thoughts.

Similarly to the findings from Study 2, for Hypothesis 7 we found that the most common type of intrusive thoughts were related to making mistakes and method of problem solving. However, unlike Study 2, one of the most common types of intrusive thoughts related to time pressure rather than previous math experience. Nonetheless, our results were similar to those found by Hunt and colleagues (2014) who also found making mistakes, method of problem

solving and time pressure to be the most prevalent types of intrusive thoughts experienced. As discussed in Study 2, the nature of the math task may play a role in the types of thoughts experienced by participants. The study herein used a math task which was more like the one used by Hunt and colleagues (2014) where participants were asked to solve a specific problem which required basic arithmetic skills. They were also presented with a fixation point between each trial. This setup may have induced a sense of time pressure among the participants. However, since most participants had likely never completed modular arithmetic before, this probably reduced the occurrence of intrusive thoughts related to previous math experience.

Finally, for Hypothesis 8, contrary to what was anticipated, the higher working memory task elicited significantly more intrusive thoughts of every type except for previous math experience and physical changes. There was also a significant increase in the proportion of intrusive thoughts related to method of problem solving when individuals participated in a higher working memory task compared to a lower working memory task. Considering that most participants may have had limited prior exposure to modular arithmetic, it is plausible that the occurrence of intrusive thoughts related to this specific task was equally prevalent in both the lower working memory and higher working memory tasks. Additionally, the novelty of the task itself may have elicited a degree of anxiety, irrespective of the working memory demand, leading to the manifestation of physical symptoms that could have been comparable across both tasks.

Implications

The results of this study indicate that the impact on performance is more noticeable in tasks with higher working memory demands compared to those with lower working memory demands. The results suggest that individuals seem to experience fewer intrusive thoughts when the task imposes lower working memory demands. Therefore, it is possible that reducing the

working memory load through the memorization of arithmetic facts could lead to a decrease in intrusive thoughts and an improvement in performance (Pham & Archibald, 2020).

The findings herein also provide support that anxiety may lead to intrusive thoughts which use working memory. This also highlights the importance of interventions which target intrusive thoughts and working memory. This could subsequently diminish math anxiety and possibly diminish the consequences of math anxiety such as those related to math interest (Hembree, 1990) and math performance (Barroso et al., 2021). As previously stated in Study 2, expressive writing may be an intervention that could help reduce intrusive thoughts as means of enhancing working memory and improving math performance. Additionally, new advancements in the field suggest that emotional working memory training could help improve working memory capacity while reducing trait anxiety (Velooso & Ty, 2021). This intervention is designed to improve capacity and control of working memory specifically in relation to emotional stimuli. In their study Velooso and Ty (2021), completed a randomized controlled trial whereby individuals with high trait anxiety were either randomly assigned to an emotional working memory training group or a control group. Participants in the emotional working memory training group participated in an emotional Dual n-Back task whereby they were presented with emotionally salient facial expressions as well as words designed to elicit strong emotional reactions (e.g., “hate”, “evil” “dead”). Participants were asked to redirect their focus from emotionally charged stimuli towards more neutral stimuli (e.g., location of the words). They found that after 20-minute practices every day for 20 days, there were not only improvements in working memory, but also a reduction in trait-anxiety compared to control groups. Although this intervention has not yet been applied specifically to the math anxiety context, it provides promising results within clinical contexts and should be further explored. Moreover,

interventions aimed at reducing an individual's math anxiety hold promise for enhancing mathematical performance, particularly in tasks requiring elevated levels of working memory capacity. Detailed descriptions of these interventions are provided in the general discussion.

Limitations

The COVID-19 pandemic resulted in this study being conducted completed remotely over Gorilla. This may have led to participants completing the survey in different environments which may have influenced their level of engagement and concentration throughout the task. Although efforts were made to ensure data quality and validity (e.g., attention check questions), potential limitations from using a remote survey cannot be completely ruled out. Additionally, the COVID-19 pandemic was a stressful time for many individuals which resulted in intrusive thoughts for some (Del Río-Casanova et al., 2021). As such, the frequency of intrusive thoughts reported within the current study may be an overestimation of their occurrence during non-exceptional circumstances.

Another limitation of this study is that due to various practical constraints we had unequal group sizes for women and men whereby approximately three quarters of our sample identified as women. This discrepancy in group sizes could potentially introduce bias and affect the generalizability of the findings. Additionally, the homogeneity of the participant sample introduces another limitation. The sample was composed of mainly young, anglophone adults following an undergraduate program and of mid-to-high socioeconomic status. Again, this affects the generalizability of the results to more diverse populations and contexts. Caution should be exercised when extrapolating the results. Future studies should consider trying to replicate this study using equal group sizes, a more heterogenous sample, and with an in-person survey.

Additionally, the novelty of the modular math approach may have imposed an additional cognitive load on participants' working memory capacity. Given the unfamiliarity of the modular math concepts such as interpreting the meaning of the three lines or understanding how to complete the modular operation, participants may have been required to retain this information in their working memory throughout the task. As a result, even in tasks presumed to have low demands on working memory, participants may have experienced heightened cognitive load due to the need to process and retain novel information which could have potentially impacted their performance. Future studies should try and replicate the results using a more familiar math task.

Conclusion

In summary, the present study found both gender and math anxiety to be significant predictors of the frequency of intrusive thoughts. It also highlights that those with higher math anxiety experience more intrusive thoughts and generally have lower performance on a higher working memory demanding task. The results also indicate no gender differences in the types of intrusive thoughts and that higher math anxious individuals may not experience every type of intrusive thoughts more frequently. It also highlights that the most common types of intrusive thoughts were related to making mistakes, method of problem solving, and time pressure. Finally, higher working memory tasks elicited more intrusive thoughts of every type. These findings provide important insight into both the gender and math anxiety differences in intrusive thoughts during lower and higher working memory tasks. Future research should investigate interventions addressing both intrusive thoughts and working memory.

GENERAL DISCUSSION

The underrepresentation of women in STEM fields is a widely acknowledged concern which is often suggested as being related to the necessity of mathematics within STEM disciplines (Levy et al., 2021). It has been proposed that math anxiety, which is believed to be more prevalent among women, may act as a deterrent for them to pursue careers in STEM fields (Levy et al., 2021). As such, the primary aim of this dissertation was to develop a better understanding of the gender differences in math anxiety. Moreover, there is extensive evidence that links math anxiety to diminished math performance (e.g., Ashcraft et al., 2007; Carey et al., 2016; Pellizzoni et al., 2022). Some literature suggests that women are not only more vulnerable to having math anxiety (e.g., Miller & Bichsel, 2004; Else-Quest et al., 2010; Zhang et al., 2019; Xie et al., 2019), but they have also been found to underperform in math compared to men (Else-Quest et al., 2010; Pirls et al., 2019; Delage et al., 2021). Therefore, Study 1 of this dissertation sought to advance current research by examining whether the observed gender difference in mathematical performance could be better explained, at least in part, by differing levels of math anxiety in men and women.

Researchers have also predominantly focused on the cognitive interference theory (Eysenck & Calvo, 1992) as an explanation for the association between diminished mathematical performance among individuals with math anxiety (e.g., Ching, 2017; Shi & Liu, 2016b; Skagerlund et al., 2019). According to this account, intrusive thoughts experienced by individuals with math anxiety disrupt the working memory processes necessary for successfully completing math tasks (Eysenck & Calvo, 1992). Despite the significance of intrusive thoughts in understanding the link between math anxiety and poor math performance, there is very little research that investigated the frequency and nature of these thoughts. Therefore, the secondary

objective of this thesis was to delve deeper into the nature and types of intrusive thoughts experienced during math tasks. Specifically, Study 2 aimed to explore the frequency and nature of intrusive thoughts between men and women. We further investigated the frequency and nature of intrusive thoughts among individuals with varying levels of math anxiety.

While Study 2 shed some light on the experience of intrusive thoughts among participants, it remained unclear whether the frequency and nature of these thoughts differed based on the working memory demands of a task. Working memory plays a crucial role in mathematical processes, as it involves holding partial information while mentally manipulating new information (e.g., Miyake & Shah, 1999; Raghobar et al., 2010). Thus, Study 3 aimed to investigate potential differences in the frequencies and nature of intrusive thoughts among men, women, individuals with higher math anxiety, and those with lower math anxiety while performing tasks requiring varying levels of working memory demands.

This general discussion will summarize the findings from Studies 1, 2, and 3, situating them within the broader context of the math anxiety literature. Furthermore, it will explore the educational and intervention implications of these findings. Finally, limitations of the present studies will be discussed, and suggestions for future research directions in this field will be provided.

Summary of findings

Study 1 – Understanding Gender Disparities in Math Performance: The Role of Math Anxiety

Given the inconsistent findings regarding the existence of gender differences in math anxiety and math performance, Study 1 sought to explore whether we could observe gender differences in both math anxiety and math performance in a sample of undergraduate students.

Should this be apparent, we wondered whether math anxiety may be a mediator in the relations between these variables. A sample of undergraduate students ($N = 389$) was recruited to participate in a comprehensive one-hour questionnaire administered within a laboratory setting. The questionnaire included assessments of math anxiety, general anxiety, as well as a math test which included various strands of mathematics. The results revealed that women reported higher levels of math anxiety compared to men, and they also exhibited lower performance on the math test. Moreover, the analysis indicated that math anxiety partially mediated the association between gender and math performance. This notable finding suggests that the gender differences observed in math performance may be partially accounted for by variations in levels of math anxiety. This initial study sheds light on the crucial role of math anxiety in understanding gender disparities in math achievement and provided a basis for further exploration in subsequent investigations.

Study 2 – Understanding Intrusive Thoughts in Math Tasks and The Role of Gender and Math Anxiety

Study 2 aimed to explore the frequency and types of intrusive thoughts experienced by both men and women, as well as individuals with differing levels of math anxiety, during the completion of a math task. A total of 309 participants took part in the study remotely via the Gorilla platform. They provided self-reports of their math anxiety and general anxiety. Subsequently, participants completed a math task and an assessment of intrusive thoughts. The results revealed that math anxiety significantly predicted the frequency of intrusive thoughts. However, gender was not predictive of the frequency of intrusive thoughts. Furthermore, we found that the most prevalent types of intrusive thoughts reported by participants, regardless of gender or math anxiety levels, pertained to thoughts about making mistakes, previous math

experience, and method of problem solving. These findings offer valuable insights into the experience of intrusive thoughts among participants.

Study 3 – Math Anxiety, Gender, and Intrusive Thoughts: A Study Exploring Working Memory Demand

The aim of Study 3 was to examine whether the frequency and types of intrusive thoughts experienced by individuals, including men and women, and individuals with varying levels of math anxiety, would differ depending on the working memory demand of the task. To achieve this, a sample of undergraduate students ($N = 437$) was recruited to participate in a remotely administered questionnaire via the Gorilla platform. Participants provided self-reports on their levels of math anxiety and general anxiety. They were then randomly assigned to either start the questionnaire by completing a lower working memory demand math task or a higher working memory demand math task. Each participant then completed a measure of intrusive thoughts followed by a neutralizing task. They then continued to the alternate task, either a lower or a higher working memory demand math task and completed a measure of intrusive thoughts. The unexpected findings from Study 2 prompted us to change the math task to solely include novel arithmetic questions. We aimed to use mathematical tasks from a math strand that had previously generated gender differences in math performance (van de Weijer-Bergsma et al., 2022; Mullis et al., 2020) to see whether this may influence the frequency and types of intrusive thoughts experienced by participants. The results of the study indicated a significant main effect of gender and math anxiety whereby women and higher math anxious individuals experienced more intrusive thoughts. We also found a main effect of working memory whereby individuals experienced more intrusive thoughts when completing a higher working memory demand task. We did not however find interactions between gender and working memory or between math

anxiety and working memory. Additionally, these findings contribute valuable insights into the interplay between gender and math anxiety and, the experience of intrusive thoughts during tasks involving varying levels of working memory demand.

Implications for Math Anxiety Research

General Understanding of Math Anxiety. Emotions serve as a crucial mechanism for human survival because they facilitate decision-making processes (Lench et al., 2011). Anxiety, in particular, plays a significant role in signaling potential threats and prompting appropriate behaviour (Barlow, 2000). Math anxiety is a specific manifestation of anxiety, that arises from a combination of factors. External factors, such as past negative experiences with math, social stereotypes, and social messages about math, have been previously found to contribute to the development of math anxiety (Locke, 2023). These experiences paired with internal factors such as physiological symptoms, negative emotions, and intrusive thoughts, can create a conditioned response, where simply thinking of doing a math task may lead to anxiety (McKay et al., 2017).

Using a cognitive behavioural model, math anxiety can be understood through the complex interplay between thoughts, feelings, behaviours, and physiological symptoms (Josefowitz & Myran, 2017). When faced with a math task, a math anxious individual often experiences an array of intrusive thoughts such as those related to making a mistake, their previous math experience, or about the appropriate method of problem solving as suggested by the results of Study 2 and Study 3. These intrusive thoughts may lead to anxiety and physiological responses such as a racing heart, paced breathing, and dizziness. Ultimately, this anxiety provoking experience may lead a math anxious individual to internalize the idea that they don't like math, that they are bad at math, and this may lead to them avoiding future encounters with math (Bechara et al., 1997; Lench et al., 2011; Phat, 2014; Beilock & Maloney, 2015).

In parallel, when the individual experiences negative intrusive thoughts, this uses up working memory resources necessary for the completion of the math task (Eysenck & Calvo, 1992). As suggested by the results from Study 3, more challenging/working memory demanding math tasks also lead to an increase in intrusive thoughts. However, working memory is a limited resource (Pellizzoni et al., 2022; Shi & Liu, 2016) whereby when it is being used up by something like intrusive thoughts, it limits the remaining resources accessible for other tasks such as math. Though most individuals experience intrusive thoughts every day, our findings from Study 2 and Study 3 highlight that math anxious individuals experience considerably more anxiety provoking intrusive thoughts than those with lower levels of math anxiety. Subsequently, individuals with higher math anxiety end up having access to less of their working memory resources likely leading to worse performance on the math task. Together, these factors likely form a negative feedback loop, where intrusive thoughts consume working memory resources, resulting in negative feelings towards the task, physiological symptoms, and ultimately, poorer math performance. This may lead to an increased likelihood that the math anxious individual avoids later math tasks (Carey et al., 2016). Avoiding math not only diminishes the chances of having positive experiences with the subject but also impedes one's capacity to interact effectively with mathematical concepts. This avoidance likely results in reduced comprehension and proficiency in math (Carey et al., 2016). As a result, the fear of math remains unaddressed and may even intensify over time, reinforcing the cycle of avoidance and anxiety.

Given that women tend to experience more math anxiety than men, it follows that women may be at higher risk of avoiding math and therefore having reduced comprehension and proficiency in math. This may lend some explanation for the findings from Study 2 and Study 3 whereby higher math anxious women experienced more intrusive thoughts pertaining to their

previous math experiences than men. Given that they may have less overall proficiency in math, it is also possible that given that the novelty of the math task used in Study 3, they experienced more intrusive thoughts regarding the method of problem solving to be used in the task than higher math anxious men.

Gender Disparities in Math Anxiety. As highlighted in our studies, women consistently reported experiencing significantly more math anxiety than men. In Study 1, our results demonstrated that gender differences in math performance were partially mediated by the levels of anxiety, marking, to our knowledge, the first study to explore this question. While this specific research question has received limited attention in previous studies, our findings align with existing research, supporting the notion that math anxiety influences individuals' performance on math tasks (Maloney et al., 2014, 2013; Spencer et al., 1999) and that women tend to experience higher levels of math anxiety than men (e.g., Miller & Bichsel, 2004; Else-Quest et al., 2010; Zhang et al., 2019; Xie et al., 2019).

An array of factors likely contributes to this gender difference. For one, women are twice as likely as men to experience anxiety in general (Wittchen et al., 2011; Remes et al., 2016), and when they do, their symptoms tend to be more severe than those experienced by men (McLean et al., 2011). Some factors such as biological vulnerabilities have been identified as one of the culprits for this gender difference. Emerging evidence suggests that the HPA axis which regulates the stress response is more sensitized in women (Kudielka and Kirschbaum, 2005; Goel et al., 2014) leading to increased vulnerability to anxiety. Further research has indicated that specific female hormones (e.g., estrogen) may heighten an individual's susceptibility to anxiety (Kudielka and Kirschbaum, 2005; Goel et al., 2014). This suggests that hormonal fluctuations within the female body could potentially contribute to an increased vulnerability to experiencing

anxiety (Kudielka and Kirschbaum, 2005; Goel et al., 2014). These biological differences may lead to more physical symptoms of anxiety in women which may contribute to women reporting more intrusive thoughts pertaining to physical changes in both Study 2 and Study 3.

There is also evidence to suggest that social factors may influence math anxiety. For example, parents of children with higher levels of math anxiety were themselves more likely to also have higher math anxiety (Soni & Kumari, 2017). In their study, Soni and Kumari (2017) explain that the parent's own feelings toward math may impact the messages that they convey to their children about the subject, subsequently resulting in math anxiety in their child. They unfortunately did not look at gender differences in the internalization of messages. Evidence also suggests that women tend to have a higher inherent need for affiliation in interdependent relationships (Drescher and Schultheiss, 2016). While this can be adaptive, instances where attempts to affiliate are not reciprocated or result in negative outcomes can lead to heightened stress reactions (Taylor, 2006). This may render women to be more vulnerable to the perceptions, attitudes, and messages conveyed by others they affiliate with (Taylor, 2006). Consequently, when teachers and/or parents communicate negative messages about math, young girls may be more likely to internalize these messages than young boys.

Moreover, persistent stereotypes perpetuate the notion that mathematics is a "male domain" (e.g., Makarova et al., 2019; Deiglmayr et al., 2019), thereby contributing to the gender gap in math-related fields and likely in the experience of math anxiety (Bonnot & Croizet, 2011). Given this stereotype, it is possible that women become more anxious about math in fear that they may confirm the stereotype that "girls are bad at math" (Bonnot & Croizet, 2011). This might provide an explanation to the results of Study 2 whereby higher math anxious women reported significantly more intrusive thoughts related to making mistakes than men and that they

experience more intrusive thoughts regarding what people may think of them in both Study 2 and Study 3. This preconceived notion that women may be “bad at math” could also lead to a greater acceptance of women reporting their anxieties about math tasks because these experiences may be more prevalent and consequently less stigmatized than they may be for men (Ashcraft, 2002). Previous researchers have also indicated that women tend to perceive lower levels of control during math learning, leading to learned helplessness and therefore increased feelings of anxiety and powerlessness (Zirk-Sadowski et al., 2014).

Model of Math Anxiety. The model proposed by Lutterberger et al. (2018) provides valuable insights into the complex phenomenon of math anxiety by outlining its antecedents, interacting variables, and outcomes. However, the findings presented in the studies herein suggest that while this model addresses several important factors, it may not fully capture the intricacies of math anxiety. The authors effectively highlighted that gender is a significant antecedent to math anxiety which is supported by our results (as evidenced in Study 1, 2, and 3). Despite the well-documented association between intrusive thoughts and math anxiety, as well as their impact on math performance (e.g., Wigfield & Meece, 1988; Hunt et al., 2014), it is noteworthy that intrusive thoughts are not explicitly included in Lutterberger et al.'s (2018) model.

To provide a more comprehensive understanding of math anxiety, it would be important for intrusive thoughts to be incorporated into the framework of the model. Intrusive thoughts and math anxiety appear to have a bi-directional relationship whereby the higher the math anxiety the more intrusive thoughts are experienced (as apparent from the results from Study 2 and Study 3). In parallel, it is probable that the more intrusive thoughts an individual experiences, the more

their math anxiety increases. As such, it would likely be most appropriate for intrusive thoughts to appear in the interacting variables of this model.

Furthermore, while the model incorporates performance as an outcome variable of math anxiety, it fails to adequately emphasize the critical role of working memory within this relationship. Working memory is particularly important when completing math tasks as it allows an individual to retain partial information while simultaneously manipulating new information to arrive at a solution (Raghubar et al., 2010). However, given its limited nature, both external and internal distractors can deplete working memory resources resulting in poorer performance in math (Pellizzoni et al., 2022; Shi & Liu, 2016). As shown in Study 3, it appears that the disparity in performance is primarily driven by the presence of intrusive thoughts (an internal distractor) which use up working memory resources necessary for completing math tasks. Therefore, incorporating working memory within the outcome variables may provide a more comprehensive and nuanced depiction of math anxiety. By acknowledging the intricate interplay between intrusive thoughts, working memory, and math performance, the model could provide a more comprehensive and accurate representation of the complex mechanisms underlying math anxiety.

The results from Studies 2 and 3 suggest that the characteristics of the math task and the specific type of math being performed influences the types of intrusive thoughts experienced and therefore the experience of math anxiety. For instance, when students were tasked with solving problems involving various strands of mathematics (i.e., geometry and spatial sense, data management and probability, measurement, algebra and number sense and numeration) the most common intrusive thoughts revolved around making mistakes, problem-solving methods, and previous math experiences. Conversely, during a novel arithmetic task, intrusive thoughts primarily centered around making mistakes, method of problem solving, and time pressure. The

specific type of mathematics being undertaken, along with the task's level of difficulty, seem to also influence gender differences in the experience of math anxiety. Specifically, when participants were engaged in a math task that encompassed various strands of mathematics, typically encountered in fifth to seventh grade, no significant association was observed between gender and the frequency of intrusive thoughts. Conversely, in the context of a novel arithmetic task, women reported a higher occurrence of intrusive thoughts compared to men. These findings provide valuable insights into the role of task circumstances and math content in shaping the types of intrusive thoughts experienced by individuals and therefore the experience of math anxiety during math-related activities. As such, the model proposed by Lutterberger et al. (2018) would benefit from adding categories such as “type of math completed” along with the “task difficulty” in the interacting variables as they seem to directly influence the experience of math anxiety.

Math Anxiety and Math Performance. In all three of our studies, math anxiety was related to worst performance on math tasks. The cognitive interference theory (Ashcraft & Kirk, 2001; Barroso et al., 2021; Ramirez et al., 2018) suggests that math anxiety impairs math achievement because intrusive thoughts deplete working memory resources needed for completing and recalling math information (Carey et al., 2016). In Study 3, we observed a significant relationship between working memory and the frequency of intrusive thoughts, indicating that participants experienced more intrusive thoughts when engaged in high working memory-demanding math tasks. Additionally, we found a main effect of working memory on performance where the more working memory demanding the math task, the worse the performance on the task. This lends support to the cognitive interference theory by providing evidence that a higher frequency of intrusive thoughts experienced during a working memory

demanding math task may lead to a depletion of working memory and therefore worse performance on a math task (Carey et al., 2016).

Despite the findings outlined in this dissertation, previous researchers have also suggested the deficit theory which posits that a lack of math skills may lead to negative encounters with math and therefore math anxiety (Barroso et al., 2021). Though this was outside the scope of this dissertation, it is likely that the reciprocal theory may present the most accurate depiction of the relation between math anxiety and math performance. The reciprocal theory suggests a bidirectional relationship between math anxiety and performance, integrating aspects of both the deficit and cognitive interference theories (Coddling et al., 2023; Carey et al., 2016). While poor performance can trigger math anxiety, the intrusive thoughts experienced during a math task may also impede working memory demands leading to worse performance in math (Pekrun, 2006). These factors collectively influence perceptions and beliefs about math performance (Namkung et al., 2019).

Implications for Math Education

Math anxiety can lead individuals to avoid engaging in mathematical activities and miss out on opportunities to enhance their mathematical skills (Beilock & Maloney, 2015). As a result, individuals with higher levels of math anxiety may have weaker mathematical knowledge compared to their counterparts with lower math anxiety (Hembree, 1990). They may also experience less interest in math, be less confident in their math abilities, avoid math-related tasks, and generally have lower levels of proficiency and achievement in math compared to their peers (Ahmed, 2018; Ashcraft, 2002; Hembree, 1990; Namkung et al., 2019). Additionally, those affected by math anxiety exhibit reduced cognitive reflection while tackling math word problems, an essential component for cultivating a thorough comprehension of mathematical

skills and concepts (Morsanyi et al., 2014). This has significant implications for educational decisions and future career paths (Espino et al., 2017) whereby students with higher levels of math anxiety avoid pursuing STEM-related careers in adulthood (Ahmed, 2018).

While the prevalence of math anxiety in men and women has been inconsistently reported in previous studies (e.g., Levy et al., 2021), women have consistently reported higher math anxiety than men in all three studies conducted within this dissertation. Additionally, in our studies, it appears that when sampling both men and women who report having math anxiety, women report having higher instances of math anxiety than men. This discrepancy may be lead in part by the biological, social, and psychological factors described above and, together, may contribute to a reduced interest in STEM fields among women but not among men (Levy et al., 2021).

Both Study 2 and Study 3 highlight that among the most common types of intrusive thoughts experienced by individuals with math anxiety are those pertaining to making mistakes and previous math experience. It is possible that by creating a supportive and non-judgemental math learning environment early in education may help circumvent these types of intrusive thoughts. Teachers could encourage a growth mindset (Ricci, 2018) within their students where mistakes are viewed as opportunities for learning and are normalized to alleviate the fear associated with error. Teachers can emphasize that making mistakes is a natural part of the learning process and provide constructive feedback to guide students towards improvement. This would likely help reframe the role of mistakes in learning, as well as provide positive early experiences with math. Additionally, incorporating frequent opportunities for practice and feedback can help build students' confidence and reduce anxiety about previous math experiences. Structured practice sessions, collaborative learning activities, and formative

assessments can provide students with opportunities to reinforce their understanding of mathematical concepts in a low-pressure setting creating positive previous experiences in math.

Additionally, the studies herein highlight the influence of working memory demands on task performance and the occurrence of intrusive thoughts. Specifically, the results revealed that the impact on performance is particularly pronounced in tasks requiring higher working memory demands compared to those with lower working memory demands. These findings also suggest that individuals tend to experience fewer intrusive thoughts when the task imposes lower demands on working memory resources. Consequently, it is plausible to consider that reducing the cognitive load on working memory could in turn help increase individuals' math performance. As such, it is possible that by aiming to build strong math skills, individuals could reduce the working memory demand of the task and potentially decrease intrusive thoughts as well as enhance their performance on the task (Pham & Archibald, 2020). The Ontario Mathematics Curriculum (2020) emphasizes principles aimed at fostering a strong foundation in math concepts and skills, recognizing the dynamic nature of math learning where each stage builds upon the next. However, according to the Ontario Education Act (2020), the average elementary class size is of 24 students, which presents challenges in effectively addressing individual students' needs. Despite efforts to ensure equal learning opportunities for all students, in a classroom of this size, there is a high likelihood that some students' math anxiety may go unnoticed. Teachers are also often compelled to make decisions for the collective benefit of the majority of students, which can pose a risk for students who may not fully grasp basic math concepts before the class moves on to the next topic.

Furthermore, in the context of introducing new math concepts, educators can adopt a pedagogical approach that encourages students to engage in practice examples that are less

demanding on working memory. By gradually exposing students to more cognitively demanding tasks, students can develop a sense of comfort and familiarity with the concepts. This approach could mitigate the likelihood of math-anxious students experiencing negative emotions while completing the tasks, which could otherwise lead to discouragement and exacerbate the cycle in which poor math performance could perpetuate math anxiety (Carey et al., 2016).

Implication for Interventions

Timely implementation of interventions that specifically address the most challenging math anxious thoughts has the potential to alter the trajectory of math-anxious individuals during their developmental years. Such interventions can potentially mitigate the detrimental effects of math anxiety, including the avoidance of math courses and careers. By intervening early, it could become possible to reshape the path of math-anxious individuals, enabling them to circumvent the negative consequences associated with math anxiety and fostering a more positive relationship with mathematics.

Different researchers have aimed to find interventions that could help reduce math anxiety (e.g., Park et al., 2014; Jamieson et al., 2016; Bicer et al., 2020). One such intervention is expressive writing, a clinical technique that encourages individuals to openly express their feelings toward a specific stressor (Park et al., 2014). For example, in their study Park and colleagues (2014) asked adults with varying levels of math anxiety to complete a math task before and after an expressive writing task. During the expressive writing activity, individuals were asked to write about their feelings towards the upcoming math test for five to ten minutes. Park and colleagues (2014) found that when individuals participated in expressive writing prior to a math test, they performed better, reducing the performance gap between those with higher and lower math anxiety. This intervention likely acts directly upon the working memory by

mitigating intrusive thoughts to free up working memory resources. This ultimately allows individuals to concentrate exclusively on the mathematical task at hand (Park et al., 2014).

Some researchers have also suggested that the effectiveness of expressive writing tasks is enhanced when participants are provided with specific guidelines for their writing rather than guidelines that may be vague (Reinhold et al., 2018). As such, the findings from Study 2 and Study 3 can inform the development of new expressive writing interventions that may be more specific to the most common types of intrusive thoughts experienced during math. This may provide a better guide for participants on what exactly they are to be writing about and help participants focus on the intrusive thoughts depleting their working memory. For example, instead of asking participants to write about the math tasks in general, they could be guided to write about any fears related to making mistakes during the task.

Some researchers have employed interventions which incorporate the use of visual representations such as gestures or diagrams to help students when they are learning math (e.g., Hord et al., 2016; Walsh & Hord, 2019). This is thought to be helpful as it offloads some of the demands placed on the working memory and rather have it stored into memory as visual representations. Through this process, students are better able to allocate their attentional resources towards critical thinking (Ives, 2007; Xin et al., 2005). This intervention could be particularly beneficial for individuals experiencing math anxiety, as it could enable them to reduce the cognitive load imposed by the math, making it more manageable to handle the anxiety and the math at once.

There is additional evidence that reappraisal is also beneficial for individuals with higher math anxiety. In fact, Jamieson and colleagues (2016) explored the benefits of using reappraisal in a sample of 93 community college students across five semesters. They divided their sample

in two groups. The first group read an article about the benefits of physiological arousal and its importance for optimal performance (appraisal condition). Specifically, they read articles which explained that physiological arousal during a stressful situation evolved to help performance during the task. The other group read articles that suggested that ignoring stress and negative thoughts were the best way to help improve performance (control condition). By targeting beliefs about worry, students in the appraisal condition performed significantly better on their final exam and reported less math anxiety than participants in the control group. This intervention could also be modified to cater to the findings of the study herein. If individuals were able to reframe their intrusive thoughts and recognize them as a common experience with evolutionary significance, they might experience reduced anxiety and, consequently, a decrease in intrusive thoughts.

Likewise, there is evidence supporting the effectiveness of Cognitive Behavioral Therapy (CBT) in addressing math anxiety among individuals (Bicer et al., 2020). As outlined in the general introduction, the core principle of CBT is that our thoughts play a significant role on our emotions and behaviours (Bicer et al., 2020). As such, it follows that if we can alter our thoughts, we are therefore able to change our emotions and our behaviours. In this regard, the present dissertation provides valuable insights for CBT practitioners by delineating the most prevalent types of intrusive thoughts experienced by individuals with math anxiety. By incorporating interventions targeting the reduction of math anxiety, CBT therapists can potentially facilitate individuals in realizing their full potential in math.

Additionally, relaxation and breathing techniques have been found to be effective strategies that target the physiological response of math anxiety (Passolunghi et al., 2020; Schoeck, 1994). When experiencing anxiety, the body's stress response is activated, leading to symptoms such as

increased heart rate, shallow breathing, and muscle tension, to name a few (Lench et al., 2011). Relaxation techniques such as progressive muscle relaxation (e.g., Xiao et al., 2020), guided imagery (e.g., Acar et al., 2024), and mindfulness meditation (e.g., Hariri 2022) work by promoting a state of deep relaxation, which helps counteract the body's stress response. By engaging in these exercises, individuals can activate the body's relaxation response (parasympathetic nervous system) to reduce the physiological arousal associated with anxiety (Josefowitz & Myran, 2017).

Limitations and Future Directions

Though the studies in this dissertation have many strengths that have the potential of contributing to the advancement of our understanding of math anxiety, some important limitations need to be considered.

To the best of our knowledge, there is currently a lack of standardized math tests available that encompass various strands of mathematics that are widely utilized in research. Therefore, for Study 1 and Study 2, we used a measure of math that was designed by a math curriculum specialist specifically for these studies. This measure was designed to incorporate questions from different math strands (e.g., geometry, algebra) that are typically included in a fifth to seventh grade provincial examination. Our intention was to use questions presented early enough in the math curriculum that we would increase the likelihood that participants would have been exposed to these types of problems during their education. However, it appears that the level of difficulty of these questions was relatively low for our participants. Although we did not observe ceiling effects, participants generally achieved high scores on this measure. The level of difficulty of these questions paired with individuals being offered multiple choice responses resulted in limited score variability. Consequently, it became more challenging to

accurately evaluate individuals' true math abilities and differentiate between different levels of performance. This limitation can potentially impact the generalizability of our findings, as the measure may not fully capture the entire range of performances and abilities. Future research endeavors should strive to replicate these findings by employing an alternative math measure that includes diverse strands of mathematics while adequately challenging the target population. Moreover, our results indicate that the strand of the mathematics being completed can impact both the frequency and types of intrusive thoughts experienced. However, it is important to note that our study did not examine different strands of mathematics separately but rather combined them together. As a result, we cannot definitively determine which strand of mathematics elicits the highest frequency and types of intrusive thoughts. This aspect warrants further investigation.

Additionally, given the statistical challenges that arose from studying intrusive thoughts with a categorical approach, we divided math anxiety into quartiles. It is important to note that such approach introduces potential limitations, such as the arbitrary nature of quartile divisions, which may oversimplify the complexity of math anxiety. This can lead to loss of nuanced data, potentially masking subtle differences in anxiety levels and their impact on intrusive thoughts. Future research should consider this limitation.

Several limitations related to the circumstances surrounding the study as well as the methods and design also warrant consideration. In all three studies, a survey approach was employed to collect data from participants recruited through the university student research participation pool. Consequently, participants self-reported on their anxiety levels as well as the frequency and nature of their intrusive thoughts. It is important to acknowledge the potential that participants could have either over or under-represented their experiences in their responses. Furthermore, due to public safety measures implemented during the COVID-19 pandemic,

Studies 2 and 3 were conducted remotely. While participants were encouraged to complete the surveys in a quiet environment, the research team had limited control over participants' surroundings. Consequently, environmental factors could have potentially disrupted participants' ability to fully focus on the tasks. Additionally, in Study 3, participants were explicitly instructed to refrain from using calculators or papers to ensure their reliance on working memory. Despite requesting participants to confirm their adherence to these instructions and excluding those who reported using external aids, there remains the possibility of participants providing inaccurate responses, leading to potentially unreliable results. Previous researchers have also shown that gender differences in math anxiety may be context-dependent whereby women may report higher levels of math anxiety specifically in academic settings. Given the COVID-19 pandemic, participants completed the survey from the comfort of their own homes which may not have adequately mimicked the academic environment leading to lower math anxiety. Similarly, though participants completed the survey in the context of their courses, this was likely a low stakes math task given that students were provided 1% for their participation rather than for their success of task. This may have resulted in lower math anxiety as opposed to if this had been a course evaluation worth a third of the final course grade. Furthermore, the unprecedented circumstances of the COVID-19 pandemic also likely resulted in individuals' overall anxiety levels being more elevated compared to non-pandemic times. Consequently, scores reflecting generalized anxiety may have been inflated. Moreover, heightened anxiety levels could have impacted individuals' capacity to effectively manage their anxiety, potentially resulting in a higher frequency of intrusive thoughts than would have been observed under normal circumstances. To our knowledge, the studies presented herein represent the second set of studies aimed at investigating the frequencies and types of intrusive thoughts associated with math

anxiety. We chose to use the CIQ-M as a measure of intrusive thoughts, as it had been employed in prior research by Hunt et al., 2016. However, it is conceivable that additional, more prevalent types of intrusive thoughts occur during math tasks. Therefore, future research should replicate our study to try and validate our findings as well as explore qualitative data on participants' experiences of intrusive thoughts during math tasks to determine whether the identified themes align with the categories outlined in the CIQ-M.

In this research, a convenience sample of undergraduate students from a university research pool was employed to conduct the studies. Notably, most participants across all three studies self-identified as women and were young adults from mid-to-high socioeconomic backgrounds pursuing undergraduate studies. It is important to acknowledge that the homogeneity of the sample presents inherent limitations which influence the generalizability of the findings. Although the results bear implications for the undergraduate student population, it is imperative for future investigations to explore the extent to which these findings can be extrapolated to other diverse populations such as children, individuals with varying socioeconomic statuses, and individuals with differing levels of education, to name a few. Past researchers have also identified that different sociodemographic variables, such as age (Reilly et al., 2017), may also influence math anxiety. However, the focus of the studies conducted in this dissertation did not examine cross-cultural variations in math anxiety or differences in math anxiety across ethnic groups despite previous studies having found evidence of differences among groups (e.g., Fan et al., 2019). Similarly, since the participants in our study are primarily undergraduate students, who belong to a relatively homogeneous age group, age was not a primary factor of investigation. Future research should investigate how sociodemographic variables may influence the frequency and the types of intrusive thoughts experienced during a

math task. Finally, the primary focus of this dissertation was on clarifying gender differences in math anxiety and intrusive thoughts, necessitating the inclusion of participants who identified as "women" or "men" in the analytical procedures. Consequently, this approach inadvertently excluded individuals who did not identify with either of these gender categories. Future studies should expand upon these findings by employing more diverse samples and considering a broader spectrum of gender identities (e.g., non-binary, agender), thereby enhancing the external validity and applicability of the research outcomes.

Despite these limitations, this dissertation has several strengths that hold promise for advancing the current body of research on math anxiety. To the best of our knowledge, we are the first to examine math anxiety as a mediator of gender and math performance as well as the frequency and nature of intrusive thoughts experienced by men and women when doing a math task.

Conclusion

Math anxiety is a prevalent factor that significantly impacts math performance. However, the existing research on gender differences in math anxiety yields inconsistent findings. In the present dissertation, we aimed to investigate gender differences in math anxiety through the utilization of surveys. Our objectives were twofold: 1) to examine whether we could observe a gender difference in math anxiety, and 2) to explore potential differences in the experience of intrusive thoughts related to math. Our findings revealed a gender difference in math anxiety, with women consistently reporting higher levels of math anxiety compared to men. Furthermore, we observed no significant differences between men and women in terms of the frequency and types of intrusive thoughts experienced during math tasks. However, this seemed to be dependent on the math task administered. When students were asked to complete an assessment

which included various strands of mathematics, no gender differences were observed, however women experienced more intrusive thoughts when completing an assessment in arithmetic. Additionally, the types of intrusive thoughts experiences seemed to vary depending on the type of math completed.

The results of these studies emphasize the need to conduct more research to delve into the implications of these findings in the hope of helping the development of effective interventions that would eventually help reduce the gender gap in STEM careers.

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Appendix A: Math Test

Section 1: Data management and probability

Instructions: For this section you will be asked to answer 10 math questions on data management and probability. You need a PAPER and PENCIL for this section. Once you choose an answer you will automatically be directed to the next questions. Therefore, make sure to click on the answer of your choice as you will be unable to change it once selected. Work as fast and accurately as possible. Once again, make sure that you have a paper with you before clicking next.

Here are some basic formulas that may be of use to you (write them down on your paper if you do not know them):

Mean: $M = \text{average/number}$

Area of a rectangle: $A_{\text{rectangle}} = wl$

Perimeter of a rectangle: $P_{\text{rectangle}} = 2(l+w)$

Area of a triangle: $A_{\text{triangle}} = hb/2$

Volume of a rectangular prism: $V = hwl$

1- Mrs. Smyte records the number of people in the school auditorium every hour during a school day. The data she collects show a maximum of 325 people in the auditorium. Which of the following is an appropriate scale for the vertical axis of the line graph for this data?

- a. 7 increments with each increment representing 40 people
- b. 15 increments with each increment representing 20 people
- c. 10 increments with each increment representing 35 people
- d. 20 increments with each increment representing 12 people

2- Kyla is a member of the starting lineup of the school's basketball team. The heights of the other starting players are shown below.

160 cm, 156 cm, 148 cm, 147 cm

The mean height of the starting lineup is 152.4 cm. What is Kyla's height?

- a. 153 cm
- b. 151 cm
- c. 191 cm
- d. 160 cm

3- The heights of the 5 starting players on a basketball team are shown in the table below.

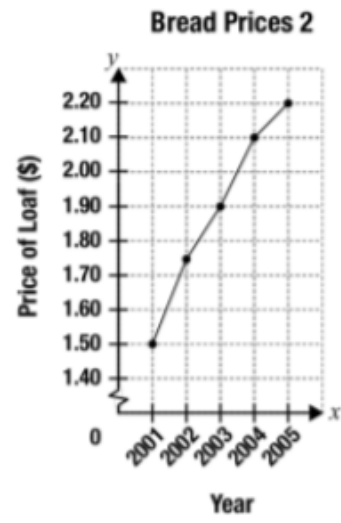
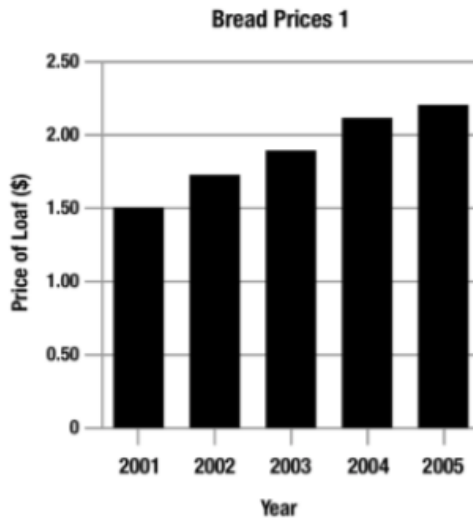
Starting Players' Heights

164 cm
168 cm
178 cm
180 cm
180 cm

What is the mean height of the five starting players?

- a. 138 cm
- b. 174 cm
- c. 178 cm
- d. 180 cm

4- The two graphs below show the same data about the mean price of a loaf of bread for each year during the last 5 years.



Graph 1 appears to show that the price of a loaf of bread has not increased much during the 5 years. Graph 2 appears to show that the price of a loaf of bread has increased by a large amount during the 5 years.

Which parts of the graphs are **most** important in making the graphs appear to show two different things?

- a. the x axis (years)
- b. the types of graphs
- c. the titles
- d. the scales

5- To pick teams, the gym teacher puts the names of 8 boys and 6 girls in a bag, as shown below. The table shows the names.



Boys	Girls
Robert	Jessica
Ivan	Sarah
Hasan	Preija
Mohamed	Minon
Salvatore	Sunetra
Kieran	Ling
Paul	
Manuel	

The first 3 names picked at random from the bag were Paul, Jessica and Sarah. The names are not put back in. What is the probability that the next name picked at random will be a boy?

- a. $\frac{1}{2}$
- b. $\frac{7}{11}$
- c. $\frac{1}{7}$
- d. $\frac{8}{14}$

6- A student collects apples over a 5 days period.

Day	Apples
1	5
2	6
3	4
4	3
5	7

What is the mean number of apples that the student collected?

- a. 25
- b. 6
- c. 4
- d. 5

7- A student collects stickers over a 7-day period.

Day	Stickers
1	9
2	8
3	10
4	13
5	5
6	10
7	8

What is the mean number of stickers that the student collected?

- a. 9
- b. 10
- c. 8
- d. 63

8- To pick teams, the gym teacher puts the names of 8 boys and 6 girls in a bag, as shown below. The table shows the names.

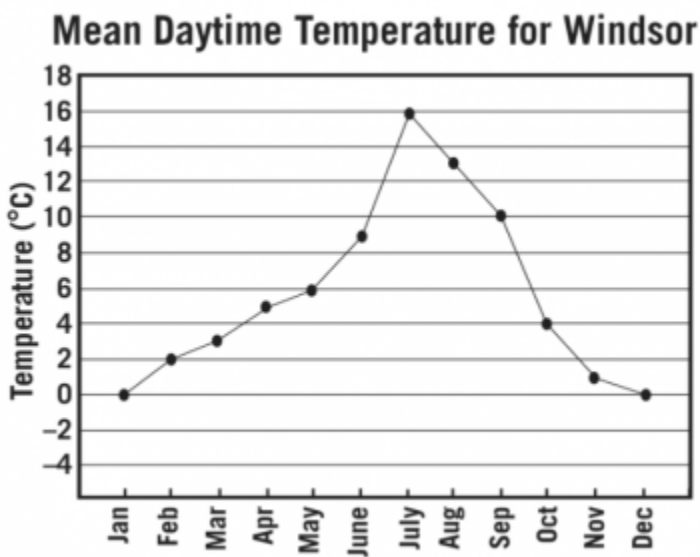


Boys	Girls
Robert	Jessica
Ivan	Sarah
Hasan	Preija
Mohamed	Minon
Salvatore	Sunetra
Kieran	Ling
Paul	
Manuel	

What is the probability that a boy's name will be picked?

- a. $4/7$
- b. $1/8$
- c. $3/7$
- d. $6/8$

9- The graph below shows the mean daytime temperature for Windsor.



Which month had a mean daytime that is twice February's?

- a. April
- b. March
- c. October
- d. September

10- Maddie and Lisa's score on 5 math quizzes are shown in the table below.

Math Scores out of 30

Maddie's scores	20	23	28	21	23
Lisa's scores	21	22	26	25	26

According to the data in the table, Maddie's median score is

- a. higher than Lisa's median score.
- b. the same as Lisa's median score.
- c. lower than Lisa's mean score.
- d. the same as Lisa's mean score.

Section 2: Measurements

Instructions: For this section you will be asked to answer 10 math questions on measurement. You need a PAPER and PENCIL for this section. Once you choose an answer you will automatically be directed to the next questions. Therefore, make sure to click on the answer of your choice as you will be unable to change it once selected. Work as fast and accurately as possible. Once again, make sure that you have a paper with you before clicking next.

Here are some basic formulas that may be of use to you (write them down on your paper if you do not know them):

Mean: $M = \text{average/number}$

Area of a rectangle: $\text{rectangle} = wl$

Perimeter of a rectangle: $\text{rectangle} = 2(l+w)$

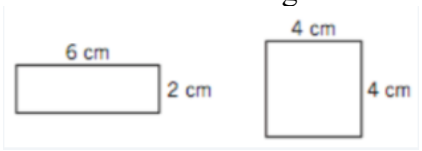

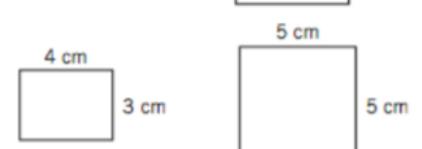
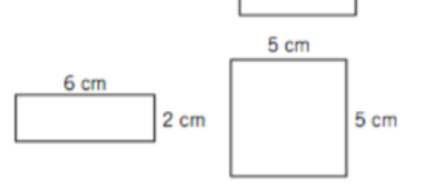
Area of a triangle: $\text{triangle} = hb/2$

Volume of a rectangular prism: $V = hwl$

1- Ms. Vanstone asks her students to draw a rectangle and a square with the areas and perimeters given below.

	Rectangle	Square
Area	12 cm ²	25 cm ²
Perimeter	16 cm	20 cm

Which shows two correct drawings?

- a. 
- b. 
- c. 
- d. 

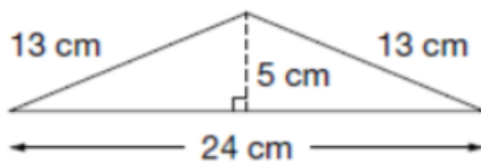
2- Sometimes measurement can be estimated, and at other times it must be very accurate. A list of locations where running times might be measured is shown below.

1. Olympics
2. on the playground
3. school track meet

Which list shows the locations in order from the greatest to the least need for accuracy?

- a. 3, 2, 1
- b. 3, 1, 2
- c. 1, 2, 3
- d. 1, 3, 2

3- What is the area of the triangle shown below?

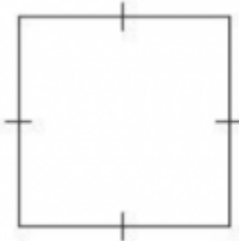


- a. 60 cm^2
- b. 65 cm^2
- c. 120 cm^2
- d. 156 cm^2

4- Which is the equivalent to 1 m^2 ?

- a. 10 cm^2
- b. 100 cm^2
- c. 1000 cm^2
- d. $10\,000 \text{ cm}^2$

5- Chris has a square garden with an area of 38.4 m^2 , as shown in this diagram.



He decreases the length of each side by 1.7 m to make it a smaller garden.

Which is closest to the perimeter of the smaller garden?

- a. 37 m
- b. 32 m
- c. 25 m
- d. 18 m

6- Which is the most appropriate unit of measurement to describe the area of the floor of a gym?

- a. km^2
- b. cm^3
- c. m^2
- d. m^3

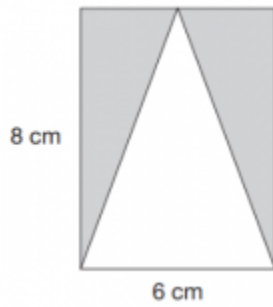
7- How many grams are in 1.5 kg?

- a. 1500 g
- b. 150 g
- c. 15 g
- d. 1.5 g

8- Martha can run 900 metres in 10 minutes. At this rate, approximately how many kilometers can she run in 60 minutes?

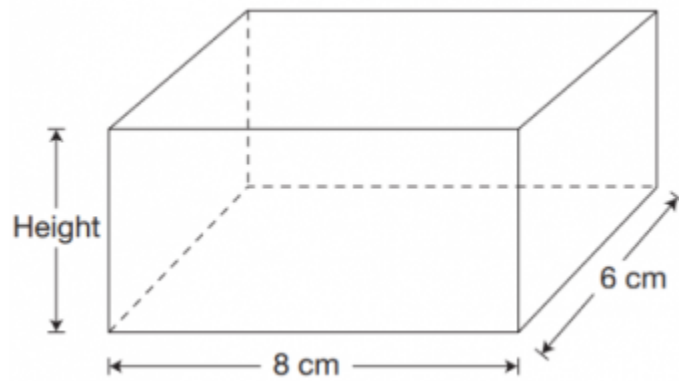
- a. 4
- b. 5
- c. 6
- d. 7

9- What is the total area of the shaded region in this diagram?



- a. 12 cm^2
- b. 24 cm^2
- c. 26 cm^2
- d. 48 cm^2

10- This rectangular prism has a volume of 192 cm^3 .



What was its height?

- a. 2 cm
- b. 4 cm
- c. 6 cm
- d. 8 cm

Section 3: Number sense and numeration

Instructions: For this section you will be asked to answer 10 math questions number sense and numeration. You will need a PAPER and PENCIL for this section. Once you choose an answer you will automatically be directed to the next questions. Therefore, make sure to click on the answer of your choice as you will be unable to change it once selected. Work as fast and accurately as possible. Once again, make sure that you have a paper with you before clicking next.

1- How many minutes in 5 hours?

- a. 65 minutes
- b. 120 minutes
- c. 300 minutes
- d. 240 minutes

2- A store sells 1 orange for 3.00\$, what is the cost of 8 oranges?

- a. 48.00\$
- b. 16.00\$
- c. 96.00\$
- d. 24.00\$

3- What is the value of $7.3 - 1.5$?

- a. 8.8
- b. 5.8
- c. 6.3
- d. 6.2

4- Which of these expressions have a value of 500?

- a. 5×10
- b. 50×10
- c. 5×1000
- d. 50×1000

5- How many minutes are in a day?

- a. 1440 minutes
- b. 84 minutes
- c. 170 minutes
- d. 3600 minutes

6- A store sells 2 oranges for 6.00\$. What is the cost of 8 oranges?

- a. 48.00\$
- b. 16.00\$
- c. 96.00\$
- d. 24.00\$

7- What is the value of $0.73 - 0.15$?

- a. 0.88
- b. 0.58
- c. 0.63
- d. 0.62

8- Which of these expressions has a value of 0.555?

- a. $55.5 / 100$
- b. $55.5 / 1000$
- c. 5.55×100
- d. 5.55×1000

9- How many minutes are in 365 days?

- a. 8 700 minutes
- b. 21 900 minutes
- c. 262 800 minutes
- d. 525 600 minutes

10- Look at the numbers below.

$3/2$, $5/8$, $9/4$, $1 \frac{7}{8}$

Which list shows these numbers ordered from smallest to largest?

- a. $5/8$, $3/2$, $1 \frac{7}{8}$, $9/4$
- b. $5/8$, $3/2$, $9/4$, $1 \frac{7}{8}$
- c. $3/2$, $5/8$, $1 \frac{7}{8}$, $9/4$
- d. $3/2$, $9/4$, $5/8$, $1 \frac{7}{8}$

Section 4. Algebra

Instructions: For this section you will be asked to answer 10 math questions on algebra. You need a PAPER and PECNIL for this section. Once you choose an answer you will automatically be directed to the next questions. Therefore, make sure to click on the answer of your choice as you will be unable to change it once selected. Work as fast and accurately as possible. Once again, make sure that you have a calculator and paper with you before clicking next.

1- Solve this equation: $1 = 10 - W$

- a. $W = -9$
- b. $W = -11$
- c. $W = 9$
- d. $W = 11$

2- Solve this equation: $\frac{a}{5} = 3$

- a. $a = 15$
- b. $a = 3/5$
- c. $a = 5/3$
- d. $a = -2$

3- Solve this equation: $11 + 9 = 9 + m$

- a. $m = 29$
- b. $m = 20$
- c. $m = -9$
- d. $m = 11$

4- Solve in the correct order: $\frac{8+4 \cdot 9}{2}$

- a. 18
- b. 22
- c. 54
- d. 26

5- Solve in the correct order: $\frac{20}{2} + 3 \cdot 6$

- a. 28
- b. 18
- c. 78
- d. 38

$$\frac{(6-3) \cdot 9}{1}$$

6- Solve in the correct order:

- a. -33
- b. 27
- c. 12
- d. -21

$$(10 - 3 \cdot 2) \cdot 5$$

7- Solve in the correct order:

- a. 70
- b. -20
- c. -70
- d. 20

8- Simplify the expression: $5a + 5 - 5a$

- a. $5a$
- b. 0
- c. 5
- d. $10a - 5$

9- Simplify the expression: $4 - 8v + 11v + 7 + 2v$

- a. $16v$
- b. $12v+11$
- c. $5v+11$
- d. $16v+11$

10- Factor the expression: $20a + 48$

- a. $2(10a+24)$
- b. $10(2a+48)$
- c. $4(5a+12)$
- d. $4(5a+24)$

Section 5: Geometry and spatial sense

Instructions: For this section you will be asked to answer 10 math questions on geometry and spatial sense. You need a PAPER and PECNIL for this section. Once you choose an answer you will automatically be directed to the next questions. Therefore, make sure to click on the answer of your choice as you will be unable to change it once selected. Work as fast and accurately as possible. Once again, make sure that you have a paper with you before clicking next.

Here are some basic formulas that may be of use to you:

Mean: $M = \text{average/number}$

Area of a rectangle: $A_{\text{rectangle}} = wl$

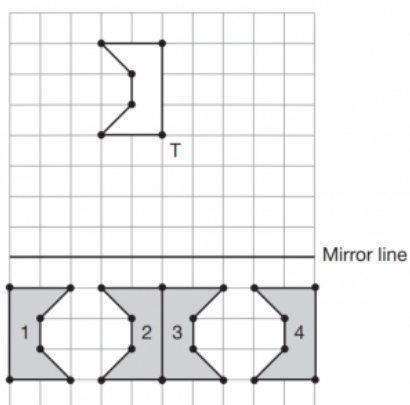
Perimeter of a rectangle: $A_{\text{rectangle}} = 2(l+w)$

Area of a triangle: $A_{\text{triangle}} = hb/2$

Volume of a rectangular prism: $V = hwl$

1- The shape on the grid below goes through the following 4 transformations in order:

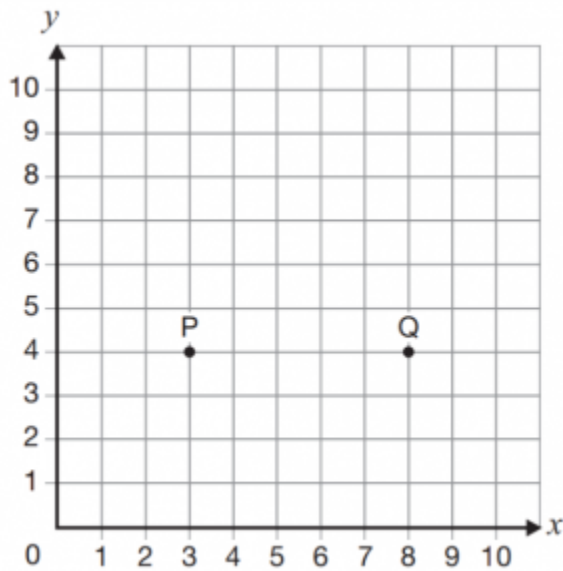
- 1- translation 5 units right
- 2- translation 3 units down
- 3- reflection across the mirror line
- 4- translation 5 units left



Which shaded shape is the result?

- a. Shape 1
- b. Shape 2
- c. Shape 3
- d. Shape 4

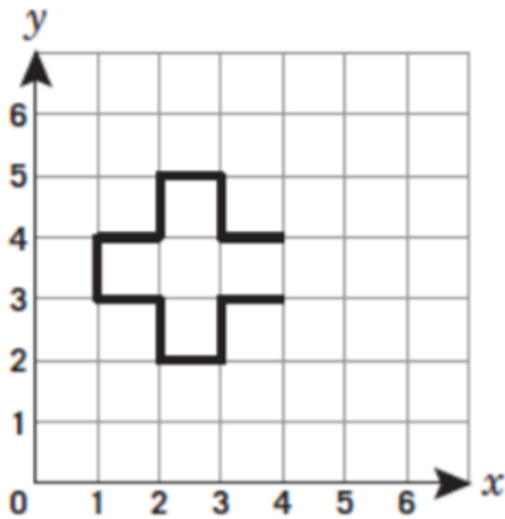
2- Point P and Q are points of a square.



Which set of ordered pairs could represent the other two points needed to form this square?

- a. (3, 8) and (8, 8)
- b. (3, 9) and (8, 9)
- c. (8, 3) and (9, 8)
- d. (7, 4) and (4, 9)

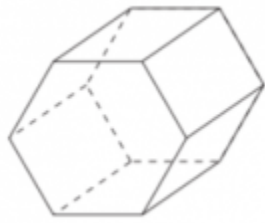
3- Brenda draws most of an addition symbol on the Cartesian plane below.



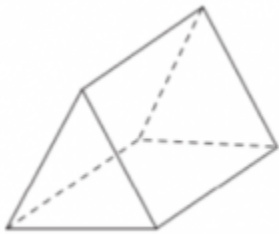
Which two ordered pairs represent the location on the grid of the two pints that should be connected to complete the addition symbol?

- a. (3, 4) and (4, 4)
- b. (4, 3) and (3, 3)
- c. (3, 4) and (4, 3)
- d. (4, 4) and (4, 3)

4- Which of the figures pictured below is a square-based pyramid?



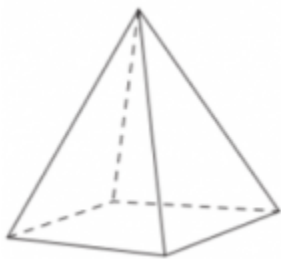
a.



b.

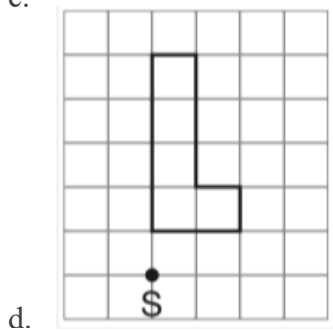
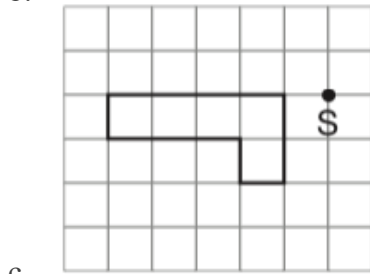
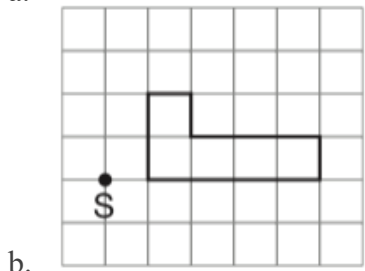
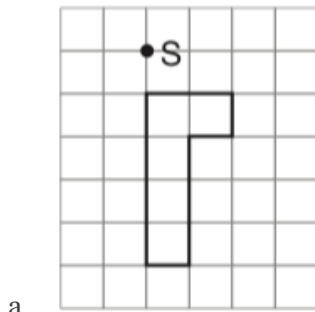
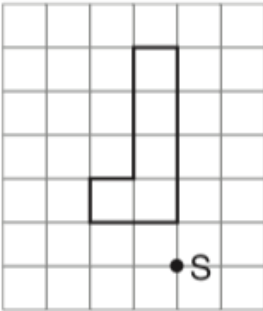


c.

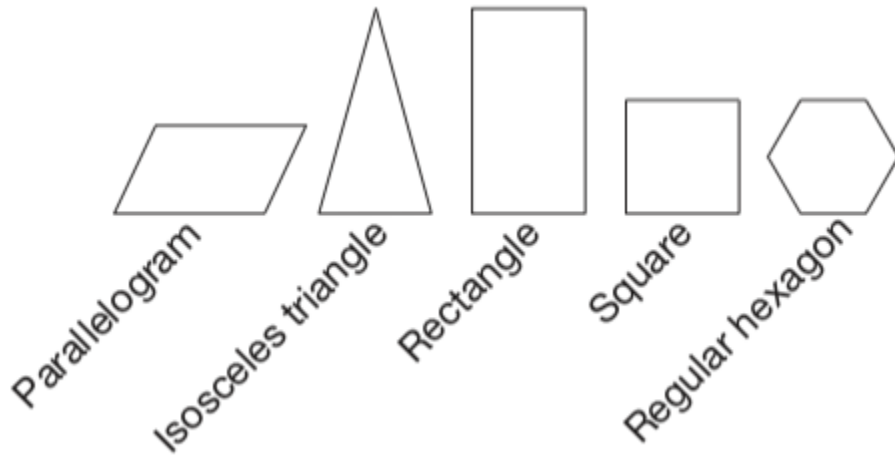


d.

5- Which of these shapes shows a 90° rotation counter-clockwise about S point of the shape below?

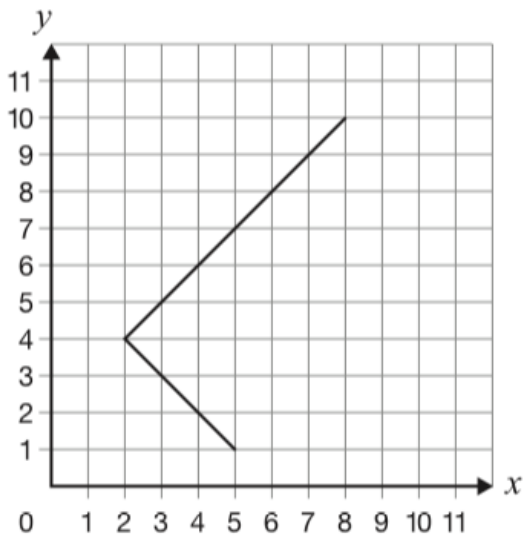


6- The shapes below are ordered from smallest to largest of which geometric properties?



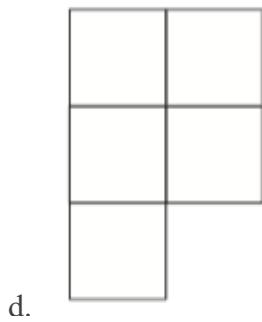
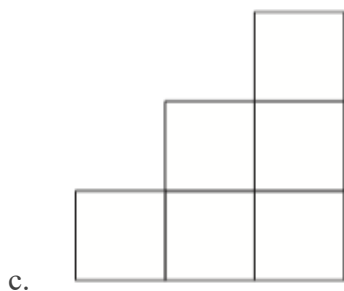
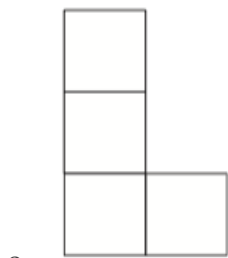
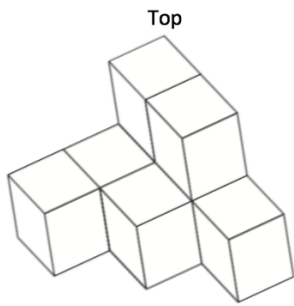
- a. Number of angles
- b. Number of lines of symmetry
- c. Number of pairs of equal sides
- d. Number of obtuse angle

7- Which point would complete the rectangle below?

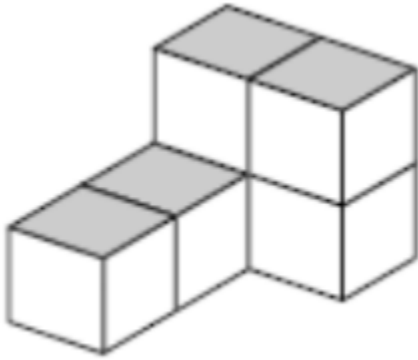


- a. (6,10)
- b. (10,6)
- c. (7,11)
- d. (11,7)

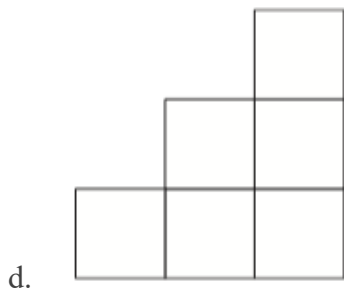
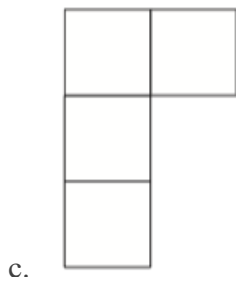
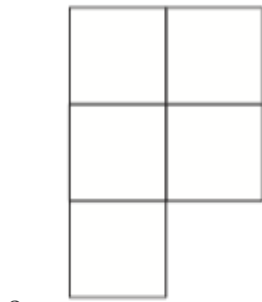
8- Which grid shows the top of the figure below?



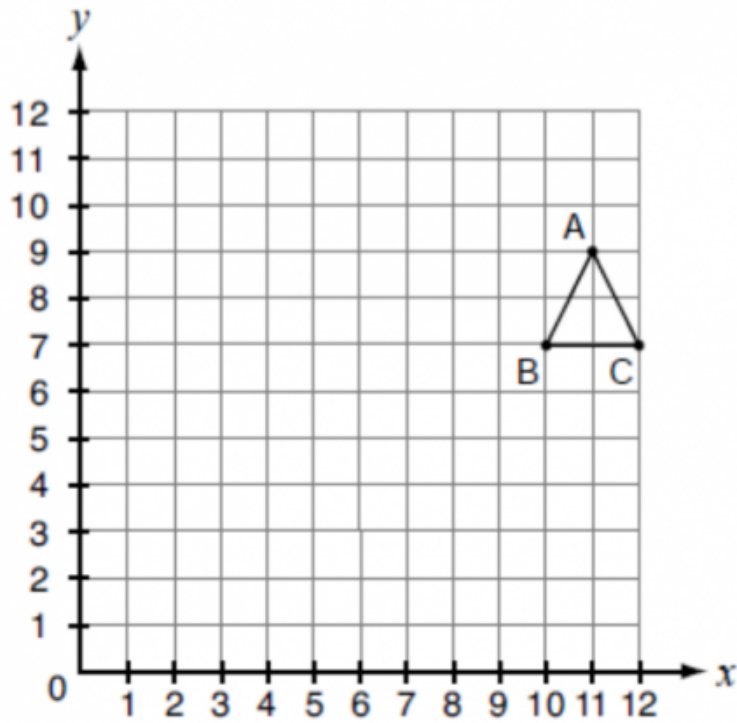
9- The following structure is built with 6 identical cubes.



What is the top view of this figure?



10- Triangle ABC is graphed on the grid below.



Triangle ABC is translated 8 units to the left, 2 units down. What is the coordinates of Point B?

- a. (4, 5)
- b. (2, 5)
- c. (3, 7)
- d. (9, 3)

Appendix B: Abbreviated Math Anxiety Scale (AMAS)

Abbreviated Math Anxiety Scale (AMAS)

Please rate each item in terms of how anxious you would feel during the event specified. Use the following scale and record your answer in the space to the left of the item:

Scale:**1 = Low Anxiety****2 = Some Anxiety****3 = Moderate Anxiety****4 = Quite a bit of Anxiety****5 = High Anxiety**

- ___ 1. Having to use the tables in the back of a math book.
- ___ 2. Thinking about an upcoming math test one day before.
- ___ 3. Watching a teacher work an algebraic equation on the blackboard.
- ___ 4. Taking an examination in a math course.
- ___ 5. Being given a homework assignment of many difficult problems which is due the next class meeting.
- ___ 6. Listening to a lecture in math class.
- ___ 7. Listening to another student explain a math formula.
- ___ 8. Being given a “pop” quiz in a math class.
- ___ 9. Starting a new chapter in a math book.

Appendix C: STAI-Trait

STAI

Sub# _____

A number of statements which people have used to describe themselves are given below. Read each statement and then circle the appropriate value to the right of the statement to indicate how you *generally* feel. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe how you generally feel.

		ALMOST NEVER	SOMETIMES	OFTEN	ALMOST ALWAYS
1.	I feel pleasant.....	1	2	3	4
2.	I feel nervous and restless.....	1	2	3	4
3.	I feel satisfied with myself.....	1	2	3	4
4.	I wish I could be as happy as others seem to be.....	1	2	3	4
5.	I feel like a failure.....	1	2	3	4
6.	I feel rested.....	1	2	3	4
7.	I am "calm, cool, and collected".....	1	2	3	4
8.	I feel that difficulties are piling up so that I cannot overcome them.....	1	2	3	4
9.	I worry too much over something that doesn't really matter.....	1	2	3	4
10.	I am happy.....	1	2	3	4
11.	I have disturbing thoughts.....	1	2	3	4
12.	I lack self-confidence.....	1	2	3	4
13.	I feel secure.....	1	2	3	4
14.	I make decisions easily.....	1	2	3	4
15.	I feel inadequate.....	1	2	3	4
16.	I am content.....	1	2	3	4
17.	Some unimportant thought runs through my mind and bothers me.....	1	2	3	4
18.	I take disappointments so keenly that I can't put them out of my mind ..	1	2	3	4
19.	I am a steady person.....	1	2	3	4
20.	I get in a state of tension or turmoil as I think over my recent concerns and interests.....	1	2	3	4

Appendix D: Sociodemographic questions

1. How old are you?
2. What is your gender?
 - a) Male
 - b) Female
 - c) You don't have an option that applied to me. I identify as (please specify)
3. In which faculty does your program belong?
 - a) Faculty of Arts
 - b) Faculty of Education
 - c) Faculty of Engineering
 - d) Faculty of Health Sciences
 - e) Faculty of Law
 - f) Faculty of Medicine
 - g) Faculty of Science
 - h) Faculty of Social Sciences
 - i) Telfer School of Management
 - j) Other (please specify)
4. What is your first language?
5. Which of the following categories best describes your family's annual gross income?
 - a) Less than \$15 000
 - b) \$15 000 to \$34 999
 - c) \$35 000 to \$49 999
 - d) \$50 000 to \$74 999
 - e) \$75 000 to \$99 999
 - f) \$100 000 or more

Appendix E: Cognitive Intrusive Questionnaire for Maths

The following questions relate to unpleasant or worrisome thoughts you may have experienced during the maths task. Please answer them as truthfully as possible.

1. **During the maths task that you have just completed**, did you experience thoughts about :
 - making mistakes
 - time pressure
 - method of problem solving
 - what people would think
 - panicking
 - previous maths experiences
 - Physical changes (sweating, heart beat, etc)

2. Please note down any further thoughts that worried or troubled you during the maths task. If you would like to expand on those ticked above, please do so.

3. Referring to the most worrisome or troubling thoughts you ticked or mentioned, please rate (by circling) the following :

3.1 How often did the thoughts enter your mind?

1	2	3	4	5
Rarely	A few times	Often	Very often	Continuously

3.2 How unhappy did these thoughts make you feel?

1	2	3	4	5
Not at all	Slightly	Moderately	Very	Extremely

3.3 How worried did these thoughts make you feel?

1	2	3	4	5
Not at all	Slightly	Moderately	Very	Extremely

3.4 How difficult was it to remove these thoughts from your mind?

1	2	3	4	5
Not at all	Slightly	Moderately	Very	Extremely

3.5 What did you do when the thoughts came into your mind? (please answer every question)

a) I didn't do anything, they went of their own accord.

1	2	3	4	5
Not at all	Slightly	Moderately	Very	Extremely

b) I reassured myself by saying they aren't important

1	2	3	4	5
Not at all	Slightly	Moderately	Very	Extremely

c) I did or thought something to reduce the effects of the thoughts

1	2	3	4	5
Not at all	Slightly	Moderately	Very	Extremely

d) I tried to reason about the thoughts

1	2	3	4	5
Not at all	Slightly	Moderately	Very	Extremely

e) I tried to replace the thoughts with other thoughts.

1	2	3	4	5
Not at all	Slightly	Moderately	Very	Extremely

f) I distracted myself with things around me.

1	2	3	4	5
Not at all	Slightly	Moderately	Very	Extremely

g) I focused more on the question.

1	2	3	4	5
Not at all	Slightly	Moderately	Very	Extremely

3.6 How much effort did it take to stop/reduce the thoughts?

1	2	3	4	5
None at all	Slight amount	Moderate amount	Much	Very much

3.7 How effective were any strategies you used to stop or reduce the thoughts?

1	2	3	4	5
Not at all	Slightly	Moderately	Very	Extremely

3.8 To what extent did the thoughts stop you being able to calculate during the task?

1	2	3	4	5
Not at all	Slightly	Moderately	Very	Extremely

3.9 **During the maths task that you have just completed**, did you experience thoughts about :

Relationship problems

Family problems

Health problems

Work problems

Financial problems

Problems with car/house, etc.

Other personal problems

Appendix F: Modular arithmetic**Trial**

- # $5 \equiv 2 \pmod{3}$
- # $5 \equiv 2 \pmod{2}$
- # $62 \equiv 14 \pmod{3}$
- # $62 \equiv 14 \pmod{9}$
- # $3 \equiv 1 \pmod{2}$
- # $3 \equiv 1 \pmod{3}$
- # $83 \equiv 35 \pmod{4}$
- # $83 \equiv 35 \pmod{5}$

Lower Working Memory Load

- # $8 \equiv 5 \pmod{3}$
- # $8 \equiv 5 \pmod{2}$
- # $7 \equiv 3 \pmod{4}$
- # $7 \equiv 3 \pmod{3}$
- # $6 \equiv 1 \pmod{5}$
- # $6 \equiv 1 \pmod{3}$
- # $9 \equiv 6 \pmod{3}$
- # $9 \equiv 6 \pmod{4}$
- # $8 \equiv 1 \pmod{7}$
- # $8 \equiv 1 \pmod{3}$
- # $7 \equiv 5 \pmod{2}$
- # $7 \equiv 5 \pmod{3}$
- # $9 \equiv 4 \pmod{5}$
- # $9 \equiv 4 \pmod{3}$
- # $7 \equiv 4 \pmod{3}$
- # $7 \equiv 4 \pmod{4}$
- # $9 \equiv 3 \pmod{6}$
- # $9 \equiv 3 \pmod{5}$
- # $6 \equiv 2 \pmod{4}$
- # $6 \equiv 2 \pmod{3}$
- # $9 \equiv 1 \pmod{2}$
- # $9 \equiv 1 \pmod{3}$
- # $9 \equiv 7 \pmod{2}$
- # $9 \equiv 7 \pmod{3}$
- # $8 \equiv 6 \pmod{2}$
- # $8 \equiv 6 \pmod{3}$
- # $9 \equiv 2 \pmod{7}$
- # $9 \equiv 2 \pmod{6}$

- # 3 \equiv 2 (mod 1)
- # 3 \equiv 2 (mod 2)
- # 5 \equiv 1 (mod 4)
- # 5 \equiv 1 (mod 3)
- # 6 \equiv 3 (mod 3)
- # 6 \equiv 3 (mod 2)
- # 7 \equiv 2 (mod 5)
- # 7 \equiv 2 (mod 4)
- # 8 \equiv 2 (mod 6)
- # 8 \equiv 2 (mod 5)
- # 4 \equiv 1 (mod 3)
- # 4 \equiv 1 (mod 2)

Higher Working Memory Load

- # 42 \equiv 27 (mod 3)
- # 42 \equiv 27 (mod 4)
- # 83 \equiv 27 (mod 8)
- # 83 \equiv 27 (mod 9)
- # 32 \equiv 14 (mod 6)
- # 32 \equiv 14 (mod 7)
- # 36 \equiv 27 (mod 3)
- # 36 \equiv 27 (mod 4)
- # 45 \equiv 29 (mod 8)
- # 45 \equiv 29 (mod 9)
- # 43 \equiv 27 (mod 8)
- # 43 \equiv 27 (mod 7)
- # 53 \equiv 26 (mod 3)
- # 53 \equiv 26 (mod 4)
- # 54 \equiv 36 (mod 6)
- # 54 \equiv 36 (mod 7)
- # 73 \equiv 37 (mod 6)
- # 73 \equiv 37 (mod 7)
- # 54 \equiv 26 (mod 7)
- # 54 \equiv 26 (mod 6)
- # 52 \equiv 17 (mod 7)
- # 52 \equiv 17 (mod 4)
- # 41 \equiv 27 (mod 7)
- # 41 \equiv 27 (mod 6)
- # 82 \equiv 55 (mod 9)
- # 82 \equiv 55 (mod 8)

$$\# 56 \equiv 38 \pmod{3}$$

$$\# 56 \equiv 38 \pmod{4}$$

$$\# 41 \equiv 23 \pmod{3}$$

$$\# 41 \equiv 23 \pmod{4}$$

$$\# 43 \equiv 18 \pmod{5}$$

$$\# 43 \equiv 18 \pmod{3}$$

$$\# 54 \equiv 27 \pmod{9}$$

$$\# 54 \equiv 27 \pmod{8}$$

$$\# 63 \equiv 48 \pmod{3}$$

$$\# 63 \equiv 48 \pmod{4}$$

$$\# 67 \equiv 18 \pmod{7}$$

$$\# 67 \equiv 18 \pmod{6}$$

$$\# 75 \equiv 59 \pmod{4}$$

$$\# 75 \equiv 59 \pmod{5}$$