The development of mathematical anxiety and its relationship with mathematical performance leading up to National Testing in primary aged children.

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Copyright.

Abstract.

The focus of this thesis is the development of mathematical anxiety and its relationship with mathematical performance. In particular, this relationship is explored with primary aged children during the year of National Testing. Mathematical anxiety is described as feelings of apprehension around undertaking mathematical tasks both in education and everyday life. Mathematical anxiety has been negatively associated with many different types of mathematical performance in both children and adults. In exploring this relationship account is taken of mathematical anxiety theory and cognitive (Working Memory, Non-verbal Intelligence and Reading ability) and emotional (Interest in mathematics, Trait and State Anxiety) factors. Employing a longitudinal design, the research explored the way in which the relationship between mathematical anxiety and mathematical performance changed at the different time points for the two groups of children.

A first study explored mathematical anxiety and three forms of mathematical performance, fluency, arithmetic, and word problem solving a year before the children undertook their National Standard Attainment Tests (SATs). Further studies explored mathematical anxiety and mathematical performance at the beginning of the year, just before and the end of the year in which the children completed their SATs.

There was a negative correlation between mathematical anxiety and mathematical performance, and this became stronger as children neared completion of their SATs. In the case of the older group the negative correlation continued after completion of the SATs. Evidence was found of a directional relationship between mathematical anxiety and mathematical performance. This directional relationship was from prior mathematical performance (Mathematical fluency and word problem solving) leading to higher levels of mathematical anxiety. Evidence was also found that interest in mathematics was a mediator in the relationship between mathematical anxiety and mathematical performance. This research emphasizes that the relationship between mathematical anxiety and mathematical performance is an important factor to be considered in primary education.

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Declaration:

This thesis comprises the candidate's own original work and had not, whether in the same or different form been submitted to this or any other University for a degree. All experiments were designed and analysed by the candidate and all testing was conducted by the candidate.

Introduction

The development of mathematical anxiety and its relationship with mathematical performance in children in primary education is investigated through a longitudinal design. In particular the children are studied before, during and after their year of National Testing. In exploring this relationship other factors that are known to influence mathematical performance are measured, namely cognitive (Working Memory, Non-verbal Intelligence and Reading ability) and emotional (Interest in mathematics, Trait and State Anxiety) factors. Chapter one discusses the development of mathematical anxiety, theories and models of mathematical anxiety and establishes the background to mathematical anxiety research in children. Chapter two discusses mathematical performance development in children, theories and stages of mathematical performance and establishes the background to mathematical performance research. It then leads onto previous research conducted to determine the relationship between mathematical anxiety and mathematical performance. Chapter three describes the methodology of the thesis, detailing the design of the thesis, the methodological procedures, the tests used to measure the variables and the data analyses used. Chapter four describes the development of mathematical anxiety over time, through repeated measures ANOVAS and structural equation modelling in particular latent growth curve modelling. Chapter five describes the relationship between mathematical anxiety and mathematical performance from each of the studies for the younger (Key Stage one) cohort. Chapter six describes the relationship between mathematical anxiety and mathematical performance from each of the studies for the older (Key Stage two) cohort. Chapter seven describes the longitudinal relationship between mathematical anxiety and mathematical performance through structural equation modelling namely cross lagged panel models. Chapter eight describes the relationship between interest in mathematics with mathematical anxiety and mathematical performance, looking at whether interest in mathematics mediates the directional relationship between mathematical anxiety and mathematical performance. Chapter nine provides a summary and general discussion of the research questions within the thesis. Appendices for each analyses chapter are provided with supplemental information associated with the thesis. Bibliography provides a complete list of all the references cited within the thesis.

Original contribution to Knowledge

Despite there being a substantial literature base on the relationship between mathematical anxiety and mathematical performance in adults and a growing number of studies working with children, longitudinal studies are rare. In addition, there is a lack of research which concentrates on the development of mathematical anxiety and mathematical performance of children before and during the year in which they take part in National testing. This research is therefore original in that it will provide an understanding of the relationship between mathematical anxiety and mathematical performance at a key stage in the children's primary education.

The research finding that the correlations between mathematical anxiety and mathematical performance are stronger just before the SATs for the older children is further evidence that high stakes testing produces an environment for this relationship to strengthen. As this is only for the older children, the value of testing children in a more supportive environment decreases the strength of the relationship. An important consideration for governments and schools to consider, is whether summative assessment can be delivered in a way to maximise all children's potential.

The research finding that prior mathematical performance predicts later mathematical anxiety is one of value to teachers and educators in understanding the way that children's early experiences of failure are managed. The building of a supportive culture, where mistakes are valued and learnt from would develop less anxious and more resilient young mathematicians. Equally the research finding that interest in mathematics is a mediator within the relationship between mathematical anxiety and mathematical performance is an important one for governments, schools, teachers, and parents. As finding a means to promote interest in mathematics and overcome the culturally acceptable value of being negative about maths and accepting poor performance within the UK is important in promoting good academic and everyday numeracy.

Chapter 1. - Mathematical Anxiety.

Chapter contents:

This chapter sets the context for this thesis in that it gives a detailed discussion of mathematical anxiety, through a summary and critique of previous research. It sets the context and importance of studying mathematical anxiety, discussing the main theories and models proposed by researchers to explain the effects of mathematical anxiety on mathematical performance. It discusses in detail the development and individual differences of mathematical anxiety in children. Then it looks at factors that previous researchers have found that influence children's mathematical anxiety.

This chapter is divided into the following sub-sections

- Introduction
  - Conceptualisation of mathematical anxiety
- Measurement and structure of mathematical anxiety
- Theories and models of mathematical anxiety of how mathematical anxiety affects mathematical performance.
- Development of mathematical anxiety in children.
- Individual differences in mathematical anxiety
  - Age
  - Gender
- Environmental Factors affecting mathematical anxiety.
  - Home
  - School
  - Geographical Region

1.1. Introduction:

Anxiety is defined as an emotional reaction experienced by individuals in response to a perceived threat, which could be described as a personality trait or a transitory state (Endler & Kocovski, 2001; Lewis, 1970; Speilberger, 1966). Anxiety as a personality trait is where individuals behave in a consistently anxious state in all different situations (Speilberger, 1966). Transitory Anxiety manifests itself in physiological changes within the body e.g., perspiration and palpitations of the heart and higher scores on introspective reports by individuals (Speilberger, 1966). Mathematical anxiety is an emotional reaction that influences mathematical performance of children and adults. Individuals experience feelings of apprehension when confronted by any mathematical tasks either in an academic or everyday life context (Dowker, 2016). This anxiety solely around mathematics is known to distinguish itself from other forms of anxiety for example, general and test anxiety (Ashcraft, Krause, & Hopko, 2007; Hembree, 1990). Mathematical anxiety has been recognised as one of the significant factors in shaping mathematical learning and performance in adults (Maloney & Beilock, 2012; Ramirez, Chang, Maloney, Levine, & Beilock, 2015). More mathematically anxious high school and college students are less likely to take optional mathematics courses (Ashcraft, Kirk & Hopko, 1998), avoid tasks with mathematics (Ashcraft, 2002; Hembree, 1990; Liew, Lench, Kao, Yeh & Kwok, 2014) or plan science, technology, engineering and mathematics (STEM) careers (Chipman, Krantz & Silver, 1992). This is becoming more of an issue with the increase in STEM jobs, which require a good level of mathematical understanding and competence, rises each year globally (Durman, 2017; Fayer, Lacey, & Watson, 2017). Therefore, there is a need to better understand mathematical anxiety and its effects early in childhood, to ensure that children and later adults are in the best position to achieve mathematically.

1.1.1. Conceptualisation of Mathematical anxiety.

Dreger & Atkin (1957), first described mathematical anxiety as separate from general anxiety, naming the construct as "number anxiety". They identified this separate anxiety construct, through asking adult participants questions about their experiences of mathematics and measuring their galvanic skin resistance, whilst completing mathematical problems. From this they identified individuals who were particularly anxious about numbers and arithmetic. Wigfield & Meece, (1988), later described mathematical anxiety as a bidimensional construct based on Liebert & Morris, (1967), ideas about test anxiety. This divided anxiety into two separate dimensions namely cognitive and affective (Liebert & Morris, 1967). The cognitive dimension is described as "worry" which refers to "concern about task performance and the consequences of failure in tests". The affective dimension is described as "emotionality" which refers to "nervousness and tension in testing situations" (Liebert & Morris, 1967). These two dimensions, cognitive and emotional have been used as a basis for determining the measurement and structure of mathematical anxiety in adults and children.

1.2 Measurement and structure of Mathematical Anxiety

The most prolific means of assessing mathematical anxiety in participants is the use of rating scales, where individuals answer questions regarding how they feel about mathematics. Initial attempts to devise measurements of introspective reports of mathematical anxiety were developed to be used with adults. Dreger and Aiken, (1957), modified the Taylor Manifest Anxiety scale (Taylor, 1953), with three questions specifically about anxiety around mathematics. Richardson and Suinn, (1972), developed a measurement specifically to look at mathematical anxiety. This mathematical anxiety rating scale (MARS) asked participants to answer 98 questions to determine the anxiety they felt in several mathematical situations. (Richardson & Suinn, 1972). Later versions of this scale were designed which shortened the number of questions for efficiency of usage (Plake & Parker, 1982). Plake and Parker, (1982), conducted a principal axes factor analysis, which identified two clear factors "mathematics evaluation and learning mathematics anxiety". This resulted in the development of the mathematical anxiety rating scale -revised (MARS-R) (Plake & Parker, 1982), with only twenty-four items. Hopko et al., (2003), conducted an exploratory factor analysis, which identified the same two factors "mathematics evaluation anxiety and learning mathematics"as Plake and Parker (1982). Their abbreviated mathematics anxiety scale (AMAS) (Hopko, Mahadevan, Bare, & Hunt, 2003) reduced the scale to only nine items.

Measurement of mathematical anxiety for children had to be specifically designed, as the scales devised for adults were not accessible to children. Common to all the rating scales used with children, is the use of Likert Scales, psychometric scales that allow researchers to establish how individuals feel about something (Likert, 1932). Typically, they consist of a series of questions or statements and individuals express their feelings from strongly agree, agree to disagree, strongly disagree with a middle neutral point. In those devised for children the response scales use child friendly language or faces to aid understanding (Bell, 2007; Buchanan & Niven, 2002).

There is some variability in the factors identified within mathematical anxiety, there are some studies which indicate two factors (Carey, Devine, Hill, & Szucs 2017a; Suinn, Taylor & Edwards, 1988; Wu, Willcutt, Escovar, & Menon, 2014) and others that outline three factors (Harari, Vukovic, & Bailey, 2013; Jameson, 2013b). Suinn Taylor & Edwards, (1988), devised an anxiety rating scale based on the MARS (Richardson & Suinn, 1972) but specifically for children aged nine to twelve (Mathematics anxiety rating scale- elementary: MARS-E). They conducted a factor analysis which identified two factors of mathematical anxiety, namely "mathematical test anxiety and mathematical performance adequacy anxiety". They suggested that these two factors align to other two factor measurements of mathematical anxiety (MARS; Richardson & Suinn, 1972), although there is some discussion of a third factor namely "numerical or calculation anxiety".

Wu, Barth, Amin, Malcarne, & Menon, (2012) devised the Scale for Early Mathematical Anxiety (SEMA) asking children aged seven to nine years, how they feel at answering mathematical questions and in certain situations surrounding mathematical performance. Their Principal components analysis revealed two factors, "numerical processing anxiety and situational and performance anxiety". This scale then allows for a younger group of children to be included and allows for researchers to question much younger children about their mathematical anxiety.

Carey et al., (2017a) developed the modified Abbreviated Mathematics Anxiety Scale (mAMAS), they asked a large-scale sample of UK children aged eight to eleven, how anxious they felt in situations requiring them to do mathematics. Their CFA confirmed that the scale had two factors, the same as the adult scale (AMAS; Hopko et al., 2003), "mathematics evaluation and mathematics learning anxiety". This scale differs from both the previous scales in that it was specifically designed for a UK sample. As the authors suggest that there are subtle language differences that English children would not understand in the American scales (Carey et al., 2017a).

Harari et al., (2013), developed the mathematics anxiety scale for young children, from the other scales for children MARS-E (Suinn et al., 1988) and the Math Anxiety questionnaire (Wigfield & Meece, 1988), with children aged six to seven. They used a Likert scale but reduced the answers to four instead of 5 or 7 respectively. They argued that younger children needed a simpler choice of responses. Although, there is evidence that younger children still respond to the extremes even when options are reduced (Chambers & Johnston, 2002). Their exploratory factor analysis identified three factors namely, "negative reactions, numerical confidence and worry". This scale differs from the MARS-E in that it identifies a three-factor structure.

Jameson, (2013a, 2013b), developed the Children's Anxiety in Math scale (CAMS), asking children aged five to ten years, how they feel in mathematical situations. Included within the questions was a focus on their feelings about their performance and errors in mathematics. A five-point Likert scale was used but differently to Harari et al., 2013, this scale provided the children with a series of smiley faces from very anxious to not anxious at all. The exploratory factor analysis identified three factors, namely "general mathematics anxiety, mathematical performance anxiety and mathematical error anxiety". The Children's Anxiety in Math scale (CAMS) (Jameson, 2013a, 2013b) scale differs from previous scales in that it brings in the element of how children feel about their performance in mathematics and their mathematical errors.

From the measurement of mathematical anxiety an understanding of the arrangement of the different factors within mathematical anxiety and how they relate to each other, namely the structure of mathematical anxiety has been developed. Structures of mathematical anxiety in children (Carey et al., 2017a; Harari, Vukovic, & Bailey, 2013; Jameson, 2013a; Jameson, 2013b; Suinn et al., 1988; Wu, Barth, Amin, Malcarne, & Menon, 2012) have been related to specific mathematical tasks and situations such as number processing, problem solving, testing, performance or error.

These structures have been divided into two and three factors. Suinn et al., (1988), investigating mathematical anxiety in children aged nine to twelve, identified two factors in their proposed structure, "numerical processing anxiety and situational and performance anxiety". Wu et al., (2012), investigating mathematical anxiety in children aged from seven to nine identified two different factors. "Numerical processing anxiety (anxiety related to understanding and working with numbers) and situational performance anxiety (anxiety related to the actual completing of the mathematics especially in class and under test conditions)". Carey et al, (2017a), investigating mathematical anxiety in children from age eight to thirteen also identified two different factors. "Mathematics evaluation anxiety and mathematics learning anxiety". As described earlier these structures separate mathematical anxiety into two factors, with Suinn et al., (1988) and Wu et al., (2012) both focussing on number and situational mathematics. Whereas Carey et al., (2017a) divide mathematical anxiety into "mathematics evaluation and mathematics learning". What a two-factor structure does not provide is the scope to separate out mathematical anxiety into anxiety around performance and anxiety around errors, an important distinction especially in times of high stakes testing.

Three factor structures of mathematical anxiety enable more distinction of the factors within mathematical anxiety. Jameson (2013a, 2013b) identified three factors, "general mathematical anxiety (anxiety around mathematics), mathematics performance anxiety (anxiety around performance in mathematics) and mathematics error anxiety (anxiety around making mistakes in mathematics)". Jameson's (2013a, 2013b) structure differs from previous structures in that it brings in the element of error in performance, this factor clearly looks at how anxious children feel when they make mistakes. An important consideration in times of National testing, as a clear focus is placed on children not making mistakes and achieving their best mathematically. Harari et al., (2013), identified three factors, "negative reactions, the feelings of tension and the physiological reactions" that individuals have to mathematics, similar to Liebert & Morris, 1967, "emotionality factor, worry (anxiety around performance in mathematics) and numerical confidence (anxiety around how confident an individual, feels about numbers)". Harari et al., (2013), three factor structure better explains mathematical anxiety as in brings in the factor of numerical confidence compared to two factor structures. This allows the ability to determine how mathematical anxiety is affected by how confident children are at mathematics. Both of these three factor structures are similar to each other in having the cognitive factor of worry (Liebert & Morris, 1967), that is how anxious children feel around their performance in mathematics.

In this thesis the structure of mathematical anxiety used was one composed of three factors, "general, mathematical performance and mathematical error anxiety "as proposed by Jameson, (2013a, 2013b). It was of particular importance to include performance and error factors within the assessment of mathematical anxiety to link to the fact that the testing period within the thesis was during the children's National testing year, a particular time of performance for the children. In the UK, the National testing used is Standard Attainment Tests (SATS) (Standards and Testing Agency, 2016) in school year 2 (children aged six to seven) and school year 6 (children aged ten to eleven). A teaching and learning time of particular focus on the children's errors in mathematics and how they are dealt with to lead to increased performance.

Therefore, from the structure and measurement of mathematical anxiety, researchers have developed ways in which to view mathematics anxiety. In order to understand the process of how mathematical anxiety affects the mathematical performance of individuals and provide an explanation of the process, theories and models have been developed.

1.3 Theories and models of how mathematical anxiety affects mathematical performance.

In psychology, theories and models are used to explain concepts and processes experienced by individuals. Theories are described as a set of ideas or conceptual frameworks that have been developed, to explain a concept, process, or behaviour (Croker, 2012). Models on the other hand are described as either physical, symbolic, visual, or verbal representations of the concept or process that provide a way of making it easier to understand (Reese & Overton, 1970).

Thus, when exploring the relationship between mathematical anxiety and mathematical performance it is worth first considering the relationship between general anxiety and performance. Eysenck and Calvo's (1992), Processing Efficiency Theory, claims that experiencing feelings of worry will always impair the quality of cognitive performance as it reduces working memory capacity. The empirical evidence for this theory was based on studies which compared the cognitive performance of anxious individuals to non-anxious individuals, when subjected to distracting stimuli (Calvo & Eysenck, 1996; Eysenck & Graydon, 1989). This theory was further developed into the Attentional Control Theory (Eysenck, Derakshan, Santos, & Calvo, 2007), which suggests that there is an attentional allocation towards irrelevant aspects of the task. These irrelevant aspects of the task could be the worrying thoughts of anxious individuals (Eysenck et al., 2007). Moreover, they proposed that this reduction in working memory capacity was because the individual's performance is divided between the task and their worrisome thoughts (Eysenck et al, 2007). These theories have been the basis of researchers (Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007) theorising on the explanation of how mathematical anxiety affects mathematical performance.

Ashcraft & Kirk, (2001), carried out several experiments with adults aged twenty-one to twenty-six. In their first experiment, they assessed mathematical anxiety and working memory (listening span and computation span). They found that adults with high levels of mathematical anxiety had lower levels of working memory. In the second experiment, they set up a dual task paradigm, where students were required to solve basic addition facts up to two column digits with carrying (operations with answers over the base ten), whilst retaining information from a memory task. From this they concluded that high anxiety students might be in a situation with three tasks, the mathematical task, the memory task, and their mathematical anxiety. They suggested that mathematics anxiety exerts an effect on the students' mathematics performance, because their minds are preoccupied on worrying thoughts rather than concentrating on the information important to complete their mathematical tasks (Ashcraft & Krause, 2007). This then means they direct their attention away from solving the task at hand towards their worries (Ashcraft & Krause, 2007). Ashcraft, (2002), suggests that mathematical anxiety works by disrupting the working memory resources that would be involved in solving the mathematical task at hand.

From this theoretical basis, researchers (Ashcraft et al., 2007; Carey, Hill, Devine, & Szucs, 2016; Hembree, 1990; Lyons & Beilock, 2012; Maloney, 2016; Tobias, 1986) modelled how mathematical anxiety affects performance. These models provided them with a representation of the process between mathematical anxiety and mathematical performance. Figure 1.1 summarises the models proposed to reflect the directional nature of the relationship between mathematical anxiety and mathematical performance. The blue arrow represents the causal relationship described in the Disruption/Debilitating anxiety models (Carey, Hill, Devine, & Szucs, 2016; Hembree, 1990; Lyons & Beilock, 2012). These models all propose that it is mathematical anxiety that causes poor mathematical performance. The orange arrow represents the causal relationship, described in the Deficit/reduced competency models (Maloney, 2016; Tobias, 1986). These models propose that it is poor mathematical performance that then leads to mathematical anxiety. The green arrows represent the cyclical causal relationship, described in the reciprocal model (Ashcraft et al., 2007). This model proposes that mathematical anxiety causes poor mathematical performance, which in turn then causes increased mathematical anxiety.

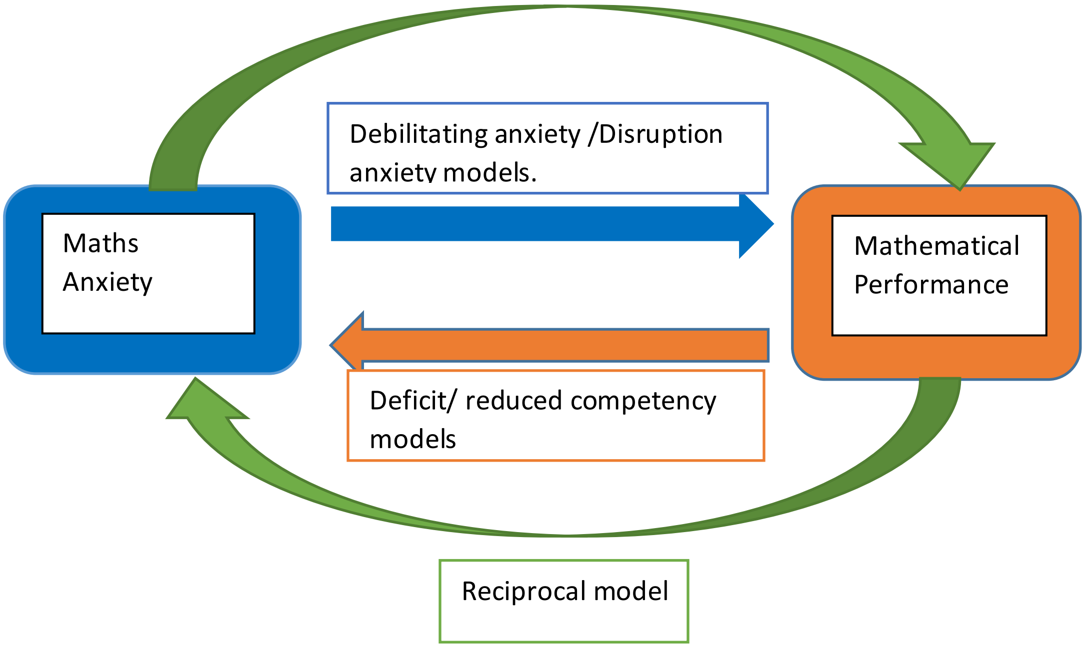

Figure 1.1: Summarises the models of the causal links between mathematical anxiety and mathematical performance.

Mathematical performance is thought to lead to mathematical anxiety and several models have been proposed to explain this unidirectional relationship. The Deficit model (Carey et al., 2016; Tobias, 1986), assumes that the memories that an individual has of their inability to succeed at mathematical tasks leads to an increasing anxiety in the future. This seems to be the case in particular for timed tests and exams (Tobias, 1986). Maloney's, (2016) reduced competency model, suggests that it is poor numerical and spatial ability that leads individuals to poor mathematical performance, which in turn causes their mathematical anxiety. It is suggested that this poor performance makes them susceptible to the social negativity surrounding mathematics (Maloney, 2016). Studies that offer support to models of mathematical performance leading to mathematical anxiety include longitudinal studies where an individual's mathematical anxiety and mathematical performance is studied over time. Ma and Xu, (2004) carried out a study with adolescents from ages thirteen to eighteen and found that a student's prior mathematical performance predicted their later mathematical anxiety. Similarly, Sorvo, Koponen, Viholainen, Aro, Raikkonen, Peura, Tolvanen, & Aro, (2019) demonstrated support for the Deficit model in that prior mathematical fluency predicted later mathematical anxiety in children from ages seven to eleven. Support for the deficit model has also been found in cross sectional studies, where children who have been identified as having mathematical difficulties were found to have more mathematical anxiety than children identified as not experiencing difficulties (Passsolunghi, 2011; Rubinsten & Tannock, 2010; Wu, et al., 2014). Equally other researchers using cross sectional studies, working with adults, suggest that individuals experience mathematical anxiety due to their poor mathematical performance. This poor mathematical performance is linked to the adult's lack of basic numerical magnitude skills, which leads to deficiencies in their higher order mathematical skills (Maloney, Ansari & Fugelsang, 2011; Nunez-Pena & Suarez-Pelliconi, 2014).

The deficit and reduced competency models offered explanations of memories of past mathematical performance and social negativity around mathematics. These explanations failed to account for individuals with poor mathematical skills and negative experiences who are not mathematically anxious (Ramirez, Shaw, & Maloney, 2018a) and individuals with good mathematical skills who are mathematically anxious (Lee, 2009). The Interpretation account model proposes that it is how the individual interprets their mathematical performance that effects their mathematical anxiety (Ramirez, Shaw & Maloney, 2018a). The authors of the interpretation account model link it to the theoretical basis provided by "appraisal theory" (Arnold, 1950; Barrett, 2006; Lazarus, 1991; Schacter & Singer, 1962). They propose a constructionist view of attitudes and how they impact on mathematical anxiety (Bem, 1972; Chaiken & Yates, 1985; Wilson, Lindsey, & Schooler, 2000). Their model proposes that it is not their worries or competency that determines their mathematical anxiety but rather it is how they interpret their mathematical experiences and outcomes (Ramirez, Shaw & Maloney, 2018a). Evidence provided to support this model includes research around young people's perceived ability in mathematics rather than their actual achievement. Meece, Wigfield & Eccles, (1990) investigated with young people aged eleven to thirteen, their perceived ability in mathematics, their mathematical anxiety and mathematical achievement. They found that a young person's perceived ability in mathematics was the strongest predictor of their later mathematical anxiety (Meece, Wigfield & Eccles, 1990). Research with children aged seven to eight has revealed that mathematical self-concept, how children perceive their ability in mathematics, was a strong predictor of their mathematical anxiety (Jameson, 2014). These models (deficit, reduced competency, and interpretation) suggest that prior poor mathematical performance and even how mathematical performance is perceived, is the means by which mathematical anxiety is created in individuals.

Model of relationship between mathematical anxiety and mathematical performance.	**Directional relationship**	**Explanation**	**Supporting theory**	**Supporting evidence**
Deficit Model (Carey et al., 2016; Tobias, 1986).	Poor mathematics performance leads to mathematical anxiety.	Memories that an individual has of their inability to succeed at mathematical tasks leads to an increasing anxiety in the future.		Ma & Xu, 2004; Passsolunghi, 2011; Rubinsten & Tannock, 2010; Sorvo et al., 2019; Wu, et al., 2014
Reduced Competency model (Maloney, 2016)	Poor mathematics performance leads to mathematical anxiety.	Poor mathematical performance caused by lower mathematical skills, makes individuals more mathematically anxious and leads them to be susceptible to social negativity surrounding mathematics.		Ma & Xu, 2004 Maloney, Ansari & Fugelsang, 2011; Nunez-Pena & Suarez-Pelliconi, 2014
Interpretation account (Ramirez, Shaw &	Poor mathematics performance leads to	How the individual interprets their mathematical performance, and this	Appraisal theory (Arnold, 1950; Barrett, 2006; Lazarus,	Jameson, 2014; Meece, Wigfield & Eccles, 1990

Maloney, 2018a)	mathematical anxiety.	effects their mathematical anxiety	1991; Schacter & Singer, 1962)	
Disruption account (Ramirez, Shaw & Maloney, 2018a)	Mathematics anxiety leads to poor mathematical performance	Mathematical anxiety works by disrupting mathematical performance through a reduction of an individual's working memory resources.	Processing efficiency theory (Eysenck & Calvo, 1992).	Ramirez, Gunderson, Levine & Beilock, (2013)
Debilitating anxiety model (Carey, Hill, Devine, & Szucs, 2016; Lyons & Beilock, 2012).	Mathematics anxiety leads to poor mathematical performance	Mathematical anxiety impacts whilst an individual is processing and retrieving mathematical knowledge.	Processing efficiency theory (Eysenck & Calvo, 1992).	Ashcraft, 2002; Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007; Cargnelutti, Tomasetto & Passolunghi, 2017; Ramirez et al, 2013: Ramirez, Chang, Maloney, Levine & Beilock, 2016.
Reciprocal Model (Ashcraft et al., 2007)	Cyclical relationship.	Individuals experience mathematical anxiety; this then has a negative effect on their mathematical performance and the	Processing efficiency theory (Eysenck & Calvo, 1992).	Carey et al., 2017b. Gunderson, Park, Maloney,

	resultant poor performance leads to increased mathematical anxiety.	Beilock, & Levine, 2018.

Table 1.1: Summary of the directional models of the directional relationship between mathematical anxiety and mathematical performance.

Mathematics anxiety leading to poor mathematical performance is the alternative unidirectional relationship. Models have been suggested, where mathematical anxiety is represented as how individuals experience further performance deficits (Luo, Hogan, Tan, Kaur, Ng, & Chen, 2014). The disruption account model, which explains that mathematical anxiety works by disrupting mathematical performance through a reduction of an individual's working memory resources (Ramirez et al., 2018a). Evidence supporting this model is found in research with adults, where individuals with high mathematics anxiety are slower with more errors in mathematical problems with an element of carrying (Ashcraft & Faust, 1994). Whilst research with children investigating the relationship between mathematical anxiety, working memory and mathematics achievement also supports this model. Ramirez et al., (2013), assessed working memory (digit span), mathematical anxiety (Child math anxiety questionnaire) and mathematical problem solving in children aged six to eight. They found a significant negative relationship between mathematical anxiety and mathematical achievement for children with high working memory. They suggest that children with high working memory use strategies that require more working memory and therefore are more likely to be affected by mathematical anxiety. Conversely those children with low working memory use strategies that require less working memory, e.g., use of manipulatives and fingers.

The Debilitating Anxiety Model proposes that mathematical anxiety impacts whilst an individual is processing and retrieving mathematical knowledge (Carey et al., 2016; Lyons & Beilock, 2012). That is that individuals experiencing mathematical anxiety struggle to process the information in mathematical problems and retrieve stored mathematical information as their working memory is occupied on worrying about the mathematics (Ashcraft, 2002; Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007). Evidence supporting this model includes research with adults, where adults with high mathematical anxiety performed less well on mathematical problems with high working memory requirements e.g., mathematical problems requiring carrying (problems with answers over base ten) (Ashcraft & Kirk, 2001; Ashcraft & Kirk, 2007). Further evidence is contained within Hembree's (1990), meta-analysis of research about the effects of mathematical anxiety on mathematical performance, incorporating studies with participants aged ten to adulthood. In his conclusions, he proposed that mathematics anxiety interferes with an individual's recall of prior mathematical learning and then impacts on their mathematical performance. Research with children suggests that mathematical anxiety affects children with high working memory's mathematical performance, when using strategies requiring the use of their working memory (Ramirez et al, 2013: Ramirez et al, 2016).

Further support for the unidirectional relationship of mathematical anxiety predicting mathematical performance has been found in studies with children. Cargnelutti et al., (2017), investigated the relationship between mathematical anxiety and mathematical performance longitudinally, whilst controlling for general anxiety with children aged seven to nine. They found a stronger relationship between mathematical anxiety and later mathematical performance than the other way around over time.

Finally, researchers (Ashcraft et al, 2007; Carey et al., 2016; Foley, Herts, Borgonovi, Guerriero, Levine, & Beilock, 2017; Maloney & Beilock, 2012; Maloney, Ansari, & Fugelsang, 2011), have suggested that the relationship between mathematical anxiety and mathematical performance is not unidirectional in nature but cyclical. The reciprocal model, (Ashcraft et al., 2007) proposes that as individuals experience mathematical anxiety this has a negative effect on their mathematical performance and the resultant poor performance leads to increased mathematical anxiety. Evidence to support the reciprocal model includes longitudinal (Gunderson et al., 2018) and cross-sectional (Carey et al., 2017b) research with children. Gunderson et al., (2018), using cross lagged panel models, found that there were significant cross lagged pathways between mathematical anxiety and mathematical performance in children from ages six to eight. Of particular importance to this thesis is that fact that this reciprocal relationship was found in a longitudinal study in their first two years of formal education (Gunderson et al., 2018), as within this thesis similar young children will be investigated. Carey et al., (2017b) using latent profile analysis found reciprocal relations between mathematical anxiety and mathematical performance in primary (children aged eight to nine years) and secondary (children aged eleven to thirteen).

The number of different models proposed indicate that the relationship between mathematical anxiety and mathematical performance is a complex one. Complicated by the fact that the research is so diverse in nature with differences in age of participants, gender of the participants, measure of mathematical anxiety, measure of mathematical performance, condition under which mathematical performance is measured and whether the study is cross-sectional or longitudinal. Therefore, in this longitudinal research it will be important to examine this relationship in detail to better understand the directional nature of this relationship.

1.4 Development of mathematical anxiety.

The development of mathematical anxiety, how this anxious feeling about mathematics operates in children during their school years is only just being explored. This type of research leads to questions around whether mathematical anxiety is a stable construct through a child's education, whether it changes with age or is it dependent on a specific point in a child's education. Of particular importance is whether National testing as a specific time point affects the development of mathematical anxiety.

Evidence for the development of mathematical anxiety has been explored through two types of studies. Firstly, with the use of longitudinal methods where the children's mathematical anxiety is measured at different time points (Krinzinger, Kaufmann, & Willmes, 2009; Sorvo et al., 2019). The second through cross sectional studies, where differences between different age groups of children's mathematical anxiety is measured at the same time (Gierl & Bisanz, 1995; Gunderson et al., 2018; Sorvo, Koponen, Viholainen, Aro, Raikkonen, Peuro, Dowker, & Aro, 2017). The importance of these types of research to a child's education is significant as mathematical anxiety has been self- reported in the very young (Harari et al., 2013; Jameson, 2014; Ramirez et al., 2013; Ramirez et al., 2016; Wu et al., 2012) to older children (Devine, Fawcett, Szucs, & Dowker, 2012; Haase, Julio-Costa, Pinheiro-Chagas, Oliveira, Micheli, & Wood, 2016; Hill, Mammarella, Devine, Caviola, Passolunghi, & Szucs, 2016; Ho, Senturk, Lam, Zimmer, Hong, Okamato, Chui, Nakazawa, & Wang, 2000; Hunt, Bhardwa, & Sheffield, 2017; Krinzinger et al., 2009; Ma & Xu, 2004; Sorvo et al., 2017) and its effects on their educational lives could be exponential (Wigfield & Meece, 1988). Studies have looked at the development of mathematical anxiety in children at a group level. Longitudinal studies examined the changes in the mean level of mathematical anxiety over different time points at the group level to provide an indication of the changes in mathematical anxiety (Sorvo et al., 2019). For example, Krinzinger et al., (2009) in a longitudinal study of children aged six to nine, found that the mean level of mathematical anxiety increased with time. Cross sectional studies examined the difference in mean levels of mathematical anxiety between different school year groups. For example, Gierl and Bisanz, (1995) found that mathematical test anxiety scores increase between children from eight to twelve years of age. The researchers attributed this finding to the fact that children become more mathematically anxious, especially around mathematical testing, the more time they spend in school (Gierl & Bisanz, 1995). On the other hand, Gunderson et al., (2018) found mathematical anxiety about mathematics related activities higher in the children aged six to seven compared to children aged seven to eight. Whilst Sorvo et al., (2017) also found that mathematical anxiety about mathematics related activities was higher in the younger children. These researchers attributed this to the fact that the younger children were just starting school and were anxious about mathematics related activities through their unfamiliarity with them (Gunderson et al., 2018; Sorvo et al., 2019). Therefore, these conflicting results suggest that there are changes in mean levels of mathematical anxiety dependent on the age of the children but more importantly linked to the type of mathematical anxiety being measured. For example, mathematical anxiety related to mathematical related activities or mathematical anxiety related to a failure in mathematics (Gunderson et al., 2018; Sorvo et al, 2019).

Longitudinal studies have looked at the changes in mathematical anxiety at an individual level through examining rank order stability (Krinzinger et al., 2009; Ma & Xu, 2004; Sorvo et al., 2019). These studies investigate whether the same children report the same anxiety over time (Sorvo et al., 2019). In rank order stability, individuals retain their position relative to others within the group over time, with respect to their level of mathematical anxiety. Therefore, the stability coefficients for mathematical anxiety measured at different time points are examined. Ma and Xu, (2004), found that rank order stability (0.6) was strongest from students aged thirteen to eighteen. Sorvo et al., (2019) found similar rank order stability (0.51) in children aged from seven to eleven. Krinzinger et al., (2009) found similar stability coefficients (0.49-0.6) for children aged from six to nine. The conclusions from these three studies suggest that mathematical anxiety is a stable construct for both older and younger children and that the same individual children report the same mathematical anxiety levels over time. This rank order stability could be an explanation for the contradictory results reported earlier where some researchers reported mean changes increasing and others decreasing with age.

It has been suggested that any differences in the development of mathematical anxiety could be attributed to the individual differences of children. As a child's age or gender may be a factor that contributes to their level of mathematical anxiety and will be explored in this thesis.

1.5 Individual Differences:

1.5.1. Age.

As stated earlier studies have found significant maths anxiety in early primary aged children, with researchers reporting maths anxiety in children aged four to six (Jameson & Ross, 2011; Petronzi, Staples, Sheffield, & Hunt, 2019) through to children aged six to seven (Harari et al, 2013) as well as older children (Devine et al, 2012; Jameson, 2014; Sorvo et al. 2017; Thomas & Dowker, 2000; Wood, Pinheiro-Chagas, Julio-Costa, Micheli, Krinzinger, Kaufmann, Willmes, & Haase, 2012; Wu et al., 2012; Wu et al., 2014). Researchers have indicated that mathematical anxiety increases with age (Dowker, 2016; Krinzinger et al, 2009), whilst others suggest that it more prevalent in younger children (Gunderson et al., 2018; Sorvo et al., 2019). Researchers have suggested that the reason for an increase in maths anxiety with age, might be that children are more exposed to the negative attitudes of others (Ma & Kishor, 1997), or that they have more experiences of failure at mathematics (Ashcraft, 2002; Ashcraft et al, 2007). Another reason might be that the content of the maths significantly changes for children as they get older (Sorvo et al., 2017). The arithmetic curriculum progresses with increasingly larger numbers and more abstract concepts compared to the more accessible aspects of mathematics that younger children are exposed too (Dowker, 2016). Another factor in the increase in mathematical anxiety with age may be linked to how children feel about mathematics as a subject. Younger children appear to show more interest and enjoyment in mathematics, this interest and enjoyment then appears to deteriorate with age (Dowker, 2005; Ma & Kishor, 1997). These cognitive and emotional factors all appear to contribute to increased mathematical anxiety over time.

Alternatively, the studies that found higher levels of mathematical anxiety in younger children suggest that it is because the researchers were looking at mathematical anxiety related to mathematical related activities and not to a failure in mathematics (Gunderson et al., 2018; Sorvo et al, 2019). They offer an explanation for this, that as the children get older, they have the more exposure to mathematics related activities, and they become more familiar with what will be expected of them. Equally as the children get older, they have more experience of failure in mathematics, which might explain the previously stated research which indicates an increase in mathematical anxiety with age (Dowker, 2019a; Ma & Kishor, 1997).

Therefore, it is important to determine at what age mathematical anxiety emerges in children and how it develops throughout their time at school, to best support children to achieve mathematically.

1.5.2. Gender.

The individual difference of gender is likely to affect mathematical anxiety, as according to popular opinion and the media (Paquette, 2016; Paton, 2012), females experience more mathematical anxiety than males and its effect on mathematical performance is stronger in females than males. Moreover, in studies with adults, researchers have found that women reported higher mathematical anxiety than men (Betz, 1978; Chang & Cho, 2013; Else-Quest, Hyde & Linn, 2010; Wigfield & Meece, 1988).

In research samples of children these gender differences occur more during adolescence rather than with primary children (Devine et al, 2012; Dowker, Sarkar, & Looi, 2016; Hembree, 1990; Hill et al., 2016). This is supported by the International Programme for International student assessment (PISA) report (OECD, 2013b) of the academic abilities and attitudes of fifteen-year-old children around the world. PISA, (2012), reported that when students were asked about their anxiety towards mathematics, 35% of girls self-reported mathematics anxiety compared to only

25% of the boys. Other studies with older primary aged children have indicated that females report more mathematical anxiety (Vanbinst, Bellon & Dowker, 2020; Yuksel-Sahin, 2008). Whilst research with younger children, aged five to eleven years of age found no gender difference (Van Mier, Schleepen, & Van den Berg, 2019). Therefore, the gender difference appears strongly related to age, with females reporting more mathematics anxiety at older ages.

Research around gender differences in mathematical anxiety has been linked to either cognitive, emotional, or environmental factors. The cognitive factor affecting mathematical anxiety is linked to the popular idea that males generally fare better at mathematics than females, as they have more cognitive ability in maths and therefore as girls find mathematics more difficult, they will in turn report more mathematical anxiety. There is some research evidence of higher mathematical anxiety being reported by girls than boys at the secondary level of education (Devine et al., 2012; Frenzel, Pekrun, & Goetz, 2007; Hill et al., 2016). Additionally, previous research evidence from meta-analyses has suggested that there is a difference in mathematical performance between males and females at the secondary school level (Hedges & Nowell, 1995: Hyde, Fennema, & Lamon, 1990). Although, a meta-analysis looking at international tests such as Trends in International Mathematics and Science study (TIMSS) and the Programme for International student assessment (PISA), suggests that there may be some differences in performance between males and females, but that the effect sizes are small (Else-Quest et al., 2010). On the other hand, there is research evidence that have suggested that the gender differences at secondary level are decreasing (Hyde, Lindberg, Linn, Ellis, & Williams, 2008; Hyde & Mertz, 2009; Lindberg, Hyde, Petersen, & Linn, 2010). Whilst Devine et al., (2102) investigated the mental arithmetic of secondary aged children and found no significant gender difference. Hill et al, (2016), who investigated the calculation abilities of both primary and secondary aged children found no gender differences in performance. Therefore, it is becoming increasingly obvious that the difference in mathematical anxiety between males and females is not due to there being a cognitive difference in mathematical performance between males and females.

Therefore, it may be more appropriate to look for the reason that mathematical anxiety is reported to affect females more than males through an examination of emotional factors. A number of different emotional factors have been identified by researchers, females showing higher levels of general anxiety (Beidel & Alfano, 2011; Feingold, 1994; McClean, Asnaami, Litz & Hofmann, 2011), females having a lack of self–belief in their ability (Frenzel et al, 2007; PISA 2012 (OECD, 2013b) and having a greater willingness to disclose their personal attitudes (Ashcraft, 2002). These gender emotional differences have been identified with females attending secondary education, including their tendency to self-report lower levels of anxiety in general and more mathematical anxiety in particular (Devine et al, 2012; Hembree, 1990). The International

PISA report 2012, (OECD, 2013b) of 15-year-old children around the world found 50% of males and 60% of females reported that they worry about the difficulty they experience in mathematics classes and as a result what their marks will be like. A recent longitudinal study (Szczygiel, 2020a) with girls aged seven to eight found that they had a higher total and testing mathematical anxiety not learning mathematical anxiety than boys. The author suggested that the reason girls reported higher levels of mathematical anxiety was linked to girls being more predisposed to general anxiety (Szczygiel, 2020a).

Another reason for this gender difference affecting the mathematical anxiety of females is the suggestion that this gender difference might be because females feel a stereotype threat. This is that females perpetuate a cultural held belief that mathematics is a subject that males fare better at than females. (Beilock, Rydell & McConnell, 2007; Dowker et al., 2016; Spencer, Logel & Davies, 2016). This negative stereotypical belief then affects females reporting of mathematical anxiety as socially acceptable.

An alternative reason as to why females report more mathematical anxiety is linked to the influence of teachers on the mathematical anxiety of their students. Researchers have found that mathematical anxiety of children was influenced by the gender of the teacher. In, that female teachers who were themselves highly mathematically anxious affected the mathematical performance of their female students (Beilock, Gunderson, Ramirez, & Levine, 2010). That the female students viewed their teachers as a role model in mathematical performance and paid more attention to the style and delivery of their female teachers. The researchers felt that the result was due to the girls' acceptance of gender stereotyping, that girls are better at reading and that boys are better at mathematics, through the teacher's reinforcement of this stereotyping (Beilock et al., 2010). A note of caution is needed with this research as the teachers within this study were all female as no male teachers participated. Therefore, there is no evidence within this study as to whether male teachers with high mathematical anxiety would affect the mathematical anxiety of their female students. Other studies investigating the relationship between teacher's mathematical anxiety and their student's performance have been with samples of teacher's who are predominantly female, and therefore the results have not been analysed by gender (Hadley & Dorward, 2011; Novak & Tasell, 2017; Ramirez et al., 2018b).

It has equally been suggested that differences in the development of mathematical anxiety could be attributed to the environmental factors that the children are exposed too.

1.6 Environmental factors:

Children are exposed to several different environmental factors such as their home, school and geographical region all of which influence the development of children (Brofrenbrenner, 1984). Researchers have reported how, home environment (Huntsinger, Jose & Luo, 2016; Jameson, 2014; Maloney, Ramirez, Gunderson, Levine & Beilock, 2015; Soni & Kumari, 2015), school environment (Ashcraft et al, 2007; Beilock et al., 2010; Herts, Beilock & Levine, 2019) and geographical region (Ho et al., 2000; Luo et al., 2014; Zhang, Zhao & Kong, 2019) all affect a child's mathematical anxiety.

1.6.1 Home.

Development both cognitively and emotionally of children is influenced by adults within the home environment (Huntsinger, Jose & Luo, 2016). Parents modelling of their own mathematical anxiety has been found to predict their children's mathematical anxiety. Soni & Kumari (2015), reported through path analysis that parental mathematical anxiety was a significant predictor of older children's (aged ten to fifteen) mathematical anxiety. Emotionally the verbal statements of the parents/carers own mathematical anxiety are projected onto their children (Jameson, 2014). Moreover, Maloney et al., (2015), reported in their longitudinal study that seven-year-old children with parents with high mathematical anxiety had increased mathematical anxiety at the end of the school year. This was specifically the case with parents who regularly supported their children with their mathematical homework. Equally, parents with high mathematical anxiety do not feel confident in supporting their children's mathematical learning (Herts et al., 2019).

1.6.2. School

The relationship between teachers and the children within classrooms is of importance in children's cognitive and emotional development. Herts et al., (2019), suggest that the environment at school created by teachers influences the development of mathematical anxiety. The communication within the classroom between the teachers and the children is thought to highlight the teacher's own beliefs around mathematics, which in turn influences the beliefs of the children (Herts et al., 2019). This has led some researchers to suggest that mathematical anxiety is created within the classroom environment (Ashcraft et al, 2007, Beilock et al., 2010), although this takes little account of all the other influences on a child's mathematical anxiety.

Researchers have identified four areas in which teacher's influence children's mathematical anxiety; the teacher's style of teaching (Hembree, 1990; Herts et al., 2019; Newstead, 1998), the teacher's expectations (Friedrich, Funger, Nagengast, Jonkmann, & Trautwein, 2015), the teacher's negativity (Furner & Duffy, 2002; Jackson & Leftingwell, 1999), and the negative feedback from teachers (Ashcraft, 2002; Ashcraft et al. 2007). In mathematics classes a teacher's own mathematical anxiety is thought to affect their pupil's mathematical anxiety by determining the style of teaching they adopt. Teachers with high mathematical anxiety are thought to use a direct method of teaching instead of an investigative method (Hembree, 1990; Newstead, 1998). This direct method of teaching closes the possibilities of the teacher having to face questions that they are unable to answer due to their own mathematical anxiety. Equally, not allowing children the opportunity to investigate their mathematical problems through an element of trial and error would limit children's problem-solving ability and lead to increased mathematical anxiety (Herts et al., 2019). Negativity within classrooms has been linked to increased children's mathematical anxiety (Friedich et al., 2015). Children with negative experience of mathematics teaching, feel unsupported by their teachers, who have been described as "hostile teachers" for the negative unsupportive environment within the classroom (Furner & Duffy, 2002). This negativity leads in many cases to an avoidance of mathematics (Jackson & Leftingwell, 1999). One important aspect of this negative classroom environment is the negative feedback from teachers. Ashcraft, (2002), suggests that the repetition of negative feedback to failures in mathematical performance, causes an increase in mathematical anxiety. This internalisation of negative feedback from a non-supportive teacher sets up an environment for mathematical anxiety to flourish (Ashcraft et al., 2007). Therefore, it can be seen from previous research that school environment can in some circumstances lead to increased mathematical anxiety in children. As this research was to be conducted with primary aged children two schools were approached, so that the relationship between school environment and children's mathematical anxiety could be investigated.

1.6.3. Geographical region:

Mathematical anxiety is a feature of all countries around the world and research into the relationship between mathematical anxiety and mathematical performance has been conducted in many different countries (Ho et al., 2000; Luo et al., 2014; Zhang, Zhao & Kong, 2019). The amount and effect of mathematical anxiety might vary from one country to another linked to the cultural values of the country. Culture has been defined as "collective programming of the mind distinguishing members of one group or category of people from others" (Hofstede, 2011, p.3). Therefore, culturally through attitudes and beliefs about mathematics being a particularly difficult subject, some countries may foster mathematics anxiety. This appears to be the case in the United States, where it seems to be socially acceptable to admit that you are anxious about mathematics (Beilock, 2014), due to the difficult nature of the subject. Interestingly in the UK, it is also socially acceptable within society for individuals to admit they are not good at mathematics as it carries little social stigma (Chinn, 2016).

Mathematical anxiety studies have been carried out extensively in the United States, UK and Europe and an increasing amount in the rest of the world. One global study is The Programme for

International Student Assessment (PISA), which is carried out to assess the academic performance of fifteen-year-old young people in reading, mathematics, and science. This international test has been in operation since 2000. Every three years it ranks countries on their student's academic performance. In 2012, there was a particular focus on mathematics and the factors affecting mathematics performance. The students were asked a series of questions to which they indicated strongly agree, agree, or disagree, strongly disagree, in order to establish their index of mathematical anxiety. They were asked "whether they often worry that mathematics classes will be difficult for them; whether they get very tense when they have to do mathematics homework; whether they get very nervous doing mathematics problems; whether they feel helpless when doing a mathematics problem and whether they worry that they will get poor grades in mathematics" (OECD, 2013a). It was reported that 30% of the participants felt helpless when doing maths problems. (OECD, 2013a). The findings from the three-yearly reports are then highlighted in the government policies of the participating countries to improve their countries mathematical performance. The results from the PISA, (2012) indicated that those countries where students had reported high levels of mathematical anxiety, were in fact those countries where the students had a lower-than-average performance e.g., Tunisia, Brazil, Argentina. In comparison to those with a higher-than-average performance e.g., Netherlands, Finland, and Switzerland. Interestingly the students in the highest performing countries of Shanghai-China, Singapore, and Hong Kong- China reported just above average mathematical anxiety. Therefore, students with good mathematical achievement report that they have mathematical anxiety, and studies have looked to determine the effect of this mathematical anxiety on their student's mathematical achievement (Ho et al., 2000; Luo et al., 2014; Zhang, Zhao & Kong, 2019). Research carried out in Singapore, one of the high performing countries, highlighted that it was the student's previous achievement that was thought to affect a student's mathematical anxiety levels and that this mathematical anxiety in turn affected their future performance (Luo et al, 2014). Research using a cross national approach compared the relationship between mathematical anxiety and mathematical achievement between children aged eleven to twelve in two Asian countries, China and Taiwan and the United States. This research found a significant relationship between affective mathematical anxiety and mathematical performance for all three countries (Ho et al., 2000). Further evidence to support these findings of significant relationships between mathematical anxiety and mathematical performance comes from a recent meta-analysis (Zhang, Zhao & Kong, 2019). This meta-analysis investigated the moderating role of geographical region, namely Asia, US, and Europe. They compared 49 studies reported between 2000 and 2018 and concluded that the strongest negative relationships were with studies carried out with Asian students, followed by students from the US and finally students from European countries. Therefore, Asian students with high levels of mathematical anxiety are poorer mathematically compared to students from the US and Europe (Zhang, Zhao & Kong, 2019). It has been suggested that the strong negative relationship between mathematical anxiety and mathematical performance could be explained by the higher value placed on academic achievement in Asian countries from teachers and parents which in turn adds pressure to the Asian students (Ho et al., 2000).

Therefore, mathematical anxiety is a global construct found in many geographical regions across the world, within low and high performing countries alike, although as yet there is no clear indication of what the actual cultural influence is and how it affects mathematical anxiety in the different geographical regions of the world (Dowker, 2019a). The participants in this thesis are all being educated within the same geographical area, the Nottingham area of the UK. Although the participants are from a variety of ethnic backgrounds (see chapter 3 for school percentages).

1.7 Chapter summary:

- Mathematics anxiety is described as a multidimensional construct with two elements the “cognitive (worry)” and “affective (emotionality)” dimension.

- Mathematical anxiety in this thesis is characterised as having three factors of mathematical anxiety, general mathematical anxiety (anxiety around mathematics), mathematics performance anxiety (anxiety around performance in mathematics) and mathematics error anxiety (anxiety around making mistakes in mathematics).

- Mathematical anxiety is thought to affect children in line with Eysenck’s and Calvo’s (1992) Processing Efficiency Theory, where children’s feelings of worry about mathematics impairs their quality of mathematical performance as it reduces their working memory processing.

- Models represent the relationship between mathematical anxiety and mathematical performance.
  - Unidirectional models suggest that prior mathematical anxiety predicts later mathematical performance e.g., Disruption/ Debilitating anxiety models.
  - Unidirectional models suggest that prior mathematical performance predicts later mathematical anxiety e.g., Deficit/ reduced competency / interpretation models.
  - A cyclical model where prior mathematical anxiety and prior mathematical performance predicts later mathematical anxiety and mathematical performance e.g., Reciprocal model.

- Development of mathematical anxiety:
  - Studies suggest there are changes in mean levels of mathematical anxiety over time dependent on the age of the children.
  - Studies suggests that mathematical anxiety is a statistically stable construct for both older and younger children and that the same individual children report the same mathematical anxiety levels over time.

- Mathematical anxiety is present in children from a very young age and has been found in older children.

- Mathematical anxiety is affected by individual differences:
    - There are individual differences in mathematical anxiety linked to age and gender.

- Mathematical anxiety is affected by environmental factors:
    - Parents mathematical anxiety is thought to affect their child's mathematical anxiety.
    - Teacher's mathematical anxiety is thought to affect their pupils' mathematical anxiety.
    - There have been reported differences in mathematical anxiety dependent on a child's culture.

Chapter 2. - Mathematical Performance

Chapter contents:

This chapter sets the context and importance for studying the different types of mathematical performance children experience. It looks at the development of mathematical performance in children. The chapter summarises previous research into individual differences and factors that researchers have found to influence children's mathematical performance.

It concludes with a discussion around the relationship between mathematical anxiety and mathematical performance, through a review of previous research with children.

This chapter is divided into the following sub-sections

- Introduction
- Context and importance of studying mathematical performance
- Development of mathematics in children.
- Individual differences in mathematical development.
    - Gender
    - Age
- Factors affecting mathematical performance
    - Emotional
        - General (Trait and State) Anxiety
        - Interest in mathematics
    - Cognitive
        - Non-verbal intelligence
        - Working memory
        - Reading.
- Importance of measures in understanding the relationship between mathematical anxiety and mathematical performance.
    - Mathematical performance measures.
        - fluency
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        - Word problem solving
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        - Dual tasks
        - High-stakes testing
        - Paper and pencil

- Mathematical anxiety measures.
- Individual differences affecting the relationship between mathematical anxiety and mathematical performance.
  - Age
  - Gender

2.1. Introduction.

Mathematics is a part of children's every-day and academic lives; they learn mathematical knowledge and skills both formally and informally. Children are introduced to formal mathematics at school through the subject of mathematics as part of the curriculum. Mathematics is a subject that requires specific knowledge of number, symbols, and rules. The UK primary education system describes the subject of mathematics within the National Curriculum for Key Stages 1 and 2 as:

"Mathematics is a creative and highly inter-connected discipline that has been developed over centuries, providing the solution to some of history's most intriguing problems" (Department for Education, 2014).

Children develop mathematical literacy, that is their ability to engage with mathematics language, knowledge, and skills in their lives. Mathematical knowledge opens for children a particular way of thinking and reasoning logically in order to interpret the world around. For example, The Programme for International Student Assessment (PISA), defines mathematical literacy as

"…an individual's capacity to identify and understand the role that mathematics plays in the world, to make well-grounded judgements and to use and engage with mathematics in ways that meet the needs of that individual's life as a constructive, concerned and reflective citizen" (OECD, 2003a).

Then within the Mathematics programme of study for Key Stage 1 and 2, mathematics education is described as:

"A high-quality mathematics education therefore provides a foundation for understanding the world, the ability to reason mathematically an appreciation of the beauty and power of mathematics and a sense of enjoyment and curiosity about the subject" (Department for Education, 2013b).

Mathematics is then measured through children's ability to solve mathematical problems at different stages in their educational journey. In many countries, this involves testing of children's mathematical performance at key points. In the UK, this testing starts early in a child's education with National testing within primary schools (children aged five to eleven) and followed up in secondary schools (children aged eleven to eighteen). There is growing concern globally that teenage children (aged fifteen) are not sufficiently competent at mathematics (OECD, 2014).

2.1.1. Context and importance of studying mathematical performance

The mathematical performance of children and young people has become an ever-increasing pressure for the education authorities of countries around the world. As they are ranked according to their children's and young people's ability in mathematics (Baird, Isaacs, Johnson, Stobart, Yu, Sprague & Daugherty, 2011; OECD, 2003; OECD, 2014). The Programme for International Student Assessment (PISA) highlights the variation and performance of fifteen-year-olds in reading, writing and mathematics, every three years. The most recent PISA, (2018) revealed that the fifteen-year-old children in England did significantly better in mathematics than in previous years (DFE, 2019). As a previous PISA, 2012 (OECD, 2014) found that 22% of the UK's fifteen-year-olds were not at level 2, the basic ability to solve every day mathematical problems. Therefore, the improvement of mathematical performance of children and young people is an important factor considered globally.

One means of increasing the mathematical performance of children and young people used by many countries is high stakes testing. This high-stakes testing is used by governments as a means of assessing the value of their educational systems year on year. Some countries use high stakes testing at the end of a child's secondary education to assess which young people can progress into higher education countries, for example Finland. The UK and the USA are notably two countries that use high stakes testing at a much earlier age i.e., within their primary education. The UK in particular uses National Standard Attainment Tests (SATs) in school year two (age six to seven) and school year six (age ten to eleven) to assess children. The SATs in year six are used by the Government to judge a school's effectiveness (Ofsted, 2012) by setting national targets. These national targets define the expectations for achievement that each school must meet to be judged as a good school, providing a good education for their pupils.

Researchers have identified negative side effects from high stakes testing for teachers, leaders, governors and of course pupils (Berliner, 2011; Connor, 2003; Harlen, 2007; Ozga, 2009; Putwain, Connors, Woods, & Nicholson, 2012; Segal, Snell & Lefstein, 2016; Segool, Carlson, Goforth, Van der Embse & Barterian, 2013). For teachers, leaders and governors the strong link between a school's SATS results and their use in accountability measures is identified as adding pressure on school staff to ensure that all children reach the standard (Ozga, 2009; Segal, Snell & Lefstein, 2016). This therefore leads to the negative side effect of a narrowing of the curriculum where schools are "teaching to the test" (Ball, 2013; Keddie, 2017). This narrowing is where the main focus of the weekly timetable taught during school year six, leads towards the subjects that children will be assessed on during the SATs, e.g., reading, writing and mathematics, with little room left in the timetable for other subjects. Harlen (2007), investigated how long school year six children spent on test preparation and found that they spent thirteen days practising and taking tests. This study found that less emphasis was given to higher order cognitive skills such as thinking skills and metacognition during the preparation time for SATs. For children, this focus on testing leads to the way children view their performance in mathematics. That good mathematical performance is all about memorising facts and the speed at which you can provide an answer (Boaler, 2014, 2016). This adds pressure on the children to perform and achieve, as competitive and testing environments are thought to create anxiety in children around meeting the mathematical performance expectations (Beilock & Ramirez, 2011). Researchers propose that the SATS put children under too much pressure to achieve and that in turn effects their learning and motivation (Connor, 2001; Connors et al., 2009; McDonald, 2001; Putwain, Connors, Woods & Nicholson, 2012; Tymms & Merrell, 2007; Ward & Quennerstedt, 2018). Putwain et al., (2012) interviewed year six (children aged ten to eleven) highlighting two themes about their forthcoming SATs. The first theme highlighted the children's attitudes and feelings about SATs and the second highlighted the children's perceptions of feeling under pressure due to the performance demands of achieving well in the SATs (Putwain et al., 2012).

Alternatively, The Cambridge Primary Review (Alexander, 2010), reported that teachers, head teachers and parents were concerned about the use of high stakes testing in primary education. Although, the review reported that teachers, head teachers and parents were not necessarily against the assessment of children but that they were concerned about the type of assessment (Alexander, 2010).

Therefore, this thesis is set within this educational context of mathematical performance through an environment of high stakes testing for children within primary schools. It is therefore important to understand the development of mathematical skills and knowledge in children throughout their primary education.

2.1.2. Development of mathematics in children:

Mathematics begins for children with the realisation that there are more than one of things/objects within their immediate home environment. Children develop the understanding that things and objects come in different shapes and sizes which form patterns that can be counted (Mulligan & Mitchelmore, 2009). A growing understanding is nurtured through dialogue with the adults around them, who supportively add the language needed to develop this numeracy understanding. Therefore, the home environment provides a starting point for the development of early numeracy skills (Huntsinger, Jose, & Luo, 2016; Kleemans, Peeters, Segers & Verhoven, 2012; Simms, Cahoon, McParland, Doherty & Gilmore, 2018). The move into education extends this early numeracy understanding through a concrete physical understanding of numbers, shapes, sizes, and patterns. As children progress in their education they begin to be introduced to the symbolic formal nature of mathematics. Mathematical skills develop in children as a progression of understanding of related mathematical facts and concepts (Purpura, Baroody & Lonigan, 2013). Mathematics is a cognitively challenging subject, as the language used in mathematics have specific meanings which children must learn. Mathematics is made even more difficult for some, as many of the words are already within their everyday vocabulary with less specific meanings (Towse, Muldoon & Simms, 2016). To improve their mathematical performance, children need to acquire and be taught the language and symbols of mathematics (Ashcraft & Krause, 2007).

Mathematical development in children has been linked to the stages of cognitive development devised by Piaget (1970). Piaget (1970) suggested that children's cognitive development could be subdivided into four discrete stages, sensorimotor, preoperational, concrete operations, and formal operations. He suggested that children passed through the stages sequentially although this may not be a smooth transition. In the sensorimotor stage of development children begin to link numbers to objects. In the preoperational stage of development with the increase in verbalisation, children develop the skill of learning to count and the recognition of numbers (Klien & Bisanz, 2000). Children begin by learning and understanding the number words sequence e.g., one, two, three etc. (Munn, 2008). They link these words to quantities of things within their environment. Then they begin to develop one-to-one correspondence, as they link the number words to objects whilst reciting the words, counting. In the concrete operations stage with a significant increase in language and basic skills, children begin to develop seriation, where they order objects and classification, and where they group objects. The child's understanding of seriation leads to a generalisation across sets of quantities i.e. that counting a set of five toys and counting a set of five sweets will arrive at the same number and that the sets contain the same quantity, (Sarnecka, Goldman & Slusser, 2015). At this stage the use of manipulatives is of some importance and children use a variety of manipulatives from their fingers, natural objects to commercially produced objects such as unifix, cuisinere and numicon (Carbonneau, Marley & Selig, 2013; Dowker, 2019b). This then develops into the mental representations of number for the children, where the children know and understand that the number 3 contains three elements, researchers have named this cardinality (Gallistel & Gelman, 1992; Schaeffer, Eggleston & Scott, 1974). In the formal operation stage where children develop reasoning skills, they begin to generalise and evaluate the logical arguments in more abstract thought patterns. They begin to clarify problems by identifying the key elements, make inferences from learnt mathematical concepts, evaluate their solutions of a problem, and apply the mathematical concepts to real life problems (Ojose, 2008).

In this thesis the development of mathematical learning in particular arithmetic and problem solving are of importance. Arithmetic is the basis for much of mathematical development and at its simplest is the ability to perform operations such as addition, subtraction, multiplication, and division. To understand how arithmetic works, children need to learn the set of rules and procedures, to establish automatic processes (Lucangeli & Cormoldi, 1997). At first children need support from concrete apparatus to develop these skills, but very quickly they begin to build mental representations of the numbers. In mental arithmetic children need to encode the information, carry out the calculations and then provide the answer (LeFevre et al., 2010). Arithmetic requires children to develop an understanding of three types of knowledge. Factual knowledge, the numbers, and the types of operations. Procedural knowledge the processes that the different operations perform on the numbers e.g., addition and subtraction. Conceptual knowledge the principles behind the operations e.g., when you add two numbers together the resulting solution is more than the two numbers separately (Leferve, Wells and Sowinski, 2015). As children acquire the factual, procedural, and conceptual knowledge they then begin to build mental representations and develop mathematical fluency.

Mathematical fluency is the speed at which children can perform number operations, leading to an automaticity of the retrieval of the solutions (Vukovic & Siegel, 2010). This fluency is seen as an important stage of development and much valued within formal schooling (Department for Education, 2013b; McClure, 2014). The ability to remember arithmetic facts fluently is thought to be the foundation of solving word problems (Fuchs, Fuchs, Compton, Powell, Seethaler, & Capizzi, 2006). Meyer, Salimpoor, Wu, Geary, & Menon, (2010), suggest that good arithmetic fluency improves children's mathematical performance. As it allows the child to focus on the more complicated calculations within mathematical problems.

The teaching of mathematics knowledge and skills follows a hierarchical pattern that leads to children's mathematical understanding: children move from counting, learning arithmetic facts to performing calculation skills and then to word problem solving (Swanson, Jerman & Zheng, 2008). Word problems are arithmetical problems related to mathematical relations and properties set within sentences constructed of words (Vukovic & Siegel, 2010). To solve these word problems, the children need to apply the arithmetical procedures to solve the problems, which requires a development of more "complex and flexible thinking" (Lucangeli & Cornoldi, 1997). As children need to be able to read the problem, decide on the arithmetical process to be used and apply it to solve the problem. The word problems may include a range of contexts such as time, length, weight, data- handling and money. In these word problems, questions are posed linked to scenarios which require the children to either go shopping, deal with weights of items for cooking or calculate the prices for a school trip. Word problems are the basis of the two reasoning papers that children in school year six sit as part of their Mathematics Key Stage 2 SATS in the UK (Standards and Testing Agency, 2016). Therefore, the development of this more complex thinking throughout the primary school is an important basis which allows the children to acquire good mathematical competence. This acquisition of mathematical competence is not the same for all children as there are a range of individual differences that affect its development.

2.2. Individual differences in mathematical development.

Children grow and develop at very different rates, no more so than in their development and understanding of mathematics. This is especially evident within primary schools, where the mathematics curriculum is designed to teach key concepts and skills needed to achieve in mathematics (DFE, 2013b). The individual differences in children's mathematical abilities are identified easily as children in UK primary schools are regularly tested. This regular testing provides valuable statistics on the range of individual differences in mathematical achievement (Department of Education, 2017). Researchers have found that there is a seven-year variation in the individual mathematical performance scores of children in school year six in their National Standardised tests (SATS) (Brown, Askew, Rhodes, Denvir, Ranson & William, 2003). Recent Key Stage two results for 2017, indicated that 75% of all the 11-year-olds in the UK achieved the expected standard in mathematics, with 23% of these children achieving at greater depth (Department of Education, 2017). This therefore means that in 2017, 25% of the 11-year-olds within the UK for that year did not achieve the standard.

This wide variation in ability could be linked to children's individual number and strategy abilities in mathematical performance. One such variation in ability is linked to the magnitude of numbers as researchers have found that the performance of individuals declines as the numbers in any mathematical problem increase in size (Ashcraft & Guillaume, 2009). This decline in performance has been called the "problem size" effect (Zbrodoff & Logan, 2005). This effect could be linked to variability in the three types of knowledge required for arithmetic. Firstly, in factual knowledge, it is easier to retrieve facts to support answering a problem from memory, than having to complete the calculation. Researchers have found that it is easier to retrieve smaller numbers than larger numbers e.g., 3 + 3 will be retrieved quicker than calculating 7 + 9 (Lefevre et al., 2015). Secondly, in procedural knowledge, for those individuals who rely on counting to solve problems, it takes longer to count larger numbers (Lefevre et al., 2015; Uittenhove & Lemaire, 2016). Thirdly, for conceptual knowledge, where individuals are not secure in the concepts needed to solve the problems, the size of the numbers adds to their confusion (Lefevre et al., 2015).

Cognitive load theory suggests that factors that make learning more complex or distract an individual from paying attention add to the ability to process information (Sweller, 1988).

Cognitive load theory describes two aspects of load on an individual, intrinsic, and extraneous. Intrinsic cognitive load is the elements within a task which determine the complexity of the task. The degree to which these elements interact is thought to determine the amount of intrinsic cognitive load. If there is a low level of interactivity between the elements within a task then there is a low cognitive load, whereas if there is a high level of interactivity then there is high cognitive load. Therefore, mathematical performance tasks with low cognitive load will be those where the numbers are easily learnt and applied to find a solution. Alternatively, mathematical performance tasks with high cognitive load will involve numbers and procedures that need to be understood before they are applied to find a solution e.g., two- and three-digit numbers with carrying (Ashcraft & Kirk, 2001). Whereas extraneous cognitive load are the demands imposed on the task, which distract and make the task more complex.

Alternatively, the wide variation in ability might be linked to other individual differences such as gender or age. Thus, it is important to explore the following questions, whether a child's gender or age have a significant effect on their mathematical performance.

2.2.1. Gender differences:

One key individual difference is the effect that gender has on mathematical performance. Popular culture suggests that mathematics is a subject that males achieve more in than females (Beasley & Fischer, 2012; Dowker, 2019a). Whilst the evidence from research is inconclusive with some researchers suggesting a difference in mathematical performance by gender (Ali, 2002; Ganley & Lubienski, 2016; Hyde et al., 1990). This gender difference has been linked to the type of mathematical performance, in that males have been found to be better at problem solving and spatial skills in mathematics (Ganley & Lubienski, 2016; Hyde et al., 1990). While others suggest that there is no difference (Devine et al, 2012), supported by research findings of similar development of mathematics skills of children aged six to nine for male and female children (Kikas, Peets, Palu, & Afanasjev, 2009; Lacahance & Mazzocco, 2006).

Within the UK, National Testing suggests that the gender difference is linked to ability in mathematics, where males achieve better at the higher grades. Evidence from recent Key Stage two results for 2017, indicated there was no gender differences for children reaching the expected standard in mathematics, but there were gender differences for those children working at greater depth, where boys (24%) achieved better than girls (21%) (Department of Education, 2017). This pattern between male and female achievement is reflected in the UK'S GCSE results, where in 2018, males achieved more of the top grade nine awarded in mathematics than females (Department for Education, 2018). Other researchers in the United States have highlighted similar gender differences in mathematical performance, where more males were performing in the higher achievement bracket (Ali, 2002).

This difference in performance has been linked to the psychological factors such as attitudes and anxiety towards mathematics. Research has found that females have more negative attitudes than males towards mathematics (Ali, 2002; Hyde et al., 1990; Wigfield & Meece, 1988). Similarly, research has found that females experience more anxiety around mathematics than males (Ashcraft & Faust, 1994; Devine et al., 2012; Else-Quest et al., 2010, Hembree, 1990; Leferve, Kulak, & Heymans, 1992; Wigfield & Meece, 1988).

Gender differences have been linked to social factors, namely encouragement from parents and teachers around performance in mathematics. Girls have been found to be more susceptible to influence from their parents and teachers around their ability in mathematics (Ali, 2002). Explanations for these differences in performances have been linked to stereotypical threat, this is where individuals assume that individuals within their own group perform less well than others from another group (Beilock et al., 2007; Dowker et al., 2016; Spencer, Logel & Davies, 2016). In this case the belief that females perform less well in mathematics than males (Beilock et al., 2007; Schmader, 2002).

Research evidence above indicates differences in the effect of gender on mathematical performance. There is also a lack of females entering careers with STEM subjects (Makarova, Aeschlimann & Herzog, 2019). In 2015 women made up only 14.4% of the STEM workforce in the UK (Wise campaign, 2020). Therefore, the effect of gender continues to be of importance to researchers, educationalists, and business leaders.

2.2.2. Age differences.

Another important individual difference in mathematical performance is age. Mathematical performance increases with age due to the development of mathematical skills, knowledge and understanding (Kikas et al., 2009). Children's mathematical abilities are fostered and developed through the hierarchical curriculum they experience at school (Hart, 1981). In the UK this curriculum is spiral in nature as year on year the children meet the same mathematical themes, number and place value, number operations (addition, subtraction, multiplication and division), fractions, measurement, geometry and statistics (Bruner, 1960; DFE, 2014). The hierarchical part introduces children to age-appropriate mathematical concepts and procedures, whilst the spiral curriculum ensures that all the key concepts and procedures are revisited at each age. (Clements & Sarama, 2009).

Age differences can manifest in the types of strategies that children and young people and adults use to solve mathematical problems (Uittenhove & Lemaire, 2016). One of the earliest strategies used to support mathematical performance is that of counting using fingers, this is evident in young children who are learning one-to-one correspondence of number (Andres & Pesenti, 2016).

The strategy of counting with fingers usually declines as children become more confident with number and rely on automatic retrieval of learnt facts (Meyer et al., 2010). This strategy is thought to slow down the response time of solving problems through the physical action of counting each finger in turn (Imbo, Vandierendonck, & Fias, 2011). Whereas older children, young people and adults are thought to solve problems quicker due to their use of more efficient strategies, e.g., fact retrieval (Kaye, Post, Hall & Dineen, 1986). Although the use of finger counting has been found to persist in some adults (Smith-Chant & Le Fevre, 2003).

As indicated before, children develop their mathematical skills, knowledge and understanding at different rates and therefore children might be the same age as their peers but be at a very different level of mathematics (Brown et al., 2003). This developmental difference can be seen in the significant differences found in the developmental trajectories of children's mathematical performance over time (Jordan, Mulhern, & Wylie, 2009).

The range of individual differences in mathematical ability in children is substantial and this range can last into adulthood (Smith-Chant & LeFevre, 2003). Age and gender are not the only differences in individuals that can be linked to mathematical performance, there are other emotional and cognitive factors that researchers have shown are linked to mathematical performance.

2.3. Emotional Factors.

Mathematical performance is influenced by children's general anxiety, how they feel about mathematics and what emotions undertaking mathematical tasks invokes in them. Some of these include attitude to mathematics, interest in mathematics, self- efficacy or self-concept about mathematics and motivation, which are all thought to have a positive association with mathematical performance. In this thesis two emotional factors were considered namely general anxiety (Trait and State anxiety) and interest in mathematics in addition to mathematical anxiety.

2.3.1. General Anxiety

General anxiety is thought to be a multi-dimensional construct composed of a stable element namely Trait anxiety and a transitory element namely State anxiety (Speilberger, 1966). For individuals with anxiety their academic and every day performance is affected by their anxious thoughts. Trait anxiety has been defined as a stable form of anxiety which demonstrates an individual's susceptibility to anxiety. Individuals report their trait anxiety as how they generally feel on a day-to-day basis (Speilberger, 1966). Whereas State anxiety has been defined as a form of anxiety that fluctuates over time dependent on the circumstances and is thought to be transitory (Speilberger, 1966). Therefore, individuals report their state anxiety dependent on the circumstances at the present time, where some situations appear to provoke more anxiety than others. Studies have found that the variance in State Anxiety is predicted by environmental factors (Legrand, McGue, & Iacono, 1999) such as situational stressors.

Researchers have demonstrated a link between general anxiety and underperformance in mathematics in college students (Aronen, Vuontela, Steenari, Salmi, & Carlson, 2005). A review of eight studies investigating the relationship between Trait anxiety and problem-solving ability concluded that there was a negative association between the two (Heppner, Witty & Dixon, 2004). Grezo & Sarmany-Schuller, (2018), replicated these results and found a similar negative association between trait anxiety and perceived problem-solving ability. All these studies were carried out with college students, and it can only be assumed that there is the same negative association with children as there are no equivalent studies using children as participants.

A subset of State anxiety is Test anxiety, which is described as a fear of testing and provides an indication of an individual's worry over assessment and test situations (Putwain, 2008a). It has been linked to the performance of individuals during testing of reading, writing and mathematics (Putwain, 2008b). Equally, test anxiety has been linked to underperformance on standardised tests (Everson, Millsap & Rodigues, 1991; Segool et al., 2013). It appears that individuals who are highly anxious are unable to control their worrying thoughts under assessment or testing situations. As, the delivery of the tasks was carried out not under testing conditions (see chapter 3), a measure of test anxiety was not felt appropriate within this thesis.

As Trait and State anxiety are thought to have a negative association with mathematical performance (Aronen et al., 2005; Heppner, Witty & Dixon, 2004; Grezo & Sarmany-Schuller, 2018) and have been found to disrupt learning and performance (Moore, Rudig & Ashcraft, 2015), consideration was given to their effect on mathematical performance (see chapter 3).

2.3.2. Interest in mathematics

Interest can be defined as a preference for a subject (Jones, Wilkins, Long & Wang, 2012) and is demonstrated through self-reporting of accessing activities linked to the subject academically and in the real world, e.g., liking and enjoying that subject. Interest in a subject is described as the ability to select appropriate strategies and deepen understanding (PISA, OECD, 2003). This interest in academic subjects starts very early at the beginning of a child's school journey (Lerkkanen, Kiura, Pakarinen, Viljaranta, Poikkeus, Rasku-Puttonen, Siekkinen, & Nurmi, 2012). Previous research has identified interest as a variable that can guide attention (Renninger & Hidi, 2011), one that facilitates learning in different content areas (Renninger & Hidi, 2002) and one that supports achievement in that subject (Hidi & Renninger, 2006; Scheifele, 1991).

Interest in mathematics, is the expression of enjoyment for learning mathematics. This in turn leads to greater performance in the subject. It is an emotional factor in that positive experiences activate more interest (Pekrun, 2006), positive feedback leads to greater interest (Deci & Ryan, 1985) and negative experiences reduce interest (Frenzel, Pekrun, Dicke & Goetz, 2002).

Studies looking at the relationship between interest in mathematics and mathematical performance have found there to be a positive relationship. A greater interest in mathematics leads to greater mathematical performance from pre-schoolers (Fisher, Dobbs-Oates, Doctoroff & Arnold, 2012) to adolescents (Moore, Rudig & Ashcraft, 2015). Findings suggest that it is the positive activating emotion of enjoyment of a subject in pre-schoolers, that leads to a positive relationship between mathematical skills and early mathematical interest (Fisher et al., 2012) and the development of early arithmetic skills (Gottfried, 1990). Equally this positive relationship between interest and mathematical performance has been found in older children (Ahmed, Van der Werf, Kuyper & Minnaert, 2013; Frenzel, Goetz, Pekrun, & Watt, 2010) and adolescents (Moore, Rudig & Ashcraft, 2015) (see chapter 8 for more detail)

This review of previous literature demonstrates that interest in mathematics associates positively, whilst Trait and State anxiety associate negatively with mathematical performance. Therefore, if children have a better interest in mathematics and less Trait and State anxiety, the expectation would be that their mathematical performance improves.

2.4 Cognitive Factors.

Mathematical performance is not only influenced by emotional factors but by a child's cognitive factors. The following three cognitive factors, non-verbal intelligence, working memory and reading ability were considered as part of this thesis.

2.4.1 Non-verbal Intelligence

Intelligence has been studied by many researchers and defined in many ways. Catell and Horn (1978), proposed a model which divided intelligence into two different factors namely crystallized or fluid intelligence. Crystallised intelligence is thought to be the intelligence gained through education and age, which is regarded as a person's ability in language and knowledge (Ceci, 1991). Fluid intelligence is thought to be the intelligence connected to abstract thinking and reasoning (Sternberg, 2008). This form of intelligence is thought to be a pre-requisite ability for mathematics (Kyttala & Lehto, 2008). Previously researchers have used measures of general intelligence, which were found to be predictors of mathematics achievement (Deary, Strand, Smith, & Fernandes, 2007; Geary, 2011; Hale, Fiorello, Kavanaugh, Hoeppner & Gaither, 2001). In particular, fluid intelligence was found to be important in mathematical skills (Floyd. Evans, & McGrew, 2003).

Fluid intelligence as a measure of a child's non-verbal intelligence, is measured through children's ability to demonstrate their nonverbal reasoning during a test. Raven's Coloured Progressive

Matrices (Raven, Court & Raven, 1992), is a test that measures non-verbal intelligence. This test requires children to work through a booklet containing a series of matrices. These matrices or geometric patterns are incomplete, and the children must select the missing piece from a selection of six possible correct answers. Therefore, children need to demonstrate their fluid reasoning (intelligence) in their ability to identify the rule or trend that the pattern/matrix follows and choose the correct missing piece (Green, Bunge, Chiongbian, Barrow & Ferrer, 2017). This ability in fluid reasoning is thought to be vital in the development of mathematical skills (Kyatta & Lehto, 2008).

Children's non-verbal Intelligence has been found to be a strong predictor of mathematical performance (Fuchs, Fuchs, Hamlett, Lambert, Stuebing & Fletcher, 2008; Gagne & St Pere, 2001; Kyttala & Lehto, 2008). Moreover, it has been found to be a strong predictor of performance in National Standardised testing (Carmicheal, MacDonald, & McFarland-Piazza, 2014). Longitudinal studies provide evidence of how non-verbal intelligence is a predictor of later mathematical performance. Green et al., (2017) investigated which factors might affect future mathematical performance with children and adolescents ranging from age six to twenty-one. They found that fluid reasoning was the only predictor of future mathematical achievement. Mathematical achievement in this study was measured through tasks relating to number, applied problems and fluency. Nunes, Bryant, Evan, Bell, Gardner, Gardner & Carraher, (2007), investigated logical abilities in six-year-old children and found that they were a strong predictor of their SATs mathematical scores sixteen months later. Mathematical achievement in the Nunes et al., (2007) study was the children's SATs scores at the end of Key stage one. Therefore, non-verbal intelligence as a measure of fluid intelligence is an important factor to consider when looking at children's mathematical performance and for that reason has been included within this thesis (see chapter 3).

2.4.2 Working memory.

Another important cognitive factor is memory and in particular how memory is activated at the time of solving mathematical problems (Cooney & Swanson, 1990). Working Memory is thought to be the part of one's memory that allows individuals to temporarily hold information needed to perform cognitive tasks (Baddeley, 2010). Importantly it allows the holding of this information whilst an individual processes other information (Baddeley, 1986a). Working memory is thought to be activated when individuals are engaged in complex thinking tasks that require an element of reasoning and comprehension (Baddeley, 2010). Many researchers have applied models to describe how working memory works.

The most widely used model in research is the multi-component model (Baddeley, 1986b). This model conceptualises working memory as a system of temporary storage buffers into which the information needed to complete tasks is delivered through an individual's perceptual processes (Baddeley, 2010). It separates working memory into three components, the central executive, the phonological loop, and the visuospatial sketchpad. The central executive is thought to be a form of high-level attentional control system which manages the flow of information through the working memory. This is thought to be the part of working memory which makes the whole system work. The central executive is thought to have functions such as switching, updating and inhibition (Baddeley, 1996). The other two domain specific components the phonological loop and the visuospatial sketchpad are thought to be involved with the storage and manipulation of verbal/acoustic material and visual information respectively. A fourth component namely the episodic buffer (Baddeley, 2000) is thought to be involved with integrating information from the components of working memory with long term memory. The episodic buffer is thought to provide the link between the components and long-term memory (Baddeley, 2010).

This is just one interpretation of working memory and other researchers have developed their own models to describe the functions of this type of memory. These models are different to Baddeley's 2010 model of working memory in that they are unitary models, therefore not identifying different components. One such unitary model describes working memory as a limited attentional resource, (Engle, Kane, & Tuholski, 1999) in that it provides a system to control and allocate attention when individuals are completing complex tasks (Raghubar et al., 2010). The attention resource is described as where memories are held in a highly active state even when there is considerable interference (Kane & Engle, 2002). Another unitary model proposes that working memory is not an entity on its own but rather an activated component of long-term memory (Cowan, 2005). That the memory activation occurs within the long-term memory, but that this activation is only temporary and fades quickly unless an individual continues to attend or uses a strategy of verbal rehearsal (Cowan, 2005). Therefore, it is a transient memory in comparison to the unlimited store of long-term memory (Cowan, 2014).

Another unitary model described working memory as a limited capacity system (Case et al., 1982, Just & Carpenter, 1992). This model suggests that working memory provides a mental workspace which enables the processing and storage of information needed to complete mental arithmetic problems (Just & Carpenter, 1992).

2.4.2.1 Operationalisation of working memory.

As past research consistently indicates a positive association between mathematical performance and working memory. This thesis incorporates working memory within the design, using Engle's (Engle, Kane & Tuholski, 1999) unitary model of working memory. Working memory within this thesis is operationalised using the operation span task, a task designed to elicit a participant's attentional focus for the cognitive tasks whilst being distracted by a secondary task. Operation span was devised to provide a measure of working memory that combines manipulation of both numerical and verbal information at the same time (Peng, Nanking, Barnes & Sun, 2016). It requires children to solve simple one-digit addition and subtraction arithmetic questions (e.g., 7+3, 9-8), whilst remembering simple words (e.g., me, and, about) which follow on from each arithmetic question. These sequences of arithmetic tasks and to be remembered words are presented in increasing sets of 2, 3, 4 and 5 at a time. Operation span requires both the maintenance and manipulation of information, which are required during arithmetical tasks especially word problem solving. This therefore simulates mathematical complexity that children experience when solving word problems. As they are required to solve the arithmetic questions but equally retain the verbal information to be recalled after solving all the arithmetic questions in the sequence.

2.4.2.2 Executive Functions:

This ability to focus attention on a number of items within one's working memory is needed to control and direct an individual's attention to solve mathematical problems can also be described as the ability to carry out executive functions such as switching or shifting, updating and inhibition. Executive functions have an important role to play in mathematical performance, Baddeley's 1996 model of working memory describes the central executive component as the control part of the system, with functions such as switching, updating and inhibition. Switching or shifting is described as the ability to switch attention between different responses whilst solving complex tasks (Miyake et al., 2000). In mathematical tasks this skill is particularly important as children need to be able to switch between the numbers, operations, and strategies in order to find a solution (Andersson, 2008, Bull & Scerif, 2001). Word problem solving is an example of a task that requires switching/ shifting especially when the problem involves a series of steps to find a solution. As children need to achieve a series of correct answers to arrive at the final solution. The intermediate answers will need to be stored within their working memory. Updating is described as the ability to monitor and revise active information within working memory (Miyake, et al., 2000). Researchers have indicated that this ability is strongly related to mathematical performance (Bull & Scerif, 2001; Passolunghi et al., 2008) and to the longitudinal growth in mathematical performance (Van der Ven, 2012). The ability to keep track of intermediate answers when solving mathematical problems and self-correct these answers are important in finding a solution in multi-step problems. Inhibition is the ability to reject irrelevant information in favour of relevant information in complex task (Miyake et al., 2001). The importance of this in mathematical tasks is a child's ability to decide the correct operation to solve a problem through checking all the positive operations and rejecting them in favour of the correct one. This can be seen in mathematical problem solving where children need to suppress their inclination to use an easier operation in favour of a more efficient operation e.g., suppressing addition in favour of multiplication. An example of a word problem that could be solved using either addition or multiplication There are **4** boxes with **5** pencils in each box. How many children will get a pencil? In addition, children would do 5 + 5 + 5 + 5 = 20 in multiplication children would do 4 x 5 =20.

2.4.2.3 Executive functions and mathematics.

Thus, within the thesis executive functions within mathematical problems are an important consideration as they are thought to be important predictors of children's mathematical performance (Bull & Scerif, 2000). Importantly, children aged from eight to twelve with a higher central executive capacity have been found to be able to retrieve simple addition facts faster than children with lower capacities (Barrouillet & Lepine, 2005: Imbo & Vandierendonck, 2007). Also, the central executive functions are thought to be important in word problem solving (Passolunghi, Cornoldi & Deliberto, 1999; Passolunghi & Pazzaglia, 2004; Passolunghi & Siegel, 2001). Therefore, the measure chosen was operation span (Swanson, Kehler & Jerman, 2010; Swanson, Lee, Kehler, & Jerman, 2010), as a measure of children's central executive functions of working memory. As operation span requires the participants to switch between the arithmetic question and remembering the words, update as they keep the words in their working memory and inhibit as they need to forget the arithmetic questions once solved.

2.4.2.4 Working memory and mathematics.

Equally working memory has an important role within mathematical development and achievement. It has been found to be important in many different areas of mathematical performance. In multi- digit arithmetic performance, working memory is needed, especially when there is an element of carrying to reach the solution, as this is thought to add another step in solving the problem. (Ashcraft & Krause, 2007). In word problem solving performance working memory is needed to store the intermediate answers in solving a multi-step word problem (Ayres, 2001; Raghubar, Barnes & Hecht, 2010; St Clair, Thompson & Gathercole, 2006).

Working memory has been found to correlate positively with mathematics achievement (Bull & Lee, 2014; Friso-van den Bos, van der Ven, Kroesbergen, & van Luit, 2013; Geary, Brown & Samaranayake, 1991; Passolunghi & Siegel, 2004; Wilson & Swanson, 2001). In particular there are positive associations between working memory and mental arithmetic (Caviola, Mammarella, Cornoldi & Lucangeli, 2012, Korhonen, Nyroos, Jonsson & Eklof, 2017). It has also been found to influence the performance and acquisition of arithmetical knowledge (Imbo & Duverne, & Lemaire, 2007; Imbo & Vandierendonck, 2007). Conversely individuals who have low working memory scores have been found to have low performance scores on arithmetic word problems (Swanson & Sachse- Lee, 2001).

2.4.2.5 Working memory and high stakes testing.

Importantly for this thesis is the research studying the relationship between working memory and the performance of children in the National Standard Attainment Tests in the UK. Researchers have found that verbal working memory skills are predictive of attainment in the National Tests (Gathercole & Pickering, 2000; Gathercole, Pickering, Knight, & Stegmann, 2004; Holmes & Adams, 2006; Jarvis & Gathercole, 2003). Gathercole and Pickering (2000) investigated how children with low achievements in National Standard Attainment Tests would perform on working memory tasks. They used a test battery of tasks designed to measure each component of the Baddeley and Hitch's 1974 model of working memory, namely the central executive, phonological loop, and visuo-spatial sketchpad. They concluded that a child's working memory skills could be linked to a child's academic progress in school. They concluded that it was the central executive component which had the highest association with achievement. Jarvis and Gathercole (2003) found that verbal and nonverbal working memory central executive tasks were associated with performance in National Curriculum tests scores in school year six (children aged ten to eleven). Gathercole et al., (2004) set out to look at the association between working memory and performance in the National SATs tests in school year two (children aged six to seven). They looked at the association between the children's achievements in their SATs at school year two (children aged six to seven) and their performance on working memory measures in school year three (children aged seven to eight). They found that the children's attainment levels were significantly associated with their performance on complex span tasks, specifically aimed at assessing the central executive component of working memory. Holmes and Adams (2006) investigated the relationship between all three components of working memory and children's performance on national standard attainment tests in school year three (children aged seven to eight) and school year five (children aged nine to ten). These national tests were for optional use by schools as a means of end of year assessment. They found that all three components of working memory significantly predicted the performance on the standard attainment tests of both year groups. Their results also indicated that the relationship between working memory and mathematical performance was stronger with the visual-spatial sketchpad component for younger children, whereas for the older children it was the phonological loop component. They explain this due to the different strategies used by children in school year three (children aged seven to eight) and school year five (children aged nine to ten). The older children relying more on verbal code strategy for their mental arithmetic (Deheane & Cohen, 1995), while the younger children rely on their early visual encoding strategies (Holmes & Adams, 2006).

Researchers in other countries have also looked at the association of working memory and mathematical performance in high stakes testing. Sweden as a country introduced National testing as a means of improving their mathematical performance after a negative trend in the International Tests, (TIMSS, 2007, Gonzales, Williams, Jocelyn, Roey, Kastberg, & Brenwald, 2008; TIMSS, 2011, Provasnik, Kastberg, Ferraro, Lemanski, Roey, & Jenkins, 2012). A small scale, study of forty Swedish children aged eight to nine reported that working memory predicted overall maths ability and that working memory contributed most to basic mathematical competencies. (Nyroos & Wilkun-Hornqvist, 2012). A further large-scale study comprising five hundred and ninety-seven Swedish children aged eight to nine, investigated the relationship between working memory and the mathematical performance in National Tests. (Wilkund-Hornqvist, Jonsson, Korhonen, Eklof, & Nyroos, 2016) They reported a positive relationship between working memory and National Curriculum tests similar to studies in the UK (Jarvis & Gathercole, 2003; Gathercole et al., 2004). Another study has investigated the relationship between working memory and mathematical skills (Alloway & Passolunghi, 2011) of Italian children. They used a National standard test of mathematical skills with children of seven and eight years of age and found that working memory scores could predict the mathematical skills and arithmetic ability of these children.

2.4.3 Reading

Another important cognitive factor linked to mathematical performance is a child's reading ability. Reading is a complex cognitive process that requires the integration of several cognitive skills in order to decode symbols and derive meaning from written texts (DFE, 2013a). The two main components of reading are thought to be word recognition (symbols) and comprehension (meaning) (DFE, 2013a). One researcher outlined three types of cognitive skills that are needed to enable children to read, pictorial processing, verbal processing, and attention (Mackworth, 1972). Mathematics is a form of language with specific symbols and being able to read, interpret and understand this symbolic language is an important skill in learning about mathematics (Adams, 2003; Krutetskii, 1976). As reading and mathematics are thought to need similar cognitive processes including processing symbolic information, attention, working memory and executive functions of control (Ashkenazi & Danan, 2017), children need to develop both skills simultaneously. The two skills become ever more linked as children progress through formal education, the reading requirements of mathematics tasks such as arithmetic and word problems increases (Dowker, 2016). Previous research has supported this linkage with reading ability (Fuchs, Geary, Fuchs, Compton & Hamlett, 2016; Kail & Hall, 1999), reading comprehension (Fuchs et al., 2006; Thevenot & Barrouilett, 2015; Zheng, Swanson, & Marcoulides, 2011), vocabulary (Alloway & Passolunghi, 2011; LeFevre et al., 2010) and verbal ability (Durand, Hulme, Larkin &

Snowling, 2005; Hooper, Roberts, Sideris, Burchinal & Zeisel, 2010; Jordan, Wylie & Mulhern, 2010; Kikas et al., 2009; Pupura, Hume, Sims & Loniga, 2011) all being linked to good mathematical performance. Equally measures of reading ability are also found to correlate with mathematics achievement, often above and beyond the influence of intelligence and working memory (Fuchs et al., 2016; Grimm, 2008; Korpipaa, Koponen, Mikko, Tolvanen, Aunola, Poikkeus, Lerkkanen, & Nurmi, 2017). Reading ability has been linked to the different types of mathematical performance including single digit arithmetic (LeFevre et al, 2010; Simmons, Singleton & Horne, 2008), calculation (Andersson, 2008) and problem solving (Fuchs et al., 2006).

Research evidence has generally concluded that reading has a positive relationship with mathematics performance (LeFevre et al., 2010; Purpura & Ganley, 2014), with language ability facilitating the development and use of mathematical concepts (Gelman & Butterworth, 2005). Although there is no clear indication of the causal nature of this relationship (Gelman & Butterworth, 2005), similarities in development of both skills may provide an indication of the close relationship between arithmetic and reading skills (Kohonen et al., 2016). As the early stages of development in both reading and mathematics have a similar element of one-to-one correspondence. In reading children are learning the phonemic assembly of letter to sound. In mathematics they are learning the one-to-one coding of number to word. Therefore, skill in reading ability may help and support skill in the mathematical ability. Another important link between reading and mathematical ability is the fact that it has been found that arithmetical facts learnt by children are stored in a "verbal code" (Deheane, Piazza, Pinel, & Cohen, 2003). As arithmetical fact retrieval has been linked to the children's phonological awareness, their ability to segment and work with speech sounds. Research carried out on children with reading difficulties (Simmons & Singleton, 2009; Turner-Ellis, Miles & Wheeler, 1996), found that fact retrieval is a particular difficulty for children with reading difficulties. As children with reading difficulties appear to have difficulty with tasks of mathematical fluency, where they need to retrieve simple addition, subtraction, multiplication facts from memory quickly (Gobel, 2015). Children with good reading ability perform well in mathematics tests. Reading requirements are thought to be higher in formal mathematics tasks taught at school such as arithmetic and word problems (Dowker, 2016). In studies that use standardised mathematical tests rather than experimenter created mathematical tests, older children's verbal skills were found to be important in their mathematical performance (Alloway & Passolunghi, 2011; Jordan, Wylie & Mulhern, 2015). This shift in increasing need for more verbal skills to perform better at mathematics has been linked to change from informal to formal mathematics curriculum through school (Jordan, Wylie, & Mulhern, 2015). Conversely, for children with language difficulties, they encounter more difficulties in understanding mathematical language, changing the association between reading ability and mathematical performance to a negative one (Dowker, 2019b). A lack of verbal skills has been found to have a negative association with their mathematical development (Jordan, Kaplan & Hanich, 2002). This negative association may not be for all aspects of mathematical development but may be more specific. A longitudinal study of children with language difficulties found that they were poorer at verbal counting and calculation two years later than their age matched controls (Fazio, 1994). Other researchers have found that verbal weaknesses in children have negative relationships with two forms of mathematical tasks, word problem solving and mathematical fluency. Children with language difficulties also appear to have memory issues and it may be this link that is why they do not perform as well as children without language difficulties in mathematical fluency tasks (Grauberg, 1998). As to achieve in mathematical fluency you need a good memory for the mathematical facts. When the mathematical tasks that children are asked to perform are word problems (Jordan, Kaplan & Hanish, 2000; Jordan & Montani, 1997), performance in children with verbal weaknesses is lower than those without language difficulties.

From past research which has consistently indicated a positive association between mathematical performance and reading, a measure of reading ability was included within the design of this thesis. The measure chosen to assess the reading ability of the children used was the single word reading subtest of the York Analysis of Reading Comprehension (YARC: Snowling et al. 2009) as an indication of each child's reading ability over time (see chapter 3 for more details).

This review of previous literature demonstrates that non-verbal intelligence, working memory and reading all associate positively with mathematical performance. Therefore, if children have a better non-verbal intelligence, working memory and reading ability the expectation would be that they perform better in mathematics.

2.5. Importance of measures in understanding the relationship between mathematical anxiety and mathematical performance.

A key element within this thesis, is the relationship between mathematical anxiety and mathematical performance of children over time. Previous research looking into the effect of mathematical anxiety in children have suggested that it is significantly negatively related to mathematical performance (Carey, Devine, Hill & Szucs, 2017b; Cargnelutti, Tomasetto, & Passolunghi.,2017; Devine et al., 2012; Harari et al., 2013; Hembree, 1990; Ma, 1999; Ramirez et al, 2013; Ramirez et al., 2016; Sorvo et al., 2017; Wu et al., 2012; Zhang, Zhao & Kong, 2019) whilst others suggest that there may not be a significant relationship between mathematical anxiety and mathematical performance (Devine, Hill, Carey & Szucs, 2018; Haase et al., 2012; Hill et al., 2016; Krinzinger et al., 2009; Thomas & Dowker, 2000; Wood et al., 2012). This previous research into the relationship between mathematical anxiety and mathematical performance has sparked a debate as to why different studies achieve different results. A number of reasons have been suggested including the particular type of mathematics that children are asked to perform, whether this is simple arithmetic questions (Krinzinger et al., 2009; Thomas & Dowker, 2000) or more complex word problems (Ramirez et al., 2013; Ramirez et al., 2016; Wu et al., 2012). The condition under which the mathematical performance is assessed whether children are given as much time as they need to complete the questions (Haase et al., 2012) or are given a time limit (Harari et al., 2013; Sorvo et al., 2017). A final reason has been the different ways in which mathematical anxiety is conceptualised and measured (Sorvo et al., 2017). Studies which used measures that have been devised around assessing children's mathematical anxiety of failure in mathematics, e.g., whether they get the answer right or wrong, have found no relationship with mathematical performance (Haase et al., 2012; Krinzinger et al., 2009; Wood et al., 2012). Whereas studies which have used measures devised around mathematical anxiety in mathematical related situations, e.g. how they feel at solving mathematical problems or being in a mathematics situation, have found significant negative relationships with mathematical performance (Sorvo et al., 2017) Similarly, studies that have used measures that incorporate both anxiety about failure and mathematical related situations found significant negative relationship with mathematical performance (Harari et al., 2013; Jameson, 2013; Vukovic et al., 2013). Therefore, reviewing each of these different aspects will support the identification of the best measures and conditions to use to investigate the relationship between mathematical performance and mathematical anxiety within this thesis.

2.5.1 Mathematical performance measures.

The type of mathematical performance used within previous research has been identified as a significant factor in the relationship between mathematical anxiety and mathematical performance. The types of mathematical performance identified within studies ranges from simple arithmetic, complex arithmetic to word problem solving. This is further complicated by whether the mathematical problems include an element of carrying, the magnitude of the numbers and the number operation involved (i.e., addition, subtraction, multiplication, and division). From previous research three types of mathematical performance were identified that indicated significant relationships with mathematical anxiety, namely mathematical fluency (Sorvo et al., 2017; Vukovic et al., 2013), arithmetic (Haase et al., 2012) and word problem solving (Ramirez et al., 2013; Wu et al., 2012). Each of these three types of mathematical performance are discussed in more detail.

2.5.1.1 Mathematical fluency

Mathematical fluency is described as a child's ability to remember arithmetical facts and retrieve them from memory at speed. This is a frequent measure of mathematical performance in studies investigating the relationship with mathematical anxiety (Devine et al. 2012; Justica-Galiano, Martin-Puga, Linares, Pelegrina, 2017; Sorvo et al., 2017). One important aspect of mathematical fluency tests is that these are timed, children are given a specific time limit in which to complete as many correct answers as they can (Hulme, Brigstocke & Moll, 2016). Research has indicated that timed tests of mathematical fluency are thought to be one cause of early onset of mathematical anxiety (Boaler, 2014). As it appears that children experience more pressure when working at time compared to working without a time limit (Engle, 2002). Timed tests are used to encourage children to work quickly at mathematics and memorise number facts in the hope that they will perform better on mathematics tests (Boaler, 2014). This in fact can lead to increased mathematical anxiety and fear of mathematics which affects future performance in mathematical tests (Boaler, 2014).

Previous studies have found significant relationships between mathematical anxiety and measures of mathematical fluency. For example, Devine et al., (2012) in a study with children in years seven, eight and ten in secondary schools in the UK (children aged eleven to fifteen), used timed mental mathematics tests and found a significant correlation between mathematical anxiety and mathematical performance. Another study by Justica- Galiano, et al., 2017, used mathematical fluency tests with Spanish children aged from eight to eleven years of age, in these tests' children had to solve addition subtraction and multiplications within three minutes. They found that mathematical anxiety predicted the mathematical outcome. Equally, Sorvo et al., (2017) investigated the relationship between arithmetic fluency and mathematical anxiety in children aged seven to eleven years of age in Finland. They found that there was a significant negative relationship between arithmetic fluency and mathematical anxiety. All of the above studies were conducted using a cross sectional methodology as they compared children in different school year groups, and all found significant negative relationship between mathematical fluency and mathematical anxiety.

Alternatively, in a longitudinal study of German children aged from six to nine years of age, calculation ability was measured as children's ability to solve single digit addition and subtraction problems as quickly as possible (Krinzinger et al., 2009). The children were required to solve as many problems as they could within a minute and no correlation was found with mathematical anxiety. Whilst Sorvo et al., (2019), in another longitudinal study with Finish children aged from seven to eleven years of age found a significant negative relationship between mathematical anxiety and mathematical performance. Therefore, there appears to be a need for more studies using mathematical fluency as the measure of mathematical performance within a longitudinal methodology, to clarify the relationship between mathematical anxiety and mathematical performance.

2.5.1.2 Arithmetic

Arithmetic ability is described as a child's ability to perform number operations such as addition, subtraction, multiplication, and division (Dowker, 2015). Previous research has investigated the relationship between mathematical anxiety and mathematical performance using arithmetical problems with children (Dowker, Bennet, & Smith, 2012; Wood et al., 2012). The difference here from mathematical fluency is that the children are not timed whilst completing these arithmetic tasks. Dowker et al., (2012) used untimed basic arithmetic skills of UK children aged from eight to eleven to investigate the relationship between mathematical anxiety and mathematical performance. They found that there was no significant relationship. Another study with Brazilian and German children aged between seven and twelve, found no significant relationship between mathematical anxiety and written arithmetic calculations (Wood et al., 2012). This lack of a negative relationship may be linked to the magnitude, type of number and difficulty level within the arithmetic problems. Equally research with adults found no effect on whole number arithmetic problems but found significant anxiety effects when the problems introduced more complicated mathematical problems such as those involving numbers with decimals, fractions, percentages, and those with equations. (Ashcraft, Kirk & Hopko, 1998). Problems with a carry operation take longer to solve (Hunt & Sandhu, 2017) and as these problems use greater digit numbers (e.g., an arithmetic problem involving a two-digit by two-digit operation with a three-digit answer) an adult's mathematical anxiety affects the accuracy of their solution. Therefore, when using arithmetic problems evidence for a significant negative relationship between mathematical anxiety and mathematical performance has not been found. It is only when the arithmetic problems become more complex that evidence has found a significant negative relationship.

2.5.1.3 Word problem solving.

Word problem solving is where the arithmetical problems related to mathematical relations and properties are set within sentences constructed of words (Verschaffel, Schukajlow, Star, & Van Dooren, 2020). Researchers have investigated the relationship between mathematical anxiety and mathematical performance using word problems with children (Ramirez et al., 2013; Ramirez et al., 2016; Vukovic et al., 2013; Wu et al, 2012; Wu et al., 2014; Zhang et al., 2019). For example, Ramirez et al., (2016) investigated the problem-solving ability of children aged from six to eight years of age and found that mathematical anxiety was a significant predictor of mathematical performance in children with high working memory. Wu et al., (2012) investigated the problem -solving ability of children aged from seven to nine years of age using problems with complex verbal reasoning. Whilst Vukovic et al., (2013) investigated the ability of children aged from seven to nine years of age, to solve story problems. Both studies found that there was a significant negative relationship between mathematical anxiety and mathematical performance. In a recent meta-analysis, the largest effect sizes for the negative relationship between mathematical anxiety and mathematical performance was when the studies assessed children's problem-solving skills (Zhang et al., 2019). Therefore, in this thesis all three measures were used to assess children's performance (mathematical fluency, arithmetic, and word problems) in order to maximise the possibility of determining a relationship with mathematical anxiety. These measures were assessed under different conditions (see chapter 3).

Another aspect that researchers change when setting mathematical tasks for children is the condition under which they are asked to perform, e.g., whether the task is timed or untimed, whether the participants are asked to perform a concurrent task, whether the task is part of a high stakes testing situation or whether answers are given verbally or written.

2.5.2 Mathematical performance conditions.

To understand the effect of changing mathematical conditions on the mathematical anxiety of children cognitive load theory was considered (Sweller, 1988). As discussed earlier Cognitive load theory suggests that factors that make learning more complex or distract an individual from paying attention add to the ability to process information (Sweller, 1988). It describes these factors as intrinsic and extraneous. The extraneous cognitive load are the demands imposed on the task, which distract and make the task more complex. Therefore, the conditions under which mathematical performance is measured can be considered as extraneous cognitive load situations, e.g., adding a time pressure, or another task creating a dual task situation and the pressure of success. Each extraneous cognitive load will affect the mathematical performance especially in individuals with high levels of mathematical anxiety.

2.5.2.1. Timed tests.

Mathematical tasks completed under time pressure exerts an extraneous cognitive load which either affects the processing, decision making and selection of appropriate strategy to solve the task (Caviola, Carey, Mammarella, & Szucs, 2017b; Sweller, 1988) or uses up an individual's working memory because of their worrisome thoughts around actual performance (Ashcraft & Kirk, 2001)). Empirical evidence for this has been carried out with adults (Faust, Ashcraft & Fleck, 1996; Kellogg, Hopko & Ashcraft, 1999). Faust et al., (1996) required participants to solve whole number arithmetic problems under two conditions. Whole numbers are numbers with digits that are not expressed as decimals or fractions. The first condition was termed a high load condition, where they were asked to solve mathematical problems mentally in a timed test. The other condition was termed a low load condition, where they were asked to solve mathematical problems using a paper and pencil in an untimed test. The timed condition when participants were required to solve the problems mentally, triggered more effects of anxiety on the performance (Faust, Ashcraft & Fleck, 1996). Kellogg et al., (1999) investigated arithmetic performance of individuals with high and low mathematical anxiety with or without a time pressure. There was no difference in arithmetic performance for high and low mathematically anxious individuals, but the time pressure negatively affected their arithmetic performance (Kellogg, Hopko & Ashcraft, 1999). Hunt and Sandhu, (2017), add to the evidence on time pressure through the novel use of two types of time pressure, a time limit, or the presence of a clock in the room. They found that the error rates of individuals with high mathematical anxiety was significantly higher for problems with an element of carrying under time pressure. In testing with a clock in the room there was a negative effect in performance on the low mathematical anxiety individuals too. In all the studies the addition of a timed element has increased the effect on mathematical performance of individuals with high mathematical anxiety leading to poorer mathematical performance, as these individuals are more susceptible to the increased extraneous cognitive load.

In line with the adult studies, there have been studies with children where a time pressure has been applied (Cargnelutti et al., 2016; Devine et al., 2012; Sorvo et al., 2017, 2019; Vukovic et al., 2013). Some of these studies used measures of mathematical fluency where children are required to solve simple one-digit addition, subtraction, and multiplication problems mentally in a specified time. Significant negative relationships were found between mathematical anxiety and mathematical performance when the element of time was added (Cargnelutti et al., 2016Devine et al., 2012; Sorvo et al., 2017; Sorvo et al., 2019; Vukovic et al., 2013). All the studies found that when children were placed under a time pressure there was a significant negative relationship with mathematical performance.

Alternatively, not applying a time pressure seems to reduce some of the disadvantages for individuals with mathematical anxiety (Faust et al., 1996; Ashcraft & Kirk, 2001). It also allows for time to be spent deciding on the best strategy to solve a mathematical problem (Beilock & DeCaro, 2007; Heinz, Star, & Verschaffel, 2009). Within the thesis timed (Mathematical fluency) and non-timed (Arithmetic and word problem solving) conditions were used to vary the amount of extraneous cognitive load the children would experience.

2.5.2.2 Cognitive load.

Another form of extraneous cognitive loading on mathematical tasks is the adding of a simultaneous task to be remembered at the same time as solving the task. This has been investigated using a dual task paradigm, where individuals were asked to solve arithmetic problems under the carry and no-carry condition at the same time as remembering two letters (low cognitive load) or six letters (high cognitive load). They found that high mathematical anxiety individuals' performance was lower in the high cognitive load condition when the problems required a carrying element (Ashcraft & Kirk, 2001). The mathematical tasks as part of the thesis were not conducted under a dual task paradigm but the children were assessed on this through the measure of working memory used, e.g., operation span. Where children were asked to complete simple addition and subtraction problems whilst remembering an increasing number of words (see chapter 3 for more details).

2.5.2.3 High Stakes Testing.

High stakes testing, where pressure is applied for individuals to perform at a certain standard could be classed as another extraneous cognitive load. This pressure is applied at a school, teacher and individual level, as there is a substantial demand for individuals to perform well to reach the standard from their school and teachers (Connor, 2001; Connors et al., 2009; McDonald, 2001; Putwain et al., 2012; Tymms & Merrell, 2007; Ward & Quennerstedt, 2018). This increased demand could distract the individual and make the tasks more complex. This higher demand from teachers can then lead to children who are already anxious about their mathematical ability becoming more anxious as they try to achieve the standard. (Dowker, 2019a).

England has a high- stakes accountability regime within its education system which culminates in the KS2 SATS. But this is just the end of a series of testing that starts very early in the educational journey of English children as primary schools within the England carry out five statutory assessments. These statutory assessments start very early in Foundation 2 with the Early years Foundation stage profile (children aged 4 to 5) then moves onto the phonics screening check in year 1 (children aged 5 and 6). This is followed with the Key Stage 1 SATs in year 2 (children aged 6 and 7), with multiplication tables check in year 4 (children aged 8 and 9) and finally the key stage 2 SATs in year 6 (children aged 10 and 11). These high stakes regimes provides a distinctive context in which this thesis was carried out, the children within the thesis would have been made aware of their performance levels from a very early age. As the thesis tracked the mathematical performance of children through their year leading up to two of their high stakes tests namely the National Standard Attainment tests (SATS) in school years two and six, where pressure to achieve is prominent in primary schools.

2.5.2.4 Paper and Pencil.

One change in how children respond to mathematical tasks, in which intrinsic cognitive load could be reduced, is providing access to paper and pencil instead of children having to solve the problems mentally. This would reduce the cognitive load as intermediate elements of the problems could be written down reducing the need to store these intermediate elements within working memory (Gathercole & Alloway, 2007). This is thought to be especially the case in arithmetic problems that have an element of carrying within the solution (Ashcraft & Faust, 1994, Faust, Ashcraft & Fleck, 1996). As there is an increased need to store within the working memory the carrying numbers of the problem to reach the final solution. Thus, access to paper and pencil where the intermediate solutions can be written down reduces the intrinsic cognitive load. Therefore, two of the mathematical performance tasks (Arithmetic and word problem solving) in this thesis allowed children access to paper and pencil to reduce their intrinsic cognitive load and support their mathematical performance.

2.5.3 Mathematical anxiety measures.

The relationship between mathematical anxiety and mathematical performance is a complicated one with some research yielding a significant negative relationship (Carey, Devine, Hill & Szucs, 2017b; Cargnelutti et al.,2017; Devine, Fawcett, Szucs & Dowker, 2012; Harari et al., 2013; Hembree, 1990; Ma, 1999; Ramirez et al, 2013; Ramirez et al., 2016; Sorvo et al., 2017; Wu et al., 2012; Zhang, Zhao & Kong, 2019) and others finding weak or no relationship (Devine, Hill, Carey & Szucs, 2018; Dowker et al, 2012; Haase et al., 2012; Hill et al., 2016; Krinzinger et al., 2009; Thomas & Dowker, 2000; Wood et al., 2012). One aspect that researchers have suggested to explain these contradictory results is whether it is the measure of mathematical anxiety used. As explained in the previous chapter different measures are devised using the authors categorisation of the dimensions of mathematical anxiety. Therefore, the authors categorisation of mathematical anxiety can affect the relationship between mathematical anxiety and mathematical performance. Sorvo et al., (2017) categorise mathematical anxiety as anxiety about mathematical situations and anxiety about failure but only found a significant negative between anxiety about mathematical situations with arithmetic performance (Sorvo et al., 2017). Ho et al., (2000), categorised mathematical anxiety similarly as anxiety about mathematical situations and anxiety about failure but alternatively found a significant negative relationship with the affective component, anxiety about failure. Consequently, this is an important aspect to consider within any study on the relationship between mathematical anxiety and mathematical performance. In this thesis the Children's Anxiety in Maths Scale (Jameson, 2013a, 2013b) was used as the measure of mathematical anxiety. This categorises mathematical anxiety into general maths anxiety (e.g., When I solve maths problems, I feel), mathematical performance anxiety, (e.g., If I have to add up numbers on the whiteboard in front of the class, I feel) and math error anxiety (e.g., When I am working on maths problems that are difficult and make me think hard, I feel). Finally, it is worth considering how individual differences affect the relationship between mathematical anxiety and mathematical performance.

2.6 Individual differences affecting the relationship between mathematical performance and mathematical anxiety.

As both mathematical performance and mathematical anxiety are affected by individual differences e.g., age and gender, so is the relationship between mathematical anxiety and mathematical performance.

2.6.1 Age

Studies which have investigated the relationship between mathematical anxiety and mathematical performance have found stronger negative relationships with adolescents than with primary aged children (Zhang et al., 2019). Other authors have suggested that the negative relationship emerges in secondary schools (Ashcraft & Krause, 2007; Hill et al., 2016) due to the curriculum becoming harder and students need to engage more cognitively to succeed. Although as previously stated a significant negative relationship has been found in primary aged children (Devine et al., 2012; Harari et al., 2013; Ho et al., 2000; Ramirez et al., 2013; Ramirez et al., 2016; Sorvo et al., 2017; Vukovic et al., 2013; Wu et al., 2012, 2014). Therefore, it is important that research identifies the effects of mathematical anxiety on mathematical performance to identify how early in a child's life they begin to experience its effects. Equally what effect does a child's gender have on this relationship.

2.6.2 Gender.

There are conflicting findings around gender differences in mathematical anxiety although more studies suggest that females report more mathematical anxiety than males (Devine et al., 2012; Hill et al., 2016; Van Mier et al., 2018). For mathematical performance some studies (Ali, 2002; Ganley & Lubienski, 2016; Hyde et al., 1990) suggest that males perform better than females, although these differences are typically found in adolescents around problem solving elements of mathematical tests. (Hyde et al., 1990). A recent meta- analysis found no significant gender differences in the relationship between mathematical anxiety and mathematical performance, although this finding was from only seven studies out of the forty-nine studies reviewed (Zhang et al., 2019).

As stated earlier, mathematical performance will be measured through a combination of mathematical tasks to assess the development and individual differences in arithmetical knowledge in the children within this thesis. The following measures of mathematical performance were chosen for their similarity to measures that children were being asked to perform during their SATS. Mathematical fluency was chosen to provide an indication of the children's ability to remember arithmetical facts and retrieve them from memory at speed. Mathematical complexity was chosen to provide an indication of the children's ability to solve age-appropriate mathematical tasks. Mathematical complexity was divided into two separate tasks, the first a series of arithmetic numerical questions and the second a series of word problem questions. Mathematical complexity in the SATS is measured through the children in KS1 completing an arithmetic and reasoning paper, whilst the children in KS2 complete an arithmetic and two reasoning papers (STA, 2016) (see chapter 3). Mathematical anxiety will be measured using the Children's Anxiety in Maths Scale (Jameson, 2013a, 2013b) which categorises mathematical anxiety into general maths anxiety, math performance anxiety and math error anxiety This ensures that the children's anxiety about the actual mathematics, their performance and their error in mathematics is measured.

2.7 Chapter summary:

- Mathematical fluency was chosen to provide an indication of the children's ability to remember arithmetical facts and retrieve them from memory at speed.

- Mathematical complexity was chosen to provide an indication of the children's ability to solve age-appropriate mathematical tasks.

- Mathematical complexity was divided into two tasks, the first a series of arithmetic questions and the second a series of word problems (see chapter 3 for more detailed information on the specific mathematical tasks).

- Non-verbal intelligence, measured through the Raven's Coloured Progressive Matrices (Raven, Court & Raven, 1992), was chosen to provide an indication of the children's ability to reason and think logically.

- Working memory, as measured by Operation Span task (Swanson, Lee & Jerman, 2010), was chosen to provide an indication of the children's ability to ability to maintain and manipulate mathematical information.

- Reading, as measured by the single word reading subtest of the York Analysis of Reading Comprehension (YARC: Snowling et al. 2009), was chosen to provide an indication of the children's reading ability (see chapter 3 for the more detailed information on the specific tests).

- Interest in Mathematics, measured through the Student Interest in Mathematics Scale (Wininger, Adkins, Inman, &Roberts, 2014a, b), was chosen to provide an indication of how interested the children were in mathematics as a subject.

- Trait and State anxiety, as measured by the State Trait Anxiety Inventory for Children (STAIC) (Spielberger, Gorsuch, Lushene, Vagg, Jacobs, 1973), was chosen to give an indication of the children's general anxiety. The trait anxiety part of the test allows an indication of how anxious the children generally feel. The state part of the test allows an indication of how anxious the children feel at a particular point in time (see chapter 3 for the more detailed information on the specific tests).

- The relationship between mathematical anxiety and mathematical performance is thought to be a negative one, with children with mathematical anxiety not performing well on mathematical tasks.

- This relationship is dependent on several different factors:
    - Type of mathematical performance
    - Condition under which the mathematical performance is measured
    - Type of mathematical anxiety measure used.
    - Individual differences e.g., age and gender.

Chapter 3- Methodology.

Chapter contents:

In this chapter the design, methods and measures used within this longitudinal thesis are detailed within the following sections:

- Introduction
- Design
- Participants
- Ethics
- Key Measures
    - Mathematical Anxiety
    - Mathematical Performance
- Other measures
    - Emotional
    - Cognitive
- Procedure
- Testing timetable
- Data Analysis
- Chapter summary.

3.1 Introduction:

This thesis is a longitudinal multifactorial cohort study which was carried out to investigate the development of mathematical anxiety and the relationship between mathematical anxiety and mathematical performance. Importantly this relationship was studied during the period leading up to and after high stakes National Testing (see chapter two for more details). Moreover, emotional (State and trait anxiety and interest in mathematics) and cognitive (Non-verbal intelligence, reading and working memory) factors were taken into consideration.

Longitudinal studies allow investigators an opportunity to study the nature of growth, patterns of change and possibly the cause and effect of variables over time (Rajulton, 2001). They involve the undertaking of a series of repeated measurements of the same individuals over a time span of interest (Caruana, Roman, Hernandez-Sanchez, & Solli, 2015). The time span needs to be of a length of time where a detectable change in the variables can be safely assumed (Rajulton, 2001). Longitudinal designs are multi-level designs as they provide information at three levels. Level one, the behaviour of the variables at the cohort level over time. Level 2, the behaviour of the variables at the individual level over time and at Level 3, the outcome, relationships between variables over time. Therefore, a repeated measures longitudinal study was chosen as it enabled the analysis of change over time for mathematical anxiety and mathematical performance. It enabled the development and changes in the emotional, cognitive, and mathematical performance variables of these children to be studied at both group and individual levels. Two cohorts of children were targeted Year 2 (final year of Key Stage 1) and Year 6 (final year of Key Stage 2) within two primary schools in Nottingham and Nottinghamshire. These cohorts were specifically chosen as they were preparing for high stakes National testing (SATs). The exact timings of the studies were designed to follow the cohorts of children through this important time in their primary education. The first study was designed to be undertaken in the academic year before their Standard Attainment Tests (SATS), Year 1 and Year 5. The next three studies were to be undertaken during the SATS year. Study 2 at the beginning of the year. Study 3 just before the children took their SATS and Study 4 after the children had completed their SATs.

The key measures of mathematical anxiety and mathematical performance were carried out in all four studies. A number of other emotional and cognitive measures were carried out at time point one (year before the SATs) and time point three (just before the SATs) a year apart (see table 3.4) All measures (described below) used in the studies were chosen based on a review of previous research in this field, see introductory chapters for more detail.

Mathematical anxiety was measured by a self-report questionnaire designed to be used with children (Jameson, 2013a, 2013b). This questionnaire asked questions to determine the children's general mathematics, mathematics performance and mathematics error anxieties. Mathematical performance was measured in three ways to give a range of mathematical skills. Mathematical fluency, the ability of children to remember arithmetical facts and retrieve them at speed (Test of Basic Arithmetic and Numeracy Skills (TOBANS) Hulme, Brigstocke &Moll, 2016). Mathematical complexity the ability of children to solve age-appropriate mathematical SATs style questions (arithmetic and word problem solving). These two areas of mathematical performance (Fluency and complexity) were based on evidence from previous research that all these mathematical skills are affected by mathematical anxiety (see chapter two). Alongside these key measures it was felt that other measures needed to be considered to give a complete profile of the child. The Emotional measures chosen were State and Trait Anxiety (STAIC: Spielberger, Gorsuch, Lushene, Vagg, Jacobs, 1973), and Interest in Mathematics (Wininger et al. 2014a, 2014b). The Cognitive measures chosen were Non-verbal Intelligence (Raven, Court & Raven, 1992), Reading (YARC: Snowling et al. 2009), and Working Memory (Swanson, Kehler & Jerman, 2010; Swanson, Lee, Kehler & Jerman, 2010).

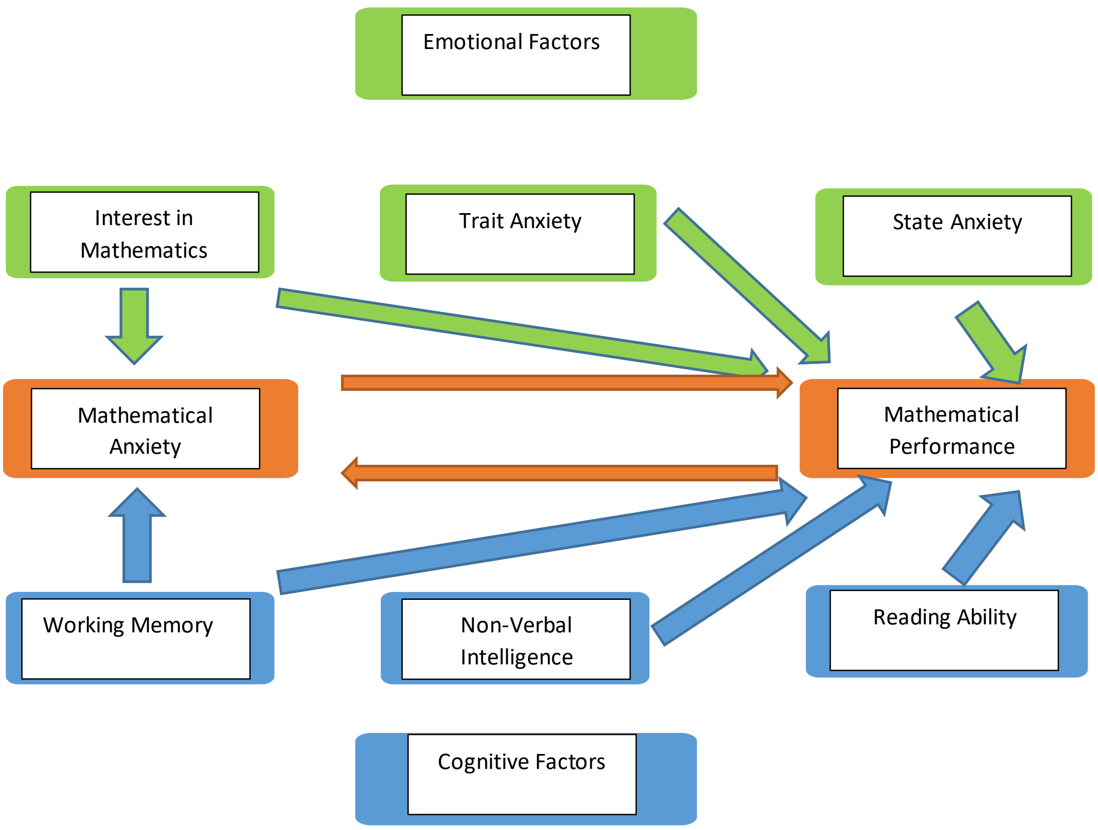

Figure 3.1: Model of the design of the thesis.

3.2 Design:

The design model for this thesis (see figure 3.1) provides a visual representation of the proposed associations between the different variables within the studies. This design model is used as a means to easier understand (Reese & Overton, 1970), the key relationship between mathematical anxiety and mathematical performance (Carey, Devine, Hill & Szucs, 2017b; Cargnelutti, Tomasetto, & Passolunghi.,2017; Devine, Fawcett, Szucs & Dowker, 2012; Harari et al., 2013; Hembree, 1990; Ma, 1999; Ramirez et al, 2013; Ramirez et al., 2016; Sorvo et al., 2017; Wu et al., 2012; Zhang, Zhao & Kong, 2019). This relationship is thought to be directional in nature as illustrated in figure 3.1, some researchers suggest that mathematical anxiety leads to poor mathematical performance (Carey et al., 2016; Hembree, 1990; Luo et al., 2014; Lyons & Beilock, 2012), whilst others suggest poor mathematical performance leads to mathematical anxiety (Maloney, 2016; Sorvo et al., 2019; Tobias, 1986). Alternatively, some researchers suggest that the relationship is more cyclical in nature, that mathematical anxiety impacts on mathematical performance which then in turn impacts on mathematical anxiety (Ashcraft et al, 2007; Carey et al., 2016; Foley, Herts, Borgonovi, Guerriero, Levine, & Beilock, 2017; Maloney & Beilock, 2012; Maloney, Ansari, & Fugelsang, 2011). The model reported above (see figure 3.1), also identifies the possible relationships between the emotional and cognitive factors on mathematical performance. The emotional factors of State and Trait anxiety are thought to have a negative effect on mathematical performance (Aronen et al., 2005; Heppner, Witty & Dixon, 2004; Grezo & Sarmany-Schuller, 2018). Whereas interest in mathematics is thought to have a positive effect on mathematical performance (Aunola, Leskinen & Nurmi, 2006, Gottfried, 1990; Koller, Baumert, & Schnebel, 2001; Marsh, Trautwein, Ludkte, Koller, & Baumert, 2005; Moore, Rudig & Ashcraft, 2015). As having an interest in mathematics has been found to have positive association with mathematical anxiety (Asif & Khan, 2011; Luo, Wang & Luo, 2009) and may even be a mediator/ moderator between the relationship between mathematical anxiety and mathematical performance (see chapter eight for more detail). All the cognitive factors (non- verbal intelligence, reading and working memory) are thought to have positive relationships with mathematical performance (see chapter two for more detail). Children's non-verbal intelligence has been found to be a strong predictor of mathematical performance (Carmicheal, et al., 2014; Fuchs, Fuchs, Hamlett, Lambert, Stuebing & Fletcher, 2008; Gagne & St Pere, 2001; Kyttala & Lehto, 2008). Children's reading ability (Fuchs, Geary, Fuchs, Compton & Hamlett, 2016; Kail & Hall, 1999), reading comprehension (Fuchs, Fuchs, Compton, Powell, Seethaler, & Capizzi, 2006; Thevenot & Barrouilett, 2015; Zheng et al., 2011), vocabulary (Alloway & Passolunghi, 2011; LeFevre, Fast, Skwarchuk, Smith-Chant, Bisanz, & Kamawar, 2010) and verbal ability (Durand, Hulme, Larkin & Snowling, 2005; Hooper, Roberts, Sideris, Burchinal & Zeisel, 2010; Jordan, Wylie & Mulhern, 2010; Kikas, Peets, Palu & Afanasjev, 2009; Pupura, Hume, Sims & Loniga, 2011) have all been linked to good mathematical performance. Working memory is thought to have a positive effect on mathematical performance (Bull & Lee, 2014; Caviola, Mammarella, Cornoldi & Lucangeli, 2012, Friso-van den Bos, van der Ven, Kroesbergen, & van Luit, 2013; Geary, Brown & Samaranayake, 1991; Imbo & Duverne, & Lemaire, 2007; Imbo & Vandierendonck, 2007; Korhonen, Nyroos, Jonsson & Eklof, 2017; Passolunghi & Siegel, 2004; Wilson & Swanson, 2001). Moreover, working memory is thought to have a role to play in the relationship between mathematical anxiety and mathematical performance, in that working memory is needed to solve mathematical tasks. That for individuals with high levels of mathematical anxiety, their anxious thoughts occupy their working memory, therefore affecting their mathematical performance (Ashcraft & Krause, 2007; Lyons & Beilock, 2012; Young, Wu & Menon, 2012) (see chapter two for more details).

These studies involved an independent measures design, where children (male and female) were sampled from two groups (Key Stage 1 and Key Stage 2).

This design enabled a series of research questions to be investigated within the thesis:

- Is there a developmental effect of mathematical anxiety across the period of study?

- What is the relationship between mathematical anxiety and mathematical performance?
    - Is the relationship between mathematical anxiety and mathematical performance significant above a child's general anxiety levels?
    - Is the relationship between mathematical anxiety and mathematical performance significant above a child's general cognitive levels?

- Does poor mathematical performance lead to mathematical anxiety or mathematical anxiety lead to poor mathematical performance?

- Can a positive interest in maths affect the relationship between mathematical anxiety and mathematical performance?

3.3. Participants

Two cohorts (Key Stage 1 and Key Stage 2) of children from two UK primary schools, one in Nottingham and the other in Ashfield Nottinghamshire, were assessed four times over an eighteen-month period. These assessments were started in the summer term of their time in either year one or year five as a baseline of their performance on all the variables. They were then followed up in year two or year six at the beginning of the year, spring term and later at the end of the summer term. These timings were designed to assess the children at the beginning of the year in which they carried out their National Standard Attainment tests, just before and after completion of the tests.

The two schools involved in the studies came from within the Nottingham area. School A, a large inner-city Nottingham primary school had 90% minority ethnic pupils and School B a large county primary school in Ashfield, Nottinghamshire had only 3% minority ethnic pupils.

The socio-economic status was based on the index of multiple deprivation (IMD) and Income deprivation affecting children Index (IDAC) scores for the areas that the schools are situated within (Department for Communities and Local Government, 2015; Ministry of Housing communities and local Government, 2019) (see table 3.1). These scores indicated average to higher-than-average deprivation and low to very low socio-economic status.

School	IMD	IDACI	Deprivation Level.	Socio-economic status
School A	2nd percentile- 3,784 out of 32,844	2nd percentile- 3,569 out of 32,844	Higher than average deprivation.	Very low.
School B	6th percentile- 17.397 out of 32,844	5th percentile- 14,827 out of 32,844.	Average deprivation	Low.

Table 3.1.- IMD and IDACI rankings for the schools showing deprivation levels (Percentiles of 1 denotes areas within the most deprived 10%).

The specific means and standard deviations of the children's ages for the two cohorts at each time of testing are displayed in table 3.2 and table 3.3.

	Time 1		Time 2		Time 3		Time 4	
Year 1 and 2 cohort	Year before SATs		Beginning of SATS year		Just before SATS		After SATS	
	n	M (SD)	n	M (SD)	n	M (SD)	n	M (SD)
Boys	37	75.6 (3.5)	35	80 (3.9)	32	85 (3.7)	30	88 (3.3)
Girls	30	75 (3.1)	29	78(3.2)	29	85 (3.3)	29	88 (3.1)
Total	67	75 (3.7)	64	80 (3.7)	61	85 (3.5)	59	88 (3.2)

Table 3.2: Means and standard deviations of the ages of Key Stage 1 cohort at the four times of testing. (n = number of children, M = mean age in months, SD = standard deviations in months).

	Time 1		Time 2		Time 3		Time 4	
Year 5 and 6 cohort	Summer term of Year 1		Beginning of SATS year		Just before SATS		After SATS	
	n	M (SD)	n	M (SD)	n	M (SD)	n	M (SD)
Boys	37	124 (3.5)	36	128.6 (3.7)	36	133 (3.5)	35	136 (3.4)
Girls	36	122 (3.7)	36	127.8 (3.8)	36	133 (3.5)	36	136 (3.4)
Total	73	123 (3.5)	72	128 (3.8)	72	133 (3.5)	71	136 (3.4)

Table 3.3: Means and standard deviations of the ages of Key Stage 2 cohort at the four times of testing. (n = number of children, M = means in months, SD = standard deviations in months).

3.4 Ethics

Following clearance by the College of Business, Law and Social Science ethics board and permission from the Head Teachers of the schools, a letter explaining the study was sent out to parents asking for their permission for their children to take part in this longitudinal study.

3.5 Key Measures

3.5.1 Mathematical Anxiety.

The Children's Anxiety in Maths Scale (Jameson, 2013a, 2013b) was used to measure the children's mathematical anxiety. This test is comprised of 16 items, including questions on each of the three dimensions of mathematical anxiety. General maths anxiety (e.g., When I solve maths problems, I feel), mathematical performance anxiety, (e.g., If I have to add up numbers on the whiteboard in front of the class, I feel) and math error anxiety (e.g., When I am working on maths problems that are difficult and make me think hard, I feel). This was not a timed test and children could take their time in deciding their answers. The children were asked to respond using a facial image scale with five facial images ranging from the very upset and anxious (scored as a 5) to very happy and not at all anxious (scored as a 1) (see chapter 3 appendix). This five-point facial scale was originally devised from research into dental anxiety in young children by Buchanan and Niven, 2002. The final score was the sum of all their scores for each item in the test, with high values indicating high anxiety levels. The maximum score was 80. Jameson (2013b) reported high internal consistency on the Children's Anxiety in Maths Scale ($\alpha = .86$) and strong evidence of validity based on relations with a measure of maths performance.

3.5.2 Mathematical performance:

There were three measures of mathematical performance. One measure of mathematical fluency, the Test of Basic Arithmetic and Numeracy Skills (TOBANS: Hulme, Brigstocke &Moll, 2016). Two measures of mathematical complexity, SATs style arithmetic and word problem questions.

3.5.3. Mathematical Fluency:

Basic arithmetic skills were used to assess the children's ability to deal with mathematical fluency. Mathematical Fluency is the ease at which number facts are automatically retrieved (Hattie & Yates, 2014). Mathematical fluency is an important skill that children need to learn in order to free up their thinking to make connections and move onto more complex examples (Hattie, Fisher & Frey, 2017), Therefore, in this project basic arithmetic skills were assessed using the Test of Basic Arithmetic and Numeracy Skills (TOBANS: Hulme, Brigstocke & Moll, 2016). This is a standardised test which consists of eight simple timed tests for the different aspects of numeracy.

It gives a measure of a child's mathematical fluency, that is their speed and accuracy at number processing and arithmetic skills. The children are required to solve as many single digit additions, addition with carry, subtraction, subtraction with carry and multiplication questions as possible within one minute. The scores for these 5 sections are added together and provide an arithmetic composite score. The other three sections are dot comparison, digit comparison and count the dots. Digit and dot comparison are accessing a child's basic number sense. Whereas count the dots is accessing a child's enumerations skills. The children are given 30 secs to complete each of these three sections. The children were awarded a point for each question that was correctly answered. Their arithmetic composite score, the sum of the number of additions, additions with carry, subtractions, subtractions with carry and multiplications was used to provide a measure of their mathematical fluency. Retest- reliability for the arithmetic composite score has been quoted by the authors as 0.97 (Hulme, Brigstocke & Moll, 2016).

Mathematical Complexity.

To assess the children's ability to deal with problems of mathematical complexity, the children were asked to complete a series of arithmetic and word problem solving questions, that became increasingly more complex. Children need to be able to understand and use all four number operations confidently. Then be able to interpret verbal information in the form of word problems into the mathematical operations to find a solution.

The questions used in the thesis to test the children (arithmetic and word problem-solving) were designed to match the mathematics programmes of study for KS1 and KS2 from the National Curriculum for English Primary Schools, 2014 (Department of Education, 2014). The questions were based on the types of arithmetic and word-problem solving questions from past SATs KS1 and KS2 papers (Gov.UK, n.d.). The arithmetic questions were designed by the researcher, using formatting such as basic symbolic number operations questions (e.g., 9 + 6 = up to 891 +100 =) and missing number formatting (e.g., 50 +? = 70). The word-problem solving problems were all formatted as word sentences (e.g., There are **20** balloons. **8** balloons fly away. How many are left? Up to, A first class stamp cost **65p** and a second-class stamp costs **56p**. How much does it cost to send **12** letters first class and **14** letters second class? How much did it cost altogether?). Then the questions were reviewed by a mathematics teacher to establish consistency and accuracy within formatting before administration with the children. Finally, questions were piloted with individual children to establish their appropriateness for the age of the children and ease of solution. The questions in the arithmetic and word-problem solving sets increased in complexity from the first to the last question. The answers were coded 2 if correct, 1 if incorrect and 0 if they did not attempt the question. The percentage of correct answers was used to score for both arithmetic and problem solving.

The questions used were the same set of questions for both the KS1 and KS2 children. The questions were designed to gradually increase in complexity and cognitive demand, so that all children made attempts on every question completing as many questions as possible up to the point it was clear that they were unable to solve the questions. All children were encouraged to complete as many questions as they could, only stopping at the point that they were unable to solve the problems. Children read the questions and decided whether they could attempt the questions or felt that they were too hard for them to tackle (see appendix 3).

3.5.4. Arithmetic:

Arithmetic questions were used to assess the children's ability to calculate with increased mathematical complexity rather than the simple single digit arithmetical questions used to assess their mathematical fluency. The children's arithmetic ability was assessed by asking them to solve a set of arithmetic questions. The questions were designed to gradually increase in complexity and cognitive demand, so that the younger children would be able to solve questions but would also provide challenge for the older children. (Question 1, 9 + 6 = ?, Question 12, 648 ÷ 27= ?). The arithmetic problems increased in complexity from one digit problems to problems involving two and three digits (see chapter 3 appendix). These problems required the children to have knowledge of whole numbers and the four basic operations (addition, subtraction, multiplication, and division). Questions used whole numbers and did not include any negative numbers, fractions, or decimals, as it was felt that this would increase the mathematical complexity beyond the capacity of the younger children. These arithmetic questions were not time limited, and the children were encouraged to complete as many of the problems that they felt able to complete. The children completed these problems with paper and pencil, with space provided for them to write out their intermediate steps and final solution.

3.5.5. Word problem solving:

Mathematical word problem solving was used to assess the children's ability to interpret the verbal information and deal with the increasing mathematical complexity. Mathematical complexity can be defined as the level of thinking or number of steps to solve a problem (Hattie, Fisher, & Frey, 2017). In this project, the children's mathematical word problem-solving ability was assessed by asking them to solve a set of mathematical word problems (see chapter 3 appendix). The questions were designed to gradually increase in complexity, through an increasing variety of operations and number of steps required to solve each problem. This meant that the younger children would be able to solve the questions and the later questions would provide challenge for the older children. (Question 2: There are 20 balloons. 8 balloons fly away. How many are left? question 11: Diana makes a muesli with 425g of oat flakes, 220g of nuts and 255g of dried fruit. The mixture provides fifteen portions. How much muesli is in each portion?).

The word problems increased in complexity from one step word problems, through two step and finally to include three step word problems (see chapter 3 appendix). The problems required the children to have knowledge of whole numbers and the four basic operations (addition, subtraction, multiplication, and division). These problems were not time limited, and the children were encouraged to complete as many of the problems that they felt able to complete. The children completed these problems with paper and pencil, with space provided for them to write out their intermediate steps and final solution.

These two measures of mathematical complexity assessed the children's mathematical abilities through the same sets of arithmetic and word problem questions at each time point. In study one, the children were asked twelve arithmetic and word problems to solve. After study one, three more higher order questions were added to the end of each set of questions, to ensure that those who had scored 100% in study one had some challenges in further studies. This was to avoid the possibility of a ceiling effect.

3.6 Emotional Measures.

Three measures of emotional factors were used, Interest in mathematics (Student Interest in Mathematics Scale: Wininger et al. 2014a, 2014b), State and trait anxiety (The State Trait Anxiety Inventory for Children (STAIC): Spielberger, Gorsuch, Lushene, Vagg, Jacobs, 1973).

3.6.1. Interest in Mathematics

A questionnaire on mathematical attitude namely Student Interest in Mathematics Scale (Wininger et al. 2014a, 2014b) was used. This is a 17-item rating scale where children respond to 17 statements describing their interest in maths linked to emotion (e.g Maths is interesting), value (e.g., Learning about maths is important), knowledge (I know a lot about maths) and engagement with maths outside the classroom (e.g., I like to do maths problems outside of school). They responded using a four-point Likert scale scored from 0= never, 1= rarely, 2 = sometimes, 3= most of the time and 4 =always. The overall reliability for this scale is quoted by the authors as 0.90 (Wininger et al. 2014b).

3.6.2. General Anxiety.

The State Trait Anxiety Inventory for Children (STAIC) (Spielberger, Gorsuch, Lushene, Vagg, Jacobs, 1973) was used to give a measure of children's general anxiety levels, specifically their Trait and State anxiety. This Inventory was specifically designed to measure anxiety in children from nine to twelve years of age but can be used with younger children with average or above average reading ability. It consists of two separate tests. The STAIC T-anxiety scale is comprised of 20 item statements that require the children to respond as to how they generally feel. This therefore gives a measure of the child's anxiety proneness, trait anxiety. Reliability for this scale is quoted by the authors as 0.78 for males and 0.81 for females (Spielberger et al, 1973). The STAIC S- anxiety scale is comprised of 20 statements that require the children to respond to as to how they are feeling at the particular moment in time. This inventory is administered with no time limits, children are encouraged to take as long as they need to think about and complete the test. This therefore gives a measure of the child's transitory anxiety state, state anxiety. Reliability for this scale is quoted as 0.82 for males and 0.87 for females (Spielberger et al, 1973).

3.7 Cognitive Measures.

Three measures of cognitive factors were used, Non-verbal intelligence (Raven's Coloured Progressive Matrices: Raven, Court & Raven, 1992), reading (York Analysis of Reading Comprehension (YARC): Snowling et al. 2009) and working memory (Operation Span task: Swanson, Kehler & Jerman, 2010; Swanson, Lee, Kehler & Jerman, 2010).

3.7.1. Non-verbal intelligence measure:

Non-verbal intelligence was measured with the Raven's Coloured Progressive Matrices (Raven, Court & Raven, 1992), where children were presented with 36 visual patterns (with one piece missing from the bottom right corner). The patterns were grouped into 3 sets of 12 items (A, Ab, B). They were not allowed to use paper to work out any of the problems and were instructed to answer each question before moving onto the next picture. No time limits were given. Children were asked to attempt all 36 items, the final score was the sum of correct answers across the 3 sets, with higher scores indicating a better non- verbal intelligence. This test is administered in book form which in initial standardisations quoted low retest reliabilities of 0.65 for children under the age of 7 but this increased to 0.80 by the time the children reach the age of 9 (Raven, Raven & Court, 1998).

3.7.2 Reading Ability:

The single word reading subtest of the York Analysis of Reading Comprehension (YARC): Snowling et al. 2009) was used to give a measure of children's word reading ability. The children were presented with a sheet of 60 words in sets of 10, which gradually increased in complexity. They were asked to read each word aloud at their own pace as the task was untimed. They were awarded a point for each word that was read correctly. The single word reading test has been found to have both high reliability with authors quoting α= .98 (Foster, 2007, Snowling et al., 2009).

3.7.3 Working Memory Capacity:

Working memory capacity was measured using the Operation Span task (Swanson, Kehler & Jerman, 2010; Swanson, Lee, Kehler & Jerman, 2010). This measure assesses working memory span by requiring the children to solve arithmetical problems whilst at the same time remembering simple words with no mathematical connection. These maths problems were simple one-digit addition and subtraction problems shown on small pieces of card. The to be remembered words were presented on separate small pieces of card, immediately following the solution of the maths problem, they were presented visually, and the children were asked to say the word, before the card was turned over. Children were given the following instructions.

"This is a memory task. You will be shown math problems, one at a time. You will read the problems aloud and give the answers. I will record your answers. After each math problem is answered, you will be shown a word to remember. You are to read the word aloud before you are shown the next math problem. When I say, 'Recall words,' you are to tell me all the words in order. You will be completing this task in sets. The first sets will have two problems, the next sets 3 problems, and so on up to sets with 5 problems. When I say, 'Recall words,' you will have as much time as you need to recall the words. You may guess if you are not sure. We will do some practice ones first."

The children were allowed two trials with sets of two arithmetical problems and two words as a practice session. Children were then presented with operation word sequences in sets of increasing size, 2, 3, 4, and 5, the children completed each set up to the point at which they could not remember all the words in the set. Children were scored as to the set of words that they could remember, i.e., if they remembered two words, they scored 2, if they remembered three words, they scored 3 etc. Children were given two attempts at each level, if they failed at both attempts the previous score was used, i.e., two attempts to remember the three words and if they failed then their score would revert to 2.

In previous research operation span has been reported to have good internal consistency (0.78) and test- retest reliability (0.83) (Unsworth, Heitz, Schrock, & Engle, 2005).

Operation span (Turner & Engle, 1989) as an example of a working memory span task was chosen specifically as it is thought to provide a measure of the child's complex cognitive behaviour within different domains e.g., reading, reasoning and problem solving (Conway, Kane, Bunting, Hambrick, Wilhem & Engle, 2005). Operation span gives a measure of a child's ability to maintain attention and store temporarily information for recall whilst being distracted by another task e.g., maintain words for recall whilst solving simple arithmetical problems (Conway et al., 2005). It is an example of a complex span task it that it "forces WM storage in the face of processing (distraction) in order to engage executive attention processes." (Conway et al, 2005). Therefore, it provided an independent measure of children's ability to maintain attention whilst being distracted. This independent measure was important within the thesis as it provided an indication of the children's ability to perform complex tasks.

3.8 Procedure.

Testing took place over four sessions, with all the assessments, apart from one, being administered on a one-to-one basis with each child and the researcher in a small quiet space within the school. The mathematical fluency test was administered in small group sessions with no more than six children at a time.

Testing was carried out over an eighteen-month period from summer of year one and five (April-July 2017), autumn term of year two and six (Sept-Dec 2017), Spring/summer term of year two and six (March-May 2018) and summer term of year two and year six (June-July 2018).

All testing was carried out by the author and general praise and encouragements were the only feedback given.

3.9 Testing Timetable.

There was a testing timetable established to provide data at the four timepoints, all the measures were tested at time point one and then retested a year later. The key measures were tested at all four time points (see table 3.4).

Time point	Measures.	Tests	Cronbach's Alpha
One- Spring and summer of previous year to SATs.	Mathematical Anxiety	Children's Anxiety in Maths Scale (Jameson, 2013a, 2013b).	α = .840
	Mathematical Fluency.	The Test of Basic Arithmetic and Numeracy skills (TOBANS)	
	Mathematical complexity.	Arithmetic.	
	Mathematical complexity	Word problems.	
	General Anxiety- Trait and State.	The State Trait Anxiety Inventory for Children (Spielberger, Gorsuch, Lushene, Vagg, Jacobs, 1973.	
		STAIC T-Anxiety	α = .841
		STAIC S-Anxiety	α = .828
	Interest in Mathematics.	The Student Interest in Maths Scale (Wininger, Adkins, Inman & Roberts, 2014a, 2014b).	α= .841
	Non-verbal Intelligence.	The Raven's Coloured Progressive Matrices (Raven, Court & Raven,1992).	
	Reading.	The single word reading section of the York Analysis of Reading Comprehension (YARC: Snowling et al. 2009).	α = .979
	Working Memory	An Operation Span task (Swanson, Kehler, & Jerman, 2010a, 2010b).	
Two- beginning of the SATs year.	Mathematical Anxiety	Children's Anxiety in Maths Scale (Jameson, 2013a, 2013b).	α = .879
	Mathematical complexity.	Arithmetic.	
	Mathematical complexity	Word problems.	

	State Anxiety	The State Trait Anxiety Inventory for Children (Spielberger, Gorsuch, Lushene, Vagg, Jacobs, 1973.	
		STAIC S-Anxiety.	α = .847
Three- just before the SATs.	Mathematical Anxiety	Children's Anxiety in Maths Scale (Jameson, 2013a, 2013b).	α = .904
	Mathematical Fluency.	The Test of Basic Arithmetic and Numeracy skills (TOBANS)	
	Mathematical complexity.	Arithmetic.	
	Mathematical complexity	Word problems.	
	General Anxiety- Trait and State.	The State Trait Anxiety Inventory for Children (Spielberger, Gorsuch, Lushene, Vagg, Jacobs, 1973.	
		STAIC T-Anxiety	α = .855
		STAIC S-Anxiety	α = .875
	Interest in Mathematics.	The Student Interest in Maths Scale (Wininger, Adkins, Inman & Roberts, 2014a, 2014b).	α = .874
	Non-verbal Intelligence.	The Raven's Coloured Progressive Matrices (Raven, Court & Raven,1992).	
	Reading.	The single word reading section of the York Analysis of Reading Comprehension (YARC: Snowling et al. 2009).	α =.974
	Working Memory	An Operation Span task (Swanson, Kehler, & Jerman, 2010a, 2010b).	

Four- After the SATs.	Mathematical Anxiety	Children's Anxiety in Maths Scale (Jameson, 2013a, 2013b).	α = .882
	Mathematical Fluency.	The Test of Basic Arithmetic and Numeracy skills (TOBANS)	
	Mathematical complexity.	Arithmetic.	
	Mathematical complexity	Word problems.	
	State Anxiety.	The State Trait Anxiety Inventory for Children (Spielberger, Gorsuch, Lushene, Vagg, Jacobs, 1973.	
		STAIC S-Anxiety	α = .90

Table 3.4. Testing timetable for each time point.

3.10 Data Analysis.

IBM Statistics SPSS 24 was used to provide descriptive statistics, correlations, and hierarchical regressions for the cross-sectional data from each cohort at each study time (Chapter five and six). Then the stability and development of mathematical anxiety throughout the project was investigated with the use of repeated measures ANOVAS and independent t-tests, (Chapter 4). Finally, structural equation modelling using IBM AMOS 24 was used to explore the longitudinal relationships in greater detail. Two types of structural equation modelling were used. Firstly, latent growth curve modelling was used to understand the stability and development of mathematical anxiety over time (Chapter 4). A basic model was run to determine whether mathematical anxiety was a stable construct with this sample. Then conditional models were run with time invariant predictors such as gender, age and school. Secondly, cross lagged panel models were used to understand the longitudinal relationship between mathematical anxiety and mathematical performance. Cross lagged panel models were run for each type of mathematical performance (mathematical fluency, arithmetic and word problem solving). Then simultaneous latent growth curve models were run with time varying predictors of the measures of mathematical performance (mathematical fluency, arithmetic and word problem solving) (Chapter 7). Descriptive statistics, correlations, hierarchical regressions, and mediation analyses were used to investigate the relationship between Interest in Mathematics, mathematical anxiety and mathematical performance at time point one and three (Chapter 8). Mediation Analyses were carried out using R software (R Core Team, 2020).

3.11 Chapter summary:

This chapter provided a detailed account of the design, methods, materials, procedure, and data analysis used within this thesis.

- Design- longitudinal multifactorial cohort study which was carried out to investigate the relationship between mathematical anxiety and mathematical performance taking account of cognitive and emotional factors.

- Methods-Testing at four time points over an eighteen-month period.

- Materials-

  Emotional Factors:

  - The Children's Anxiety in Maths Scale (Jameson, 2013a, 2013b).
  - The State Trait Anxiety Inventory for Children (STAIC) (Spielberger, Gorsuch, Lushene, Vagg, Jacobs, 1973) was used to give a measure of children's general anxiety levels, specifically their Trait and State anxiety.
  - A questionnaire on mathematical interest namely Student Interest in Mathematics Scale (Wininger et al. 2014).

  Cognitive Factors:

  - Non-verbal intelligence was measured with the Raven's Coloured Progressive Matrices (Raven, Court & Raven, 1992).
  - The single word reading subtest of the York Analysis of Reading Comprehension (YARC: Snowling et al. 2009).
  - Working memory capacity was measured using the Operation Span task (Swanson, Lee & Jerman, 2010).

  Mathematical Performance:

  - Test of Basic Arithmetic and Numeracy Skills (TOBANS) (Hulme, Brigstocke &Moll, 2016).

  - Arithmetic ability was assessed by asking them to solve a set of SAT style arithmetic questions.

    - Word problem-solving ability was assessed by asking them to solve a set of SAT style mathematical word problems.

- Procedure- Testing was carried out four times over an eighteen-month period from summer of year one and five (April-July 2017), autumn term of year two and six (Sept-Dec 2017), Spring/summer term of year two and six (March-May 2018) and summer term of year two and year six (June-July 2018).

- Data Analysis-Correlations, Hierarchical regressions, Latent Growth Curve and Cross Lagged panel modelling, Mediation analysis.

Chapter 4- Development of mathematical anxiety over time.

Chapter contents:

This chapter discusses the development of mathematical anxiety over the eighteen-month period. As, this thesis is a longitudinal study it was important to establish the development of mathematical anxiety over this significant time in the lives of primary school children. As we measured the performance of the same participants repeatedly over time on the same test and at known times, we were able to investigate the growth trajectory of their mathematical anxiety. The chapter is divided into the following subsections:

- Introduction
    - Structural Equation modelling (SEM)
    - Latent Growth Curve Modelling
    - Conditional Latent Growth Curve modelling
- Aims
- Hypotheses
- Methods: Participants, Materials and Procedure
- Results
    - Descriptive Statistics
    - Analysis of Emotional and Cognitive factors.
    - Question A) Is there a developmental increase in mathematical anxiety over time?
    - Trajectories of mathematical anxiety for individual children.
    - Baseline Latent growth curve model for mathematical anxiety
    - Question B) Does age predict the initial status and rate of growth of mathematical anxiety?
    - Question C) Does gender predict the initial status and rate of growth of mathematical anxiety?
    - Question D) Does the school that children attend predict the initial status and rate of growth of mathematical anxiety?
- Chapter Discussion and summary.

4.1 Introduction:

In developmental psychology research, a fundamental aspect is understanding the changes over time of children in their cognitive, emotional and performance abilities. It is well documented that children's abilities steadily increase over time, i.e., their cognitive abilities grow and develop leading to increased performance levels. Cognitive measures namely non-verbal intelligence (Cattell, 1987; Horn, 1968), reading (McNorgan, Alvarez, Bhullar, Gaydan & Booth, 2011, Vlachos & Papadimitriou, 2015) and working memory (Gathercole, 1999, Pickering 2001), are all predicted to increase with age. But these abilities do not increase at the same rate for all children. There are individual differences in the rate and direction of change. These individual differences are of significant interest to researchers especially in supporting the practical issues related to developing the performance capabilities of children. This change over time can be measured in days, months and even years when looking at constructs during lifespan development. Emotional factors, namely state anxiety (Legrand, McGue, & Iacono, 1999), and interest in mathematics (Gottfried, Fleming, & Gottfried, 2001, Jacobs, Lanza, Osgood, Eccles & Wigfield, 2002, Lerkkanen et al, 2012) are assumed to vary over time, whereas trait anxiety (Speilberger, 1966) is assumed to stay stable over time. Of particular interest within this thesis is the change in the emotional measure of mathematical anxiety over this particular period in primary aged children. Mathematical anxiety is assumed like state anxiety and interest in mathematics to change over time, increasing with age (Dowker, 2016). Mathematical anxiety has been found in primary aged children (Devine et al, 2012; Dowker et al, 2012; Jameson, 2014; Sorvo et al. 2017; Thomas & Dowker, 2000; Wood et al., 2012; Wu et al., 2012; Wu et al.,2014). Whereas other researchers have reported significant mathematical anxiety in older children (Carey et al., 2016; Devine et al., 2012; Hill et al. 2016; Ma & Xu, 2004; Wigfield & Meece, 1988). Wigfield & Meece, 1988). Ma & Kishor, (1997) explained the relationship between mathematical anxiety and age, as increases in mathematical anxiety corresponding to decreases in positive attitudes to mathematics as children get older. This decrease in positive attitudes and increase in mathematical anxiety has been linked to children's increased exposure to negative attitudes to mathematics from peers, parents and teachers (Beilock et al., 2010; Cohen & Rubinstein, 2017; Maloney, et al., 2015; Vukovic et al., 2013) or their increased exposure to social stereotyping around gender differences i.e. that boys are better at mathematics (Devine et al., 2012; Hill et al.,2016; Van Mier, Schleepen & Van den Berg, 2019). However, it could be failure in mathematics over time that explains the increase in mathematical anxiety with age (Dowker, 2019a). Increased experiences of failure lead to difficulties to solve mathematical tasks (Ma & Xu, 2004). This inability to solve mathematical tasks has also been linked to additional cognitive demand in the ever-increasing complexity of the mathematical curriculum with age (Clements & Sarama, 2009). The extraneous cognitive load added to mathematical tasks include numbers of increasing size (see chapter two for discussion of "problem size" effect) and more abstraction (National Curriculum, 2014; Nunez-Pena & Suarez-Pellicioni, 2014). Moreover, Wu et al., (2012) explain that younger children feel less anxious around mathematics as the mathematics they are tasked with has a lower cognitive demand.

Measuring the growth in mathematical anxiety was important within this thesis so that its change over time could be better understood. This change over time could be incremental as children's mathematical anxiety increases with an exposure to more complicated mathematical concepts, therefore feeling less confident and more anxious about mathematics. Or it could decrease in that this increased exposure enables the children to develop a better understanding of mathematical concepts, therefore feeling more confident and less anxious about mathematics. Therefore, in this thesis the development of mathematical anxiety was investigated over time.

4.1.1. Structural Equation Modelling (SEM).

Structural Equation Modelling (SEM), a multivariate form of statistical analysis was used. SEM produces an exploration of the "causal" relationships through a series of structured regression equations (Byrne, 2016). As Latent growth curve models examine both the individual change and variability over time, this SEM analysis was chosen specifically to examine whether there were any changes in mathematical anxiety over the studied time period.

4.1.2 Latent Growth Curve Modelling.

Latent Growth Curve modelling is used regularly in developmental research (Coppens, Bardid, Deconinck, Haerens, Stodden, D'Hondt & Lenoir, 2019; Phan, 2012; Sansavini, Pentimonti, Justice, Guarini, Savini, Alessandroni & Faldella, 2014). This form of modelling allows the longitudinal data of the variable in question to be plotted considering each individual's value at the initial time point and their slopes across the studied time period. This then gives an individual's own unique trajectory of change in the variable in question over time, in this thesis mathematical anxiety (Maxwell & Cole, 2007). A benefit of using latent growth curve models is the analyses considers the individuals change over time as well as the groups means (Kline, 1998). As, the latent growth curve model defines the change over time as dependent on the prior changes of the variable in question. An advantage of using latent growth curve models is that it allows for the treatment of measurement error variances within the model, and it can also be used with variables that are stable over time (Maxwell & Cole, 2007).

Another advantage of Latent growth curve modelling is that it allows the researcher to look at the intra-individual (within person) change and the inter-individual (between person) change in a particular variable (McArdle, 2009). Trajectories of the variable in question demonstrate the developmental pathway of the variable in question and can be compared.

Latent growth curve models allow for an estimation of the group intercept and the individual variability within the intercepts. This information is represented within the model as a latent variable named “intercept”. The model calculates the mean of this variable, which provides a group intercept. It also calculates the variance for this latent variable, which provides the variability within these intercepts. In Latent growth curve models the individual change/rate of growth is represented as the latent variable “slope”. This “slope” has a variability aspect to it as individuals do not have the same developmental change. Latent growth curve models allow for a linear or non-linear statistical line to be fitted to the data. The mean of the slope variable is the estimate of this best fitting line and is used to explain the linear change in mathematical anxiety across time. The variance estimate represents the variability within the individual slopes. Within the models, tests of statistical significance are carried out to provide an indication of whether the mean or the variance are greater than zero.

There are several requirements that need to be met before latent growth curve modelling can be carried out. The first requirement is that the outcome variable must be a continuous scale (Byrne, 2008). Secondly that there is an adequate sample size for the analysis to allow for person- level effects to be recognized (Willett & Sayer, 1994). Growth models have been undertaken with sample sizes as small as 22 (Huttenlocher, Haight, Bryk, Seltzer & Lyons, 1991) although sample sizes around 100 are acceptable (Curran, 2010). Thirdly, that there has been a collection of repeated measures of the same subjects on the same variable(s) using the same unit of measurement (McArdle & Epstein, 1987) sometimes referred to as waves of data collection. It is recommended that these repeated measures are over three separate occasions for each individual participant (Curran, 2010). The time lag between waves of measurement can be evenly spaced i.e., over three years at yearly intervals or unevenly spaced i.e., over differing periods of months between measurements (Byrne ,2008). Finally, that the typical method of estimation used is that of maximum likelihood (ML). This method assumes that there are continuous and normally distributed repeated measures.

Growth curve models operate using two sub models, named level 1 and level 2 models (Willett & Sayer, 1994). The level 1 model is identified as a “within –person” regression model which allows the individual change over time to be represented against the outcome variable. The level 2 model is identified as a “between –person” model that allows the inter- individual change over time to be represented against the outcome variables (Byrne, 2016). In addition, latent growth curve models can incorporate predictors to explain the intercept and slope factors. These predictors can be time invariant such as gender or time–varying such as mathematical performance.

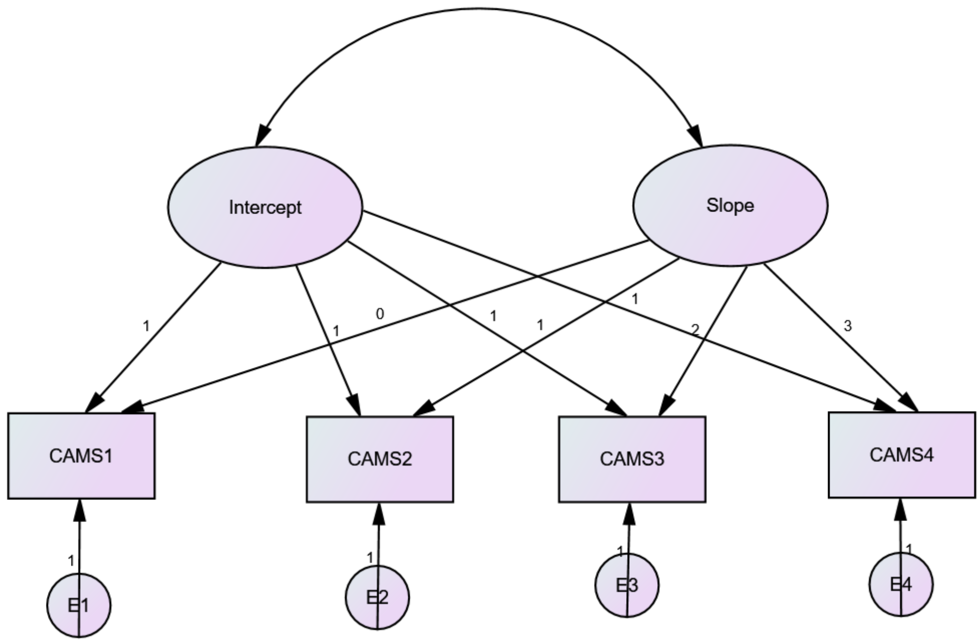

Figure 4.1: A path diagram of latent growth curve modelling for the variable Mathematical Anxiety (CAMS) over time.

Figure 4.1 uses the conventions of path diagrams where the latent variable/ factors are represented as circles, the intercept factor, and the slope factor. The items (CAMS 1 – CAMS 4) are the observed mathematical anxiety scores and are represented as rectangle boxes. These represent the aggregate mathematical anxiety scores at the four points in time. The unique variances, or measurement error (E), for each item are represented as smaller circles with a fixed value of 1. The fixed values for the slope factor (0, 1, 2) tests the hypothesis of linear growth, and the fixed values of 1 for the intercept factor allows the factor mean to represent the mean level of aggregate exploratory behaviour at the initial time of testing. The double-headed arrow between the slope and intercept factors represents their correlation or covariation and provides information about the relationship between the initial level of mathematical anxiety and its subsequent growth. This correlation can be interpreted as when there is a significant positive correlation this indicates that those individuals who are high on initial mathematical anxiety tend to have higher growth trajectories. Whereas a significant negative correlation means that those individuals who are high on initial mathematical anxiety status tend to have lower growth trajectories.

Therefore, growth curve models are an attempt to model the cross-time observations in a particular variable over time. In this thesis it is important to look at the intra-individual (within person) change and the inter-individual (between person) change over the eighteen-month period. It is assumed that each individual participant will have an intercept and slope parameter that characterises their growth trend. Conducting a growth curve analysis allows the rates of change and slopes of this change to be depicted. Therefore, the research question being asked here is “Is there a developmental change in mathematical anxiety over time?” It allows an investigation of the pattern of change over time of the children’s mathematical anxiety scores and whether it is possible to predict children’s mathematical anxiety from their previous scores at earlier points in time. In addition, whether predictors such as gender, age, school, and mathematical performance can explain the initial amount of mathematical anxiety and the individual variability in mathematical anxiety. Importantly whether these predictors affect the rate of growth in mathematical anxiety.

4.1.3-Conditional Latent Growth Curve Model with time invariant predictors.

Conditional latent growth curve models are where the random and fixed effects of the model are then conditioned onto the predictors. This then allows for a better explanation of the relationship over time dependent on other predictors. These predictors are added as covariates. Covariates such as age, gender and school are time invariant (TIC) can be used.

4.2 Aims

This thesis was designed to track, emotional, cognitive, and mathematical performance of two cohorts of primary school children. Its design enabled data to be collected over an eighteen-month period. The aim of this chapter is to investigate the development of mathematical anxiety over time.

Analyses of the longitudinal data allows the research question a), “Is there a developmental effect of mathematical anxiety across the four time points?” to be examined. (See figure 4.1). That is does the mathematical anxiety of the children change over this period, either increasing, decreasing, or remaining stable. It was hypothesised that the children ‘s mathematical anxiety would increase the nearer that they came to taking their SATs, due to the importance placed on succeeding in mathematical performance. Previous research suggests that mathematical anxiety increases when children are put under pressure to perform e.g., timed tests. (Devine et al., 2012; Vukovic et al., 2013). Whilst other researchers have suggested that the level of mathematical anxiety decreases within the year (Sorvo et al., 2019) due to the children becoming more used to studying maths in the primary school (Sorvo et al, 2017). Interestingly this research was carried out with children in Finland, where there are no high stakes testing during the primary years.

Within question a) “Is there a developmental effect of mathematical anxiety over time?” a series of questions about the development of mathematical anxiety can be examined to provide further details.

- What are the children’s trajectories of change in mathematical anxiety over time?
- Are there significant inter- individual differences in the children’s intial scores of mathematical anxiety at time one?
- Are there inter-individual differences in the growth trajectory of mathemematical anxiety in the children?

As stated previously in this chapter, growth analysis allows for the inclusion of time invariant factors that might be predictors of the change of mathematical anxiety over time. In this thesis consideration was given to three time invariant factors (see chapter one for a discussion of the factors that might influence the development of mathematical anxiety). The first factor is age, as two categories of children were tested, the younger (Key Stage 1) and the older (Key Stage 2) children allowing the following question to be addressed:

b) Does age predict the initial status and rate of growth of mathematical anxiety?

The second factor is the gender of the childen allowing the following question to be looked at:

c) Does gender predict the initial status and rate of growth of mathematical anxiety?

The third factor of interest is the effect of school, as the children were sampled from two schools (School A and School B- see chapter three for discussion of schools) allowing the following question to be addressed:

d) Do the schools children attend predict the initial status and rate of growth of mathematical anxiety?

4.3 Hypotheses

This chapter has the following hypothesis:

1) Examine the change in mathematical anxiety over time in children as they approach their SATs. Previous research has suggested that mathematics anxiety increases through childhood (Sorvo et al., 2017, Dowker, 2019a). Several reasons have been given to explain this increase including increased exposure to negative attitudes (Ma & Kishor, 1997), more experiences of failure at maths (Ashcraft, 2002) and increasingly larger numbers and more abstract concepts (Dowker, 2016). Therefore, it was hypothesised that the children, as throughout the period were being exposed to larger numbers and more complex tasks, their mathematical anxiety would increase especially the closer they were to their SATS.

H1- that the children's mathematical anxiety will increase the nearer the children get to taking their SATs.

2) Examine the effect of year on the growth of mathematical anxiety. Previous research has evidenced mathematics anxiety in children aged four to six years of age (Jamieson & Ross, 2011; Petronzi, Staples, Sheffield, & Hunt, 2019) through to children aged from six to seven years of age (Harari et al, 2013) as well as older children (Devine et al, 2012; Dowker et al, 2012; Jameson, 2014; Sorvo et al. 2017; Thomas & Dowker, 2000; Wood, Pinheiro-Chagas, Julio-Costa, Micheli, Krinzinger, Kaufmann, Willmes, & Haase, 2012; Wu et al., 2012; Wu et al., 2014). There is more research evidence for older children having increased mathematical anxiety, with several reasons given to explain this difference. Increased exposure to negative attitudes (Ma & Kishor, 1997), more experiences of failure at maths (Ashcraft, 2002) and increasingly demands of the mathematics curriculum (Dowker, 2016; Sorvo et al., 2017). Therefore, it was hypothesised that for the older children, their mathematical anxiety would increase especially the closer they were to their SATS.

H2- that the initial status and rate of growth of mathematical anxiety will be greater for the older children than for the younger children.

3) Examine the effect of gender on the growth of mathematical anxiety. Previous research has suggested that females report more mathematical anxiety than males, with studies reporting that it is more prevalent in adult and adolescence populations (Betz, 1978; Chang & Cho, 2013; Devine et al, 2012; Hembree, 1990; Hill et al., 2016; Hopko et al., 2003; Wigfield & Meece, 1988). Although recently a study with children aged from eleven to twelve years of age (Vanbinst, Bellon & Dowker, 2020) found that girls reported more mathematical anxiety than boys. Equally, two studies of elementary female children reported more mathematics anxiety than male children (Ho et al., 2000; Yuksel-Sahin, 2008) and a recent study found that girls aged five to seven years reported more total and testing mathematical anxiety than boys (Szczygiel, 2020a). Several reasons have been given to explain this gender difference including stereotype threat (Beilock, Rydell & McConnell, 2007; Dowker et al., 2016), their predisposition to general anxiety (Szczygiel, 2020a) and the influence of female teachers on their female pupils (Beilock et al., 2010). Therefore, it was hypothesised that the female children would report more mathematical anxiety and that it would increase especially the closer they were to their SATS.

H3- that the initial status and rate of growth in mathematical anxiety in girls will be greater than the initial status and rate of growth in boys.

4) Examine the effect of school on the growth of mathematical anxiety. Previous research has evidenced that mathematics anxiety is influenced by teachers own mathematical anxiety (Beilock et al., 2010) and classroom environment (Ashcraft et al., 2007). Several reasons have been given to explain this environmental difference including style of teaching (Hembree, 1990) negative feedback (Ashcraft, 2002; Ashcraft et al., 2007) and the influence of teacher's expectations (Friedich et al., 2015). Therefore, it was hypothesised that as the children were taken from two different schools there would be a difference between the mathematical anxiety reported.

H4- That there will be different initial status and rates of growth of mathematical anxiety dependent on the school that the children attended.

4.4 Methods

4.4.1 Participants

The participants in the longitudinal analysis were the children who had taken part at all four of the time points (see tables 3.1 and 3.2 in chapter 3).

4.4.2 Materials

The measures are described in chapter 3.

4.4.3 Procedure

Data was collected from all four studies and analysed using SPSS version 24, the characteristics of mathematical anxiety were explored over time using descriptive statistics and repeated measures ANOVAS. Repeated measures ANOVAS were used as this form of analysis detects any overall differences between the related means. Then latent growth curve models were modelled in IBM SPSS AMOS 24.5, to explore the change over time for an individual's mathematical anxiety. Throughout the analyses the maximum-likelihood estimation (MLE) was used in all the models. The fit of all the models was evaluated using the following indices: chi- square test (χ^2), comparative fit index (CFI) and root mean error of approximation (RMSEA). As the chi square test is known to be sensitive to sample size the other fit indices are used as they better assess the models (Hu & Bentler, 1998; Kline, 2005). For the CFI the cut off criteria used was that values close to 0.95 indicated a superior fit, (Hu & Bentler, 1999) and values >0.90 were identified as acceptable (Kline, 2005). For the RMSEA values the cut off criteria used was that those values less than 0.05 indicated good fit (MacCallum et al., 1996) (Cited in Byrne, 2016.), whilst values as high as 0.08 could be included as they represented “reasonable errors of approximation” (Browne & Cudeck, 1993).

4.5 Results

4.5.1 Descriptive Statistics

In total 130 children (59 in school year two, 71 in school year six) participated in all four studies. There were 65 (50%) males and 65 (50%) females. There were 61 children in School A (25 in school year two, 36 in school year six) and 69 children in school B (34 in school year two, 35 in school year six). The means and standard deviations for emotional, cognitive and all measures of mathematical performance by study for the whole sample are in table 4.1. Means and standard deviations for emotional, cognitive and all measures of mathematical performance for the younger children are in table 4.2 and for the older children in table 4.3.

Whole sample	Study 1	Study 2	Study 3	Study 4
(N=130)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Emotional				
Mathematical Anxiety	38.7(11.5)	38 (11.3)	39 (12.4)	39(11.3)
Trait Anxiety	32.16 (7.3)		33.05(6.9)	
State Anxiety	31.48(4.76)	33.43(5.16)	32.12(5.49)	32(6.05)
Interest in Mathematics	44.09(10.53)		43.3(11.68)	
Cognitive				
Non-verbal Intelligence	23.93(7.02)		27.09(6.18)	
Reading	34.6(16.09)		41.02(13.69)	
Working Memory	2.53(1.26)		3.15(1.34)	
Mathematical Performance				
Mathematical Fluency	69(51.4)		89(64)	93(65
Arithmetic	7.2(3.4)	7.3(5.2)	8.8(4.7)	9 (4.5)
Word Problem Solving	5.1(3.3)	5.0(4.5)	6 (4)	6.4(4.3)

Table 4.1: Means and Standard deviations for emotional, cognitive, and mathematical performance measures for the whole sample.

Younger children (N=59)	Study 1 Mean (SD)	Study 2 Mean (SD)	Study 3 Mean (SD)	Study 4 Mean (SD)
Emotional				
Mathematical Anxiety	37.3(12)	38.5 (12)	38.1 (14)	39.1(11)
Trait Anxiety	32.7(6.8)		32.5(8.5)	
State Anxiety	31.2(5)	32.7(4.6)	31.4(6.4)	32.5(5.4)
Interest in Mathematics	44.1(12)		44(1.2)	
Cognitive				
Non-verbal Intelligence	18.2(5)		22.7 (5.6)	
Reading	20.1(8.8)		30(10.2)	
Working Memory	1.5(.73)		2.1(.78)	
Mathematical Performance				
Mathematical Fluency	22.5(10)		33.6(15)	37.1(7.2)
Arithmetic	3.8(1.7)	2.3(2.2)	4.3(2.7)	4.9 (2.6)
Word Problem Solving	2.4(1.6)	1.1(1.2)	1.8 (1.7)	2.8(2.6)

Table 4.2: Means and Standard deviations for emotional, cognitive, and mathematical performance measures for the younger children.

Older children	Study 1	Study 2	Study 3	Study 4
(N=71)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Emotional				
Mathematical Anxiety	39.5(11)	37.8 (11.2)	39.9 (12)	39.2(12)
Trait Anxiety	33.3(7.0)		31.6(7.0)	
State Anxiety	31.8(4.6)	34.1(5.5)	32.3(5.8)	31.6(6.5)
Interest in Mathematics	44.1(9.3)		42.4(12.4)	
Cognitive				
Non-verbal Intelligence	28.7(4.3)		30.7(3.9)	
Reading	46.6(9.5)		50.2(8.3)	
Working Memory	3.1(1.2)		4.1(1.0)	
Mathematical Performance				
Mathematical Fluency	107(39)		136(50)	139(52)
Arithmetic	10(1.5))	11.5(2.6)	12.5(1.9)	12.3 (2.3)
Word Problem Solving	7.4(2.6)	8.3(3.4)	8.9 (3.2)	9.4(3.3)

Table 4.3: Means and Standard deviations for emotional, cognitive, and mathematical performance measures for the older children.

4.5.2 Emotional and Cognitive factors analyses.

Repeated measures ANOVAS were conducted on the emotional (State and trait anxiety and interest in mathematics) and cognitive measures (Non-verbal intelligence, reading and working memory) over time. These analyses indicated a varying pattern of change for the emotional factors. Trait anxiety and interest in mathematics stayed stable over the period with no statistically significant differences, for both the younger and older children. Whereas state anxiety changed statistically over the time period with increases and decreases at different time points but only for the older children. The children's average cognitive abilities increased from the first time point for both the younger and older children. (See appendix 4 for analysis of emotional, cognitive, and mathematical performance measures over time).

4.5.3 Question A- Is there a developmental increase in mathematical anxiety over time?

In answering the question is there a developmental increase in mathematical anxiety over time, repeated measures ANOVAs were conducted on both cohorts. The one-way repeated measures ANOVA comparing the mathematical anxiety scores at time 1 (conducted when the children were in school year one) and times 2, 3, and 4 (conducted when the children were in school year two beginning of the SATs year, just before the SATs and end of the SATs year) found no significant effect for time, Wilks' Lambda=.98, F (3,56) =.432 p=.731, multivariate partial eta squared =.023. Equally the one-way repeated measures ANOVA comparing the mathematical anxiety scores at time 1 (conducted when the children were in school year five) and times 2, 3, and 4 (conducted when the children were in school year six beginning of the SATs year, just before the SATs and end of the SATs year) found no significant effect for time, Wilks' Lambda=.93, F (3,68) =1.8, p=.053, multivariate partial eta squared =.074.

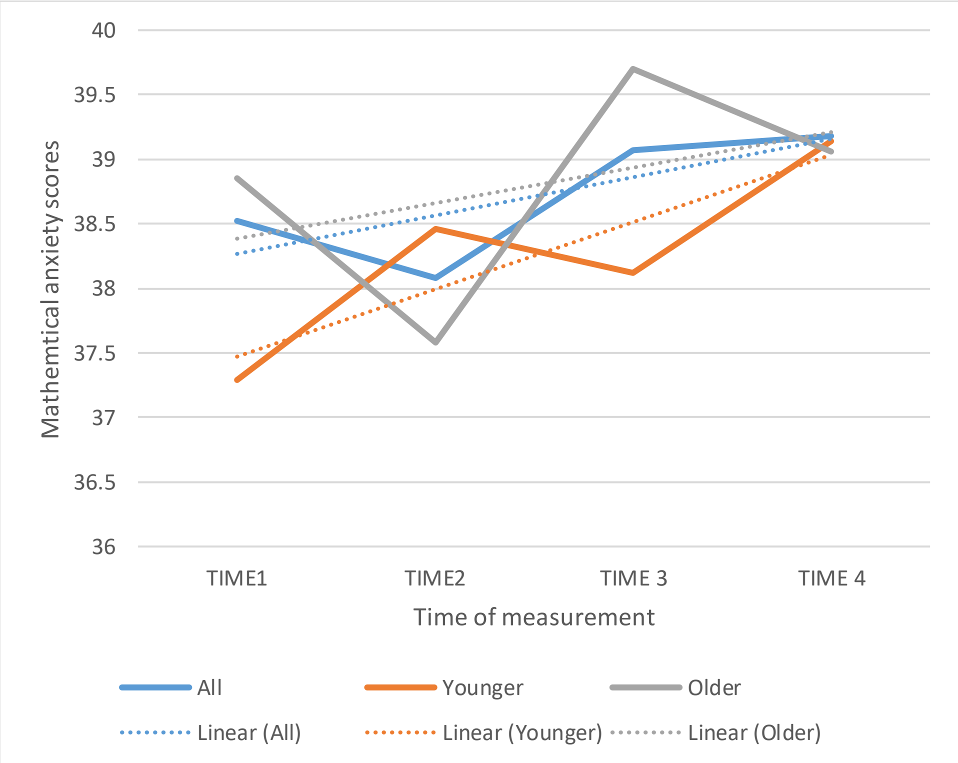

Figure 4.2: Mean trajectories for the variable Mathematical Anxiety (CAMS) for all, younger and older cohorts.

From the repeated measures ANOVAs, it was found that the average mathematical anxiety stayed stable for both the older and younger children. Figure 4.2 illustrates the mean trajectories for mathematical anxiety scores for the older, younger, and whole samples of children. Another way to answer this question, is there a developmental increase in mathematical anxiety over time, was to investigate the individual trajectories of mathematical anxiety to provide more information on the variability of mathematical anxiety.

4.5.4 Trajectories of mathematical anxiety for individual children.

Investigating individual trajectories rather than the mean differences allows the question to be answered in a more developmental way. Figures 4.3, 4.4, 4.5 and 4.6 show the individual trajectories of mathematical anxiety for random samples of children across the four time periods, to depict these trajectories more clearly, they have been split into year groups and schools. The intercepts can clearly be seen as the point of intersection of the slopes on the y axis, this identifies the initial status of mathematical anxiety for each child. The mean intercept is 38.1 at the first testing point but it is clear that there is considerable individual variation around this group mean, with individual scores ranging from a possible 16-80.

Equally, the trajectories clearly show the variance in slopes of the children, the linear lines show that the children's mathematical anxiety scores over time increase, decrease or remain stable throughout.

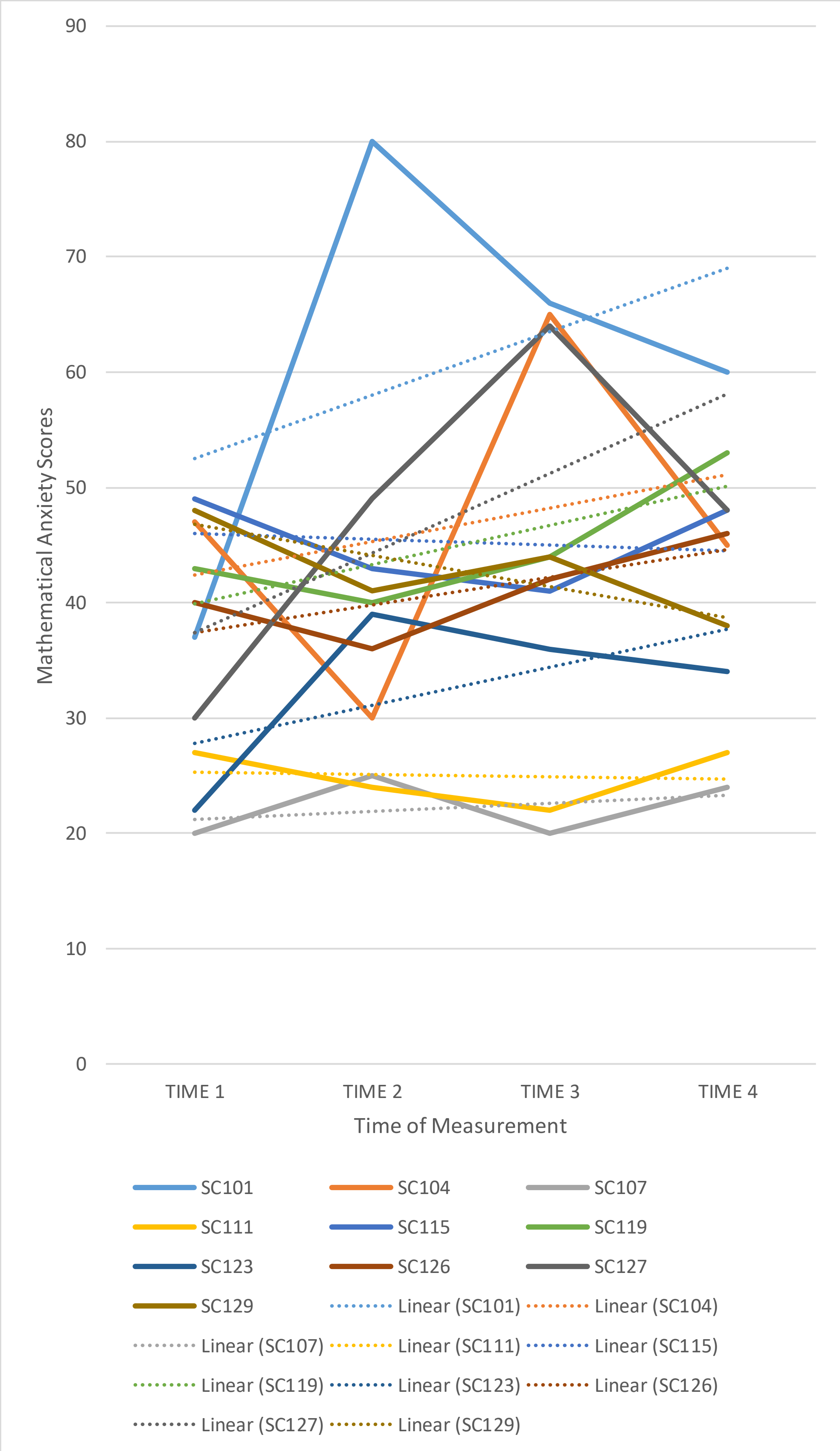

Figure 4.3: Individual trajectories and linear trendlines for a random sample of the younger children from School A of the variable Mathematical Anxiety over time.

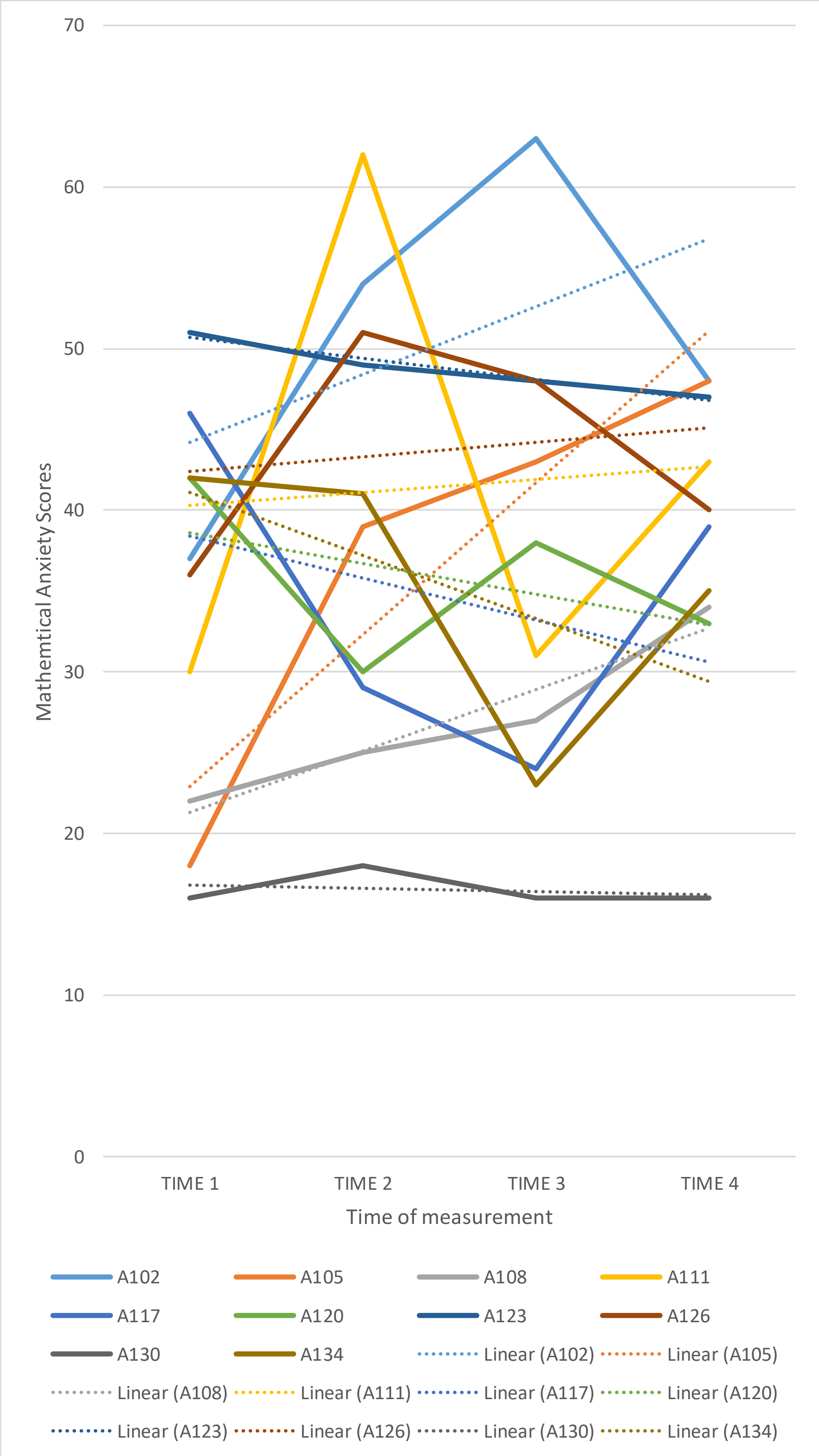

Figure 4.4: Individual trajectories and linear trendlines for a random sample of the younger children from School B of the variable Mathematical Anxiety over time.

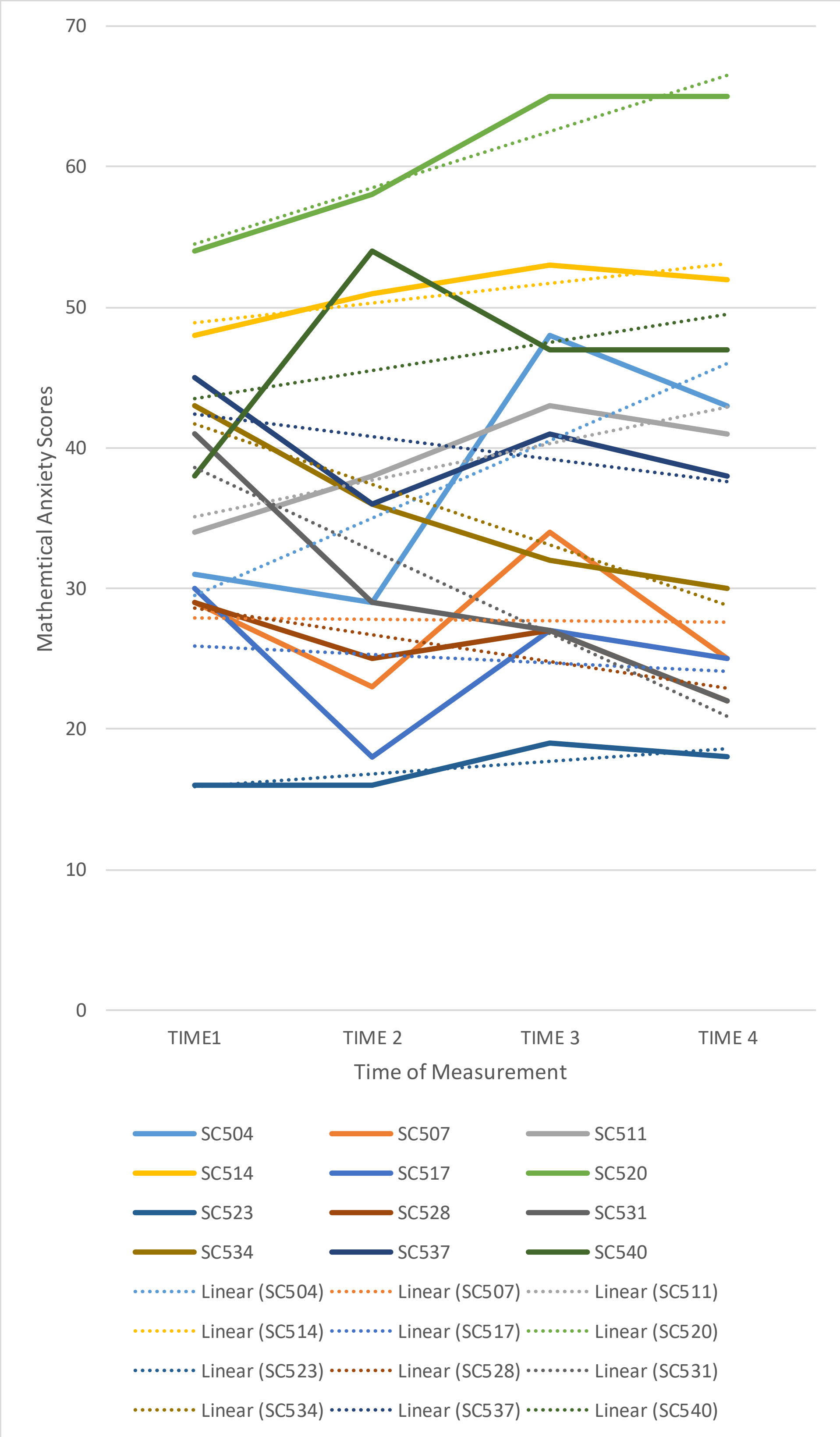

Figure 4.5: Individual trajectories and linear trendlines for a random sample of the older children from School A of the variable Mathematical Anxiety over time.

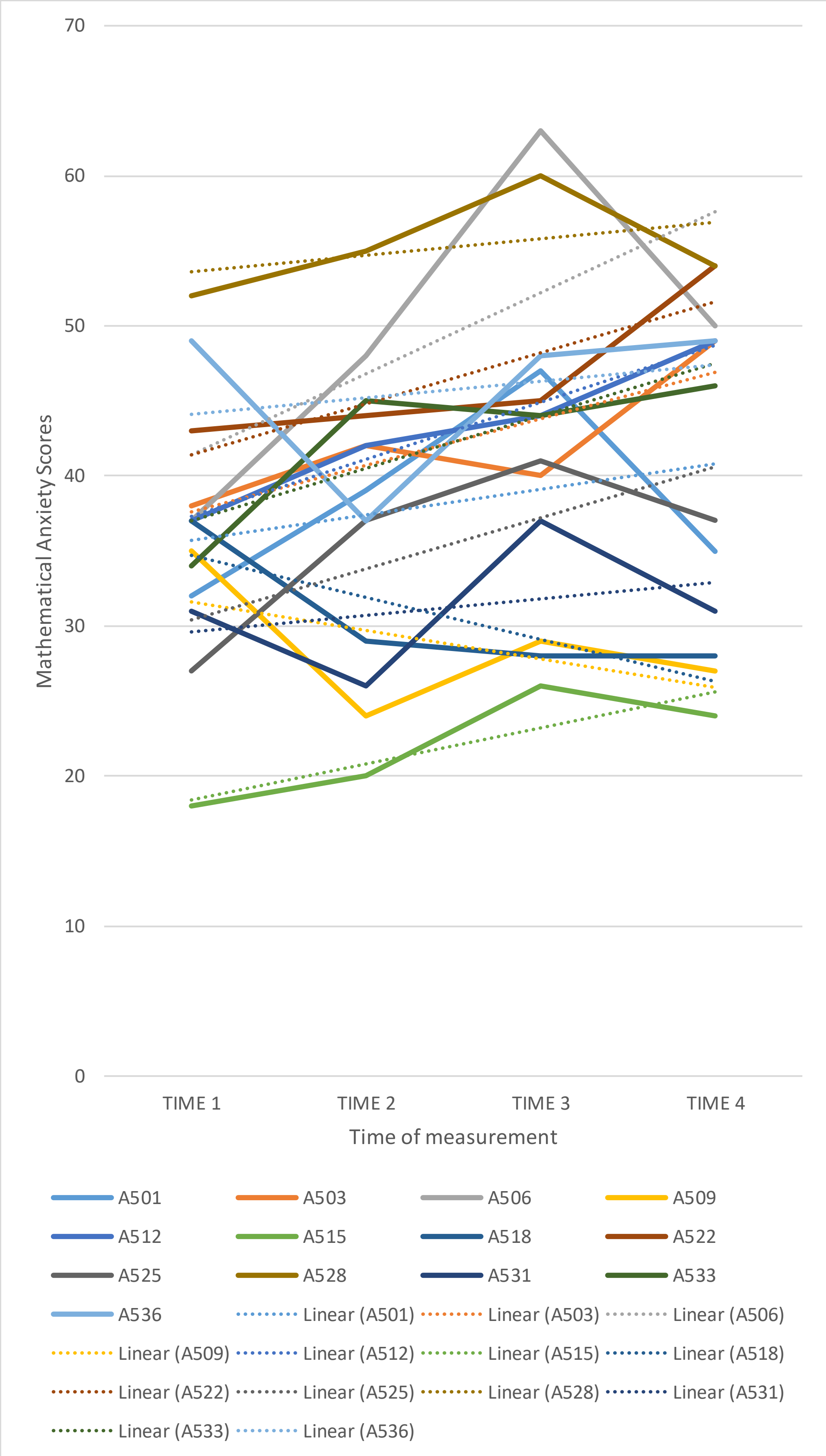

Figure 4.6: Individual trajectories and linear trendlines for a random sample of the older children from School A of the variable Mathematical Anxiety over time.

4.5.5 Baseline Latent Growth Curve Model for Mathematical anxiety.

To answer the question "Is there a developmental effect of maths anxiety over time?" the growth of mathematical anxiety was estimated using latent growth curve modelling. A baseline unconditional model, which identified the latent variables of the intercept and the slope along with the observed repeated measures of mathematical anxiety as the outcome variable was modelled.

The latent growth path diagram was modelled using IBM SPSS AMOS 24, as seen in figure 4.7. The measures of Mathematical Anxiety scores for all the 130 participants at the four different time points were used to provide the outcome variables (see Chapter 3 for detailed information of the participants). The intercept factor was defined with a free mean and variance and all loadings were set to 1. The slope factor was defined with a free mean and variance, but the loadings were defined by the meaning of the time used. As the spacing of the times between the studies is not equal a standard specification where time 1 is given a loading of zero, time 2 a loading of 1 and so on was not used. Instead, a one-unit difference was used to define the unit of time from the first study in months. Therefore time 1 was set to zero, time 2 set to 5 (as it occurred five months after time 1) time 3 to 10, (as it occurred 10 months after time 1) and finally time 4 to 13 (as it occurred 13 months after time 1). Therefore, these slopes represented change from the year before SATS, through to after the SATS taking account of the values at the beginning of the SATS year and just before the SATs.

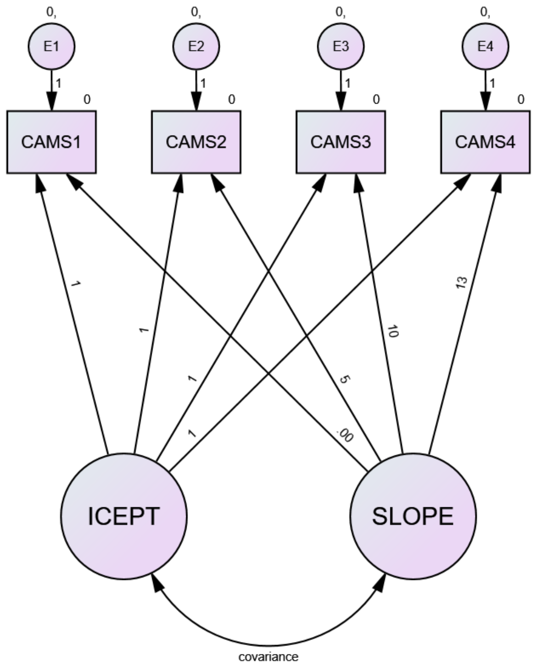

Figure 4.7: A path diagram of latent growth curve modelling for the variable Mathematical Anxiety (CAMS) over time with specified factor loadings on the slopes (ICEPT=latent intercept factor, SLOPE=latent slope factor, E= measurement error).

The initial baseline latent growth curve analysis modelled the trends in mathematical anxiety across the whole project for the four time points.

The Linear fit for this model can be described as:

$\chi^2(10) = 6.999$, $p = .221$, with an RMSEA = .056 and a CFI =.992 (see figure 4.8).

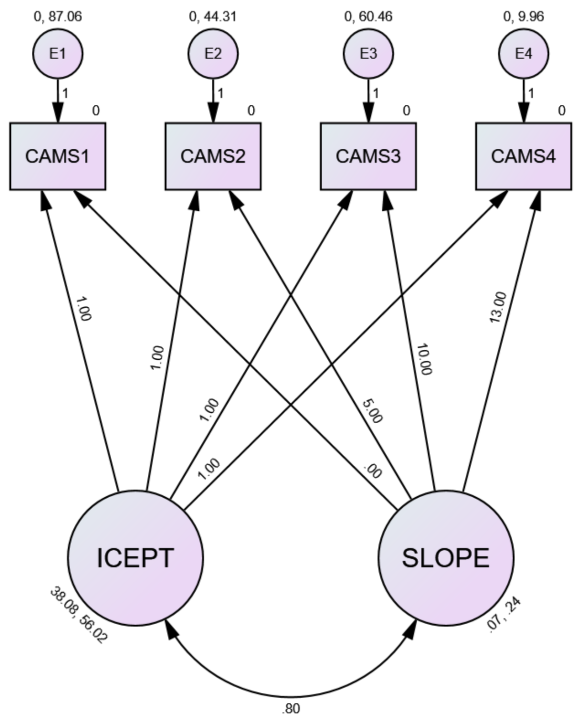

Figure 4.8: A path diagram of latent growth curve modelling for the variable Mathematical Anxiety (CAMS) over time with specified factor loadings on the slopes with means, variances and covariance displayed (ICEPT=latent intercept factor, SLOPE=latent slope factor, E= measurement error).

The mean initial status (Intercept) for this model indicated that the average participant starts at a value of 38.1 for mathematics anxiety. The variance for the initial status was 56, SE= 14.5, $p < .001$ suggesting that there is a statistically significant variance in the initial mathematical anxiety levels across all participants. The mean slope indicates that average rate of change over the project was .075 but this was not significant. The variance for this was significant with a value of .24, SE= .12, $p= .04$. The significant values for the variances of the intercept and the slope, indicates that there are significant differences in where the children start with their mathematical anxiety and the rate of change in their mathematical anxiety. This is clearly indicated when looking at the individual trajectories for each child (see figures 4.3, 4.4, 4.5, and 4.6). There is a positive covariance between the initial status and growth with a B =.80 (β = .22) but this was not significant in this model (p=.409).

Parameter	Coefficient	SE	CR	P value
Intercept mean	38.1	.91	42.2	p<.001
Intercept variance	56	14.5	3.9	p<.001
Slope mean	.08	.07	1.07	p=.284
Slope variance	.24	.12	2.1	p=.040
Intercept – slope covariance	.80	1.0	.83	p=.409

Table 4.4: Parameter estimates for basic latent growth curve model.

Estimates reported in table 4.4 show that the mean intercept and variance are statistically significant. The intercept mean was equal to the mean of the children's mathematical anxiety at the initial time and the estimate of the variance of this construct showed that there was a significant variability in the individual intercepts at the initial time. The slope mean was not statistically significant but was a positive estimate, which indicates that there was no significant difference in average rate of change of mathematical anxiety over the four time points. The variance of the slope factor was statistically significant indicating that there was individual variability in the slopes, i.e., rate of change in individual children's mathematical anxiety over time. The covariance between the intercept and the slope factors was also not statistically significant. This suggests that there is no relationship between the initial status and subsequent growth of mathematical anxiety over this time.

As there were significant estimates in the variance section for both the intercept and slope indicating strong inter individual differences in both the initial score of mathematical anxiety at time one and in their change over time, as the children progressed through their SATS year. This was taken to provide strong support for the continued statistical investigation of individual variability within the growth trajectories. Therefore, a series of conditional latent growth curve models were executed to answer questions relating to whether time invariant factors such as year, gender or school were predicting the differences in mathematical anxiety scores.

4.5.6 Question b) Does age predict the initial status and rate of growth of mathematical anxiety?

The first conditional latent growth curve analysis modelled the trends in mathematical anxiety across the whole project for the four time points adding year as a predictor. The year variable was added to attempt to explain the variability of the intercept and slope factors as seen in figure 4.8. The effect from the year factor indicates the sign and magnitude of the relationship between year and the initial amount of mathematical anxiety and the different rates of change in mathematical anxiety in the older and younger children.

The Linear fit for this model can be described as:

$\chi^2(7) = 12.21$, $p = .094$, with an RMSEA = .076 and a CFI =.979 (see figure 4.9).

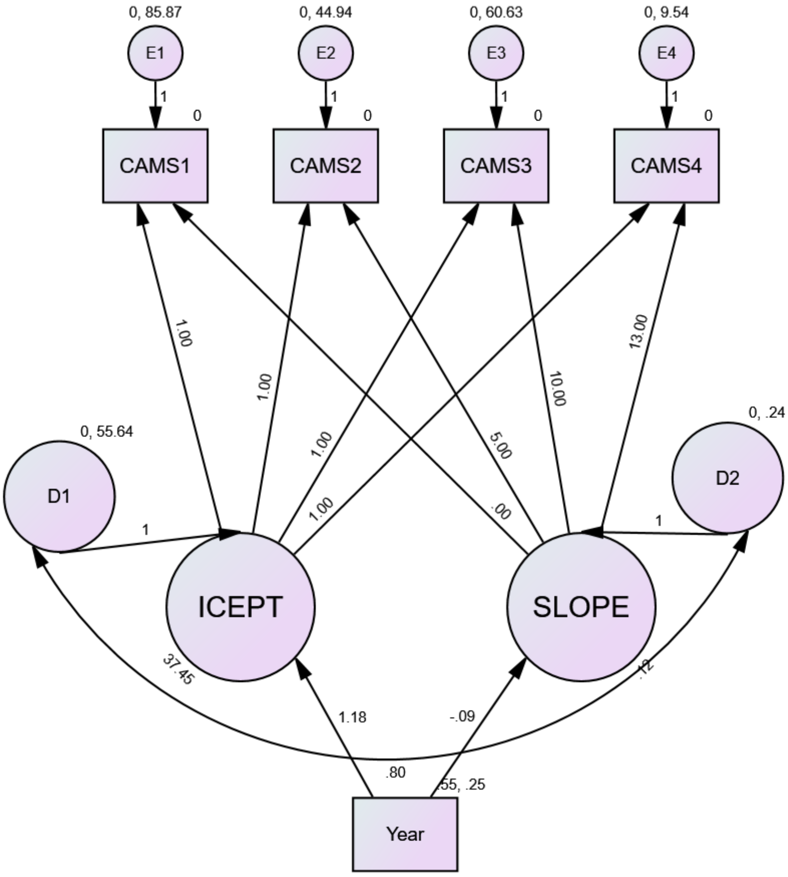

Figure 4.9: A path diagram of latent growth curve modelling for the variable Mathematical Anxiety (CAMS) over time with year as a predictor with specified factor loadings on the slopes with means, variances and covariance displayed (ICEPT=latent intercept factor, SLOPE= latent slope factor, E= measurement error, D= factor disturbance).

Parameter	Coefficient	SE	CR	P value
Year mean	.55	.044	12.5	P<.001
Year variance	.248	.031	8.03	P<.001
Intercept mean	37.5	1.3	28	P<.001
Slope mean	.125	.103	1.2	p =.227
Intercept – slope covariance (d1-d2)	.80	.96	.83	p =.406

Table 4.5: Parameter estimates for conditional latent growth curve model with year as a predictor.

The intercept for this model indicated that the average participant starts at a value of 37.5 for mathematics anxiety. The average rate of change over the project was .125 but this was not significant. In looking at the variances there was no significant covariance with a B= .8 (β= .22) as the significance level was p=.406 (see table 4.5).

Regression weights	Estimate	SE	CR	P value
Intercept ← year	1.2	1.8	.65	p =.51
Slope ← year	-.10	.14	-.67	p =.51

Table 4.6: Regression weights for conditional latent growth curve model with year as a predictor.

The regression paths for this model are of primary interest as they hold the key to whether the trajectory of mathematical anxiety differs for younger and older children (see table 4.6). Year as a predictor variable was not found to be a statistically significant predictor of both the initial status (B= 1.2, β= .08, p=.51) or the rate of change/ slope (B= -.10, β= -.09, p=.51). In this model it can be concluded that age as in the distinction of younger and older children was not a good predictor of the initial starting point of mathematical anxiety in children. Also, that the rate of change in mathematical anxiety is not distinguishable between younger and older children as indicated by the non-significant estimate (p= .51).

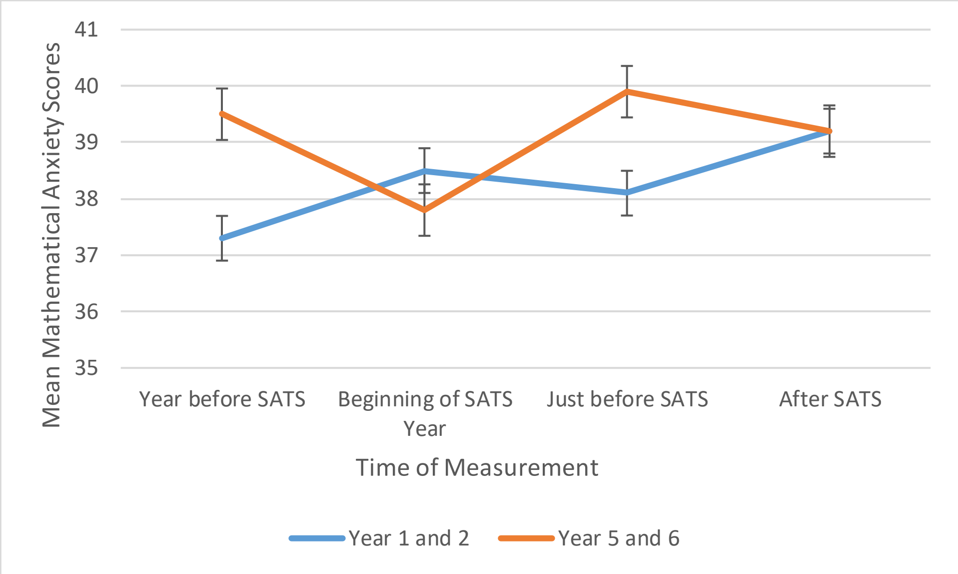

Figure 4.10: Mean trajectories for the variable Mathematical Anxiety (CAMS) by year group over time for each cohort.

Figure 4.10 displays the difference between the younger and older children's mean scores at each time point.

4.5.7 Question c) Does gender predict the initial status and rate of growth of mathematical anxiety?

The second conditional latent growth curve analysis modelled the trends in mathematical anxiety across the whole project for the four time points adding gender as a predictor. This then allows an examination of any gendered changes in mathematical anxiety over time. The gender variable was added to attempt to explain the variability of the intercept and slope factors as seen in figure 4.11. The effect from the gender factor indicates the sign and magnitude of the relationship between gender and the initial amount of mathematical anxiety and the different rates of change in mathematical anxiety in the males and females.

The Linear fit for this model can be described as:

$\chi^2(7) = 9.024$, p = .251, with an RMSEA = .047 and a CFI =.992 (see figure 4.11).

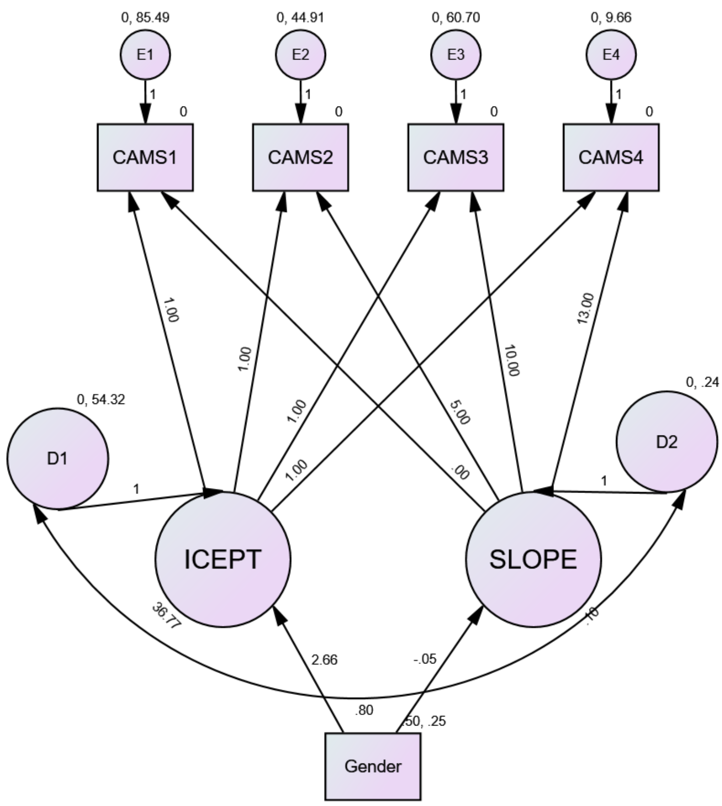

Figure 4.11: A path diagram of latent growth curve modelling for the variable Mathematical Anxiety (CAMS) over time with gender as a predictor with specified factor loadings on the slopes with means, variances and covariance displayed (ICEPT=latent intercept factor, SLOPE=latent slope factor, E= measurement error, D= factor disturbance).

Parameter	Coefficient	SE	CR	P value
Gender mean	.5	.044	11.4	p<.001
Gender variance	.250	.03	8.03	p<.001
Intercept mean	37	1.3	29.1	p<.001
Slope mean	.10	.10	1.0	p =.322
Intercept – slope covariance	.8	1.0	.84	p=.405

Table 4.7: Parameter estimates for conditional latent growth curve model with gender as a predictor.

The intercept for this model indicated that the average participant starts at a value of 37 for mathematics anxiety. The average rate of change over the project was .098 but this was not significant. In looking at the variances there was not a significant covariance with a B= .8 (β =.22) with significance level of p=.405 between the intercept and the slope (see table 4.7).

Regression weights	Estimate	SE	CR	P value
Intercept ← gender	2.7	1.8	1.5	p= .14
Slope ← gender	-.05	.14	-0.34	P=.73

Table 4.8: Regression weights for conditional latent growth curve model with gender as a predictor.

The regression paths for this model are of primary interest as they hold the key to whether the trajectory of mathematical anxiety differs for boys and girls (see table 4.8). Gender as a predictor variable was not found to be statistically significant predictor of both the initial status (B= 2.6, β= .18, p=.138) or the rate of change/ slope (B= -.05, β= -.05, p=.73). In this model it can be concluded that gender is not a good predictor of the initial starting point of mathematical anxiety in children. Also, that the rate of change in mathematical anxiety is not distinguishable between boys and girls as indicated by the non-significant estimate (p= .74).

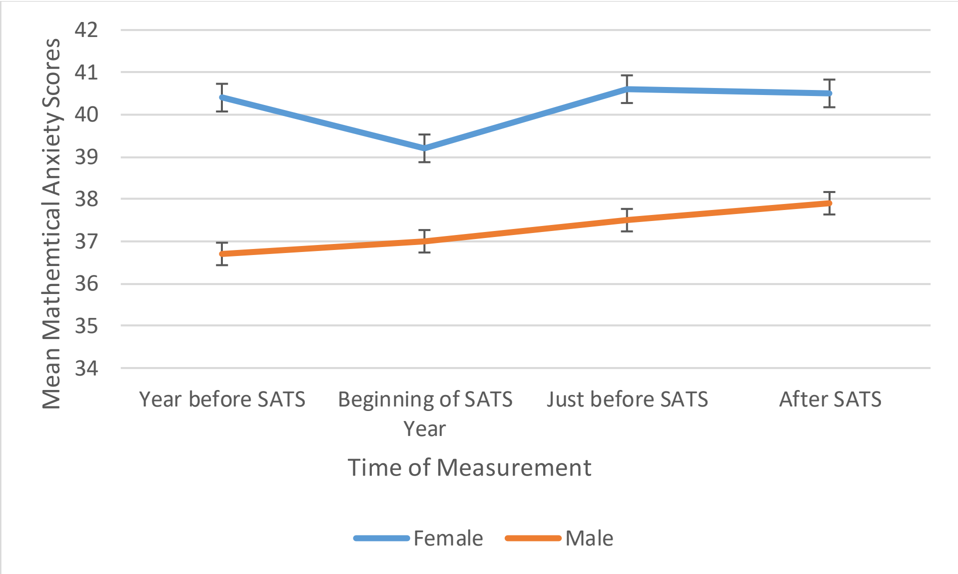

Figure 4.12: Mean trajectories for the variable Mathematical Anxiety (CAMS) by Gender over time.

Figure 4.12 displays the difference between the boys and girls mean scores at each time point.

4.5.8 Question d) Does the school that children attend predict the initial status and rate of growth of mathematical anxiety?

The third conditional latent growth curve analysis modelled the trends in mathematical anxiety across the whole project for the four time points adding school as a predictor. The school variable was added to attempt to explain the variability of the intercept and slope factors as seen in figure 4.13. The effect from the school factor indicates the sign and magnitude of the relationship between schools and the initial amount of mathematical anxiety and the different rates of change in mathematical anxiety between the two schools.

The Linear fit for this model can be described as:

$\chi^2(7) = 8.464$, p = .295, with an RMSEA = .040 and a CFI =.994 (see figure 4.13).

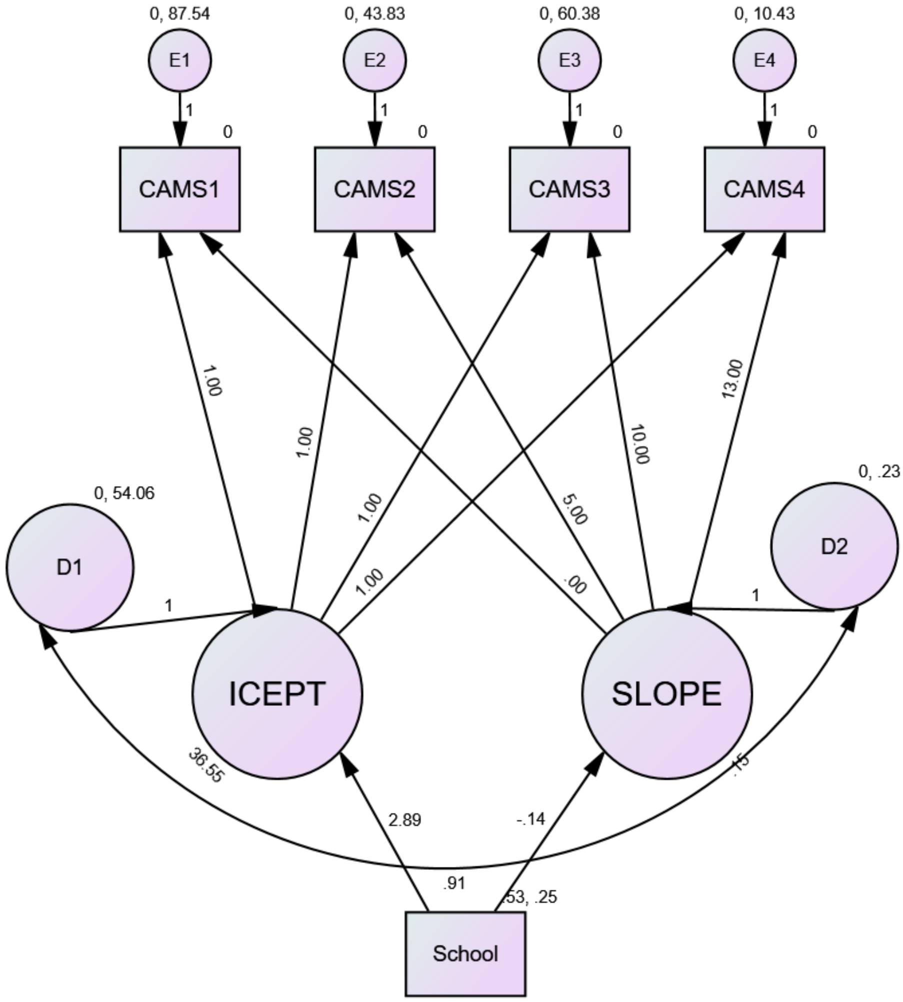

Figure 4.13: A path diagram of latent growth curve modelling for the variable Mathematical Anxiety (CAMS) over time with year as a predictor with specified factor loadings on the slopes with means, variances and covariance displayed (ICEPT=latent intercept factor, SLOPE=latent slope factor, E= measurement error, D= factor disturbance).

Parameter	Coefficient	SE	CR	P value
school mean	.531	.044	12.1	p<.001
School variance	.249	.031	8.03	p<.001
Intercept mean	37	1.3	28	p<.001
Slope mean	.150	1.0	1.5	p=.14
Intercept – slope covariance (D1-D2)	.91	1.0	.95	p=.34

Table 4.9: Parameter estimates for conditional latent growth curve model with school as a predictor.

The intercept for this model indicated that the average participant starts at a value of 36.5 for mathematics anxiety. The average rate of change over the project was .150 but this was not significant. In looking at the variances there was no significant covariance with a B= .9 (β= .26) as the significance level was p=.34 (see table 4.9).

Regression weights	Estimate	SE	CR	P value
Intercept ← school	2.9	1.8	1.6	p=.11
Slope ← school	-.14	.14	-1.02	p=.31

Table 4.10: Regression weights for conditional latent growth curve model with school as a predictor.

The regression paths for this model are of primary interest as they hold the key to whether the trajectory of mathematical anxiety differs for School A and School B children (see table 4.10). School as a predictor variable was not found to be a statistically significant predictor of both the initial status (B= 2.9, β= .19, p=.11) or the rate of change/ slope (B= -.14, β= -.15, p=.31). In this model it can be concluded that school as in the distinction of School A and School B children was not a good predictor of the initial starting point of mathematical anxiety in children. Also, that the rate of change in mathematical anxiety is not distinguishable between School A and School B children as indicated by the non-significant estimate (p= .31). Figure 4.14 illustrates the mean scores for mathematical anxiety at each time point for the different schools.

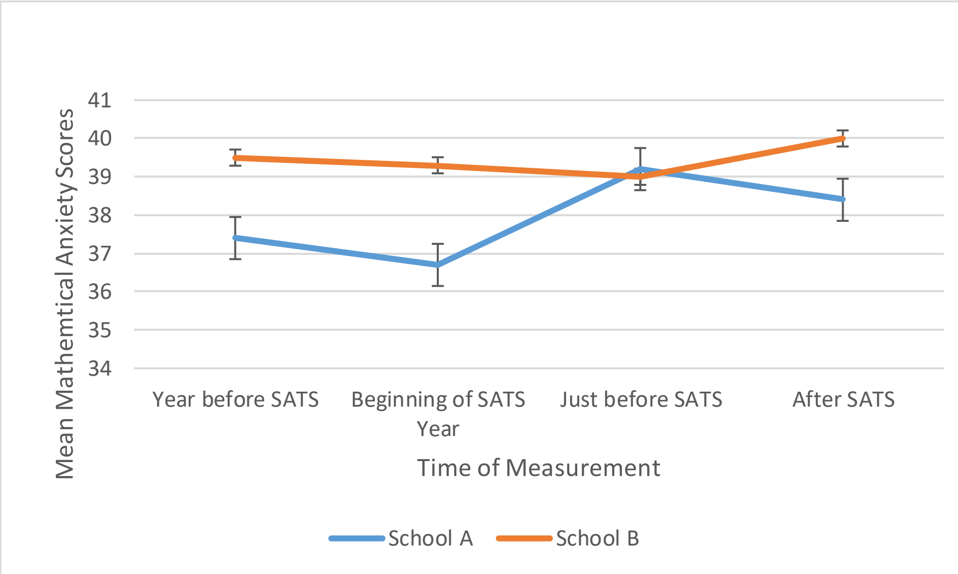

Figure 4.14: Mean trajectories for the variable Mathematical Anxiety by school group over time.

4.6 Discussion

This chapter aimed to characterise the development of mathematical anxiety over the eighteen-month period of this thesis. Results from the repeated measures ANOVAs indicated that the mean mathematical anxiety scores of both the older and younger children remained stable throughout the study time. Although there was significant variability in the individual initial mathematical anxiety and the individual trajectories of mathematical anxiety of the children (see figures 4.3, 4.4, 4.5 and 4.6). Growth curve analysis supported the previous findings in that there was no significant difference in the average rate of change of mathematical anxiety over the four time points. Moreover, it provided support for the finding of variability in individual initial mathematical anxiety at time point one and individual variability in the slopes. This individual variability led to further growth analyses to identify whether individual differences could predict this variation. Results from these further growth analyses, indicated that this individual variation in mathematical anxiety was not predicted by gender, year, or school.

The issue of whether there was a developmental effect of mathematical anxiety over time was investigated firstly at a group level through repeated measures ANOVAs. Group level mean mathematical anxiety scores remained stable with no significant differences from one time point to another for both the older and younger children. This differs from previous research as, Krinzinger et al, 2009, looked at the changes in the mean level of mathematical anxiety around failure from children aged six to nine years of age, over four time points (beginning of first grade, middle of second grade, end of second grade and middle of third grade). Using one sample t-tests they found that mathematical anxiety significantly increased with age over this study time. Although this research was carried out with primary aged children comparable to the younger children studied in this thesis and used four time points, there are some differences to the present study. Krinzinger et al., (2009) used a two-dimensional measure of mathematical anxiety (Math Anxiety Questionnaire, (MAQ): Thomas & Dowker, 2000) compared to the three-dimensional measure of mathematical anxiety (Children's Anxiety in Math Scale (CAMS): Jameson, 2013) used in the studies in this thesis. The use of different measures has been identified as a possible significant difference when comparing results from different studies (Sorvo et al., 2017).

The development of mathematical anxiety scores was confirmed by the latent growth curve modelling, which revealed that there was not a significant rate of growth in mathematical anxiety over the time period for the whole group, as the slope mean was not statistically significant. This suggests that there was no significant linear increase in the amount of mathematical anxiety reported from the initial testing point. This was the case for both the younger and older children. Longitudinal designs provide evidence for the development of mathematical anxiety over time (Ma & Xu, 2004). Ma and Xu, 2004, looked at the changes in mathematical anxiety in older children aged from twelve to eighteen, they found that the statistical stability of mathematical anxiety increased from the age of thirteen onwards. They suggested that mathematical anxiety was more apparent in children aged between thirteen and fourteen and from this age affected their subsequent mathematical anxiety scores more (Ma & Xu, 2004). This research was carried out with much older children and it could be that mathematical anxiety is stronger and develops quicker with much older children.

Explanations for increase in mathematical anxiety have suggested emotional and cognitive reasons. Emotional reasons include exposure to more negative attitudes of others (Ma & Kishor, 1997), more experiences of failure (Ashcraft, 2002; Ashcraft et al., 2007) and decreasing positive attitude to mathematics as a subject (Trice & Ogden, 1986). Moreover, it has been suggested that younger children report more interest and enjoyment in mathematics (Dowker, 2005; Ma & Kishor, 1997), the children in this study report stable interest in mathematics over time (see appendix chapter 4: Interest in mathematics).

Cognitive reasons include the increase in complexity and abstraction of the mathematics curriculum with age (Dowker, 2016).

Nonetheless investigating the individual trajectories, it can quite clearly be seen that the children reported a range of different initial status scores for their mathematical anxiety. Results from the basic latent growth curve model identified that there was significant variability in the individual intercepts at the initial time, that is that at time one, the previous year to the children taking their SATs, some of the children were already feeling significantly more anxious about mathematics than others. This was the case for both the younger and older children.

Equally individual children reported mathematical anxiety scores which had incremental, decremental and stable slopes (see figures 4.3, 4.4, 4.5 and 4.6). This finding concurs with previous research that has documented considerable variation in mathematical anxiety in children (Sorvo et al 2019). To interpret these individual differences in mathematical anxiety, latent growth curve modelling, which models the intra-individual (within person) change and the inter-individual (between person) change over the eighteen-month period was used. There was significant variability with the rate of growth of mathematical anxiety as the variance of the slope factor was significant. This would indicate that there is significant individual variability between children in their increase in mathematical anxiety (see figures 4.3, 4.4, 4.5 and 4.6).

Time invariant factors such as year, gender, and school, were investigated in order to find an explanation for the differences in the intercept and slope of mathematical anxiety. Although there looks to be trends in that there are differences in the younger and older children (see figure 4.10), females report more mathematics anxiety (see figure 4.12) and the schools have differences in mean scores at each time point (see figure 4.14). These trends are not significantly different. This is confirmed through the series of conditional growth curve models with year, gender and school included as predictors.

The inclusion of year into the conditional latent growth curve model attempted to explain whether being younger or older, predicted the initial status of mathematical anxiety, the longitudinal rate of growth and the individual difference in that growth. Year did not have a significant direct effect on the initial status of mathematical anxiety ($\beta = .08$, $p = .51$) nor the rate of growth ($\beta = -.09$, $p = .51$), therefore year did not predict how anxious the children felt a year before the SATS or their rate of growth of mathematical anxiety over the time period. As initial status of mathematical anxiety was not significantly predicted by year, therefore the level of mathematical anxiety reported by the children was not affected by which year they were in. As the slope mean was not statistically significant this suggests that there was no significant linear increase in the amount of mathematical anxiety reported from the initial testing point for both year groups. This finding of a non-significant rate of growth of mathematical anxiety does not concur with previous research around the age difference in reporting mathematical anxiety. Researchers have found that mathematically anxiety increases with age (Dowker, 2016), with children in secondary school reporting more mathematics anxiety (Ma & Kishor, 1997). As stated earlier this finding is more consistent with previous findings of younger children (Harari et al., 2013). Therefore, in this thesis, which year the children were in is not a predictor of mathematical anxiety development.

The inclusion of gender into the conditional latent growth curve model attempted to explain whether being male or female, predicted the initial status of mathematical anxiety, the longitudinal rate of growth and the individual difference in that growth. Gender did not have a significant direct effect on the initial status of mathematical anxiety ($\beta = .17$, $p = .14$) nor the rate of growth ($\beta = -.05$, $p = .73$), therefore gender did not predict how anxious the children felt a year before the SATS or their rate of growth of mathematical anxiety over the time period. This finding of no difference in mathematical anxiety scores between males and females agrees with Harari et al., (2013), who found no significant difference for children aged six to seven and Van Mier et al., (2019) for children aged seven to ten. However, it is not consistent with other researchers who have reported that females tend to express more mathematical anxiety than males in nine-year-old children (Hill et al., 2016) eleven-year-old children (Vanbinst et al., 2020) and eleven to fifteen-year-olds (Devine et al, 2012). Alternatively, a more recent study found that girls aged seven to eight years of age reported more mathematical anxiety than males but only for total and testing mathematical anxiety and not learning mathematical anxiety (Szczygiel, 2020a). Therefore, the age of the children appears to be an important factor in any gender differences in mathematical anxiety. As much younger children (aged five to six years of age) were included within the sample for analysis, this could provide an explanation why there is no significant difference in mathematical anxiety between males and females. Previous explanations for the increased mathematical anxiety in females include stereotype threat where females feel that they are not good at mathematics compared to males (Dowker et al, 2016), teacher's mathematical anxiety where female children with female teachers with mathematical anxiety, become attuned to their teacher's anxieties and develop mathematical anxiety (Beilock et al, 2010) and female willingness to admit their feelings (Ashcraft, 2002). As there was no significant difference in mathematical anxiety between males and females, all that can be established is that there was no effect of gender. Moreover, as the slope mean was not statistically significant this suggests that there was no significant linear increase in the amount of mathematical anxiety reported from the initial testing point for both males and females. Therefore, in this thesis, gender is not a predictor of mathematical anxiety development.

The inclusion of school into the conditional latent growth curve model attempted to explain whether the school that the children attended, predicted the initial status of mathematical anxiety, the longitudinal rate of growth and the individual difference in that growth. School did not have a significant direct effect on the initial status of mathematical anxiety ($\beta = .19$, $p = .11$) nor the rate of growth ($\beta = -.15$, $p = .31$), therefore school did not predict how anxious the children felt a year before the SATS or their rate of growth of mathematical anxiety over the time period. As initial status of mathematical anxiety was not significantly predicted by school, therefore the level of mathematical anxiety reported by the children was not affected by which school they attended. This non-significant effect of school on mathematical anxiety means that mathematical anxiety was not affected by the school the children attended. Previous research has suggested that environment has a significant effect on the development of mathematical anxiety. Previous explanations include the classroom environment (Ashcraft et al, 2007; Beilock et al, 2010), the style of teaching (Hembree, 1990), teachers modelling anxiety (Beilock et al, 2010), negativity of teachers (Furner & Duffy, 2002; Jackson and Leftingwell, 1999) and geographical region (Ho et al., 2015). Therefore, in this thesis, school is not a predictor of mathematical anxiety development.

4.7 Chapter summary:

4.7.1 Question A) Is there a developmental effect of mathematical anxiety over time?

- From the repeated measures ANOVAs, it was found that the average mathematical anxiety stayed stable for both the older and younger children.

- From the latent growth curve modelling the intercept mean was equal to the mean of the children's mathematical anxiety at the initial time.

- The slope mean was not statistically significant which indicates that there was no significant difference in average rate of change of mathematical anxiety over the four time points.

4.7.2 Question A1) What are the children's trajectories of change in mathematical anxiety over time?

- The trajectories clearly show the variance in slopes of the children, the linear lines show that the children's mathematical anxiety scores over time increase, decrease or remain stable throughout (see figures, 4.3, 4.4, 4.5 and 4.6).

4.7.3 Question A2) Are there significant inter- individual differences in the children's intial scores of mathematical anxiety at time point one?

- There was significant variability in the individual intercepts at the initial time, that is that at time one, the previous year to the children taking their SATs, some of the children were already feeling more anxious about mathematics than others.

4.7.4 Question A3) Are there inter-individual differences in the growth trajectory of mathemematical anxiety in the children?

- At the group level there was not a significant rate of growth in mathematical anxiety over time as the slope mean was not statistically significant.

- At the individual level there was significant variability with the rate of growth of mathematical anxiety as the variance of the slope factor was significant.

4.7.5 Is the initial status or rate of growth of mathematical anxiety predicted by gender, year, or school?

- Gender did not predict the initial status are rate of growth of mathematical anxiety over time.

- Year did not predict the initial status or the rate of growth of mathematical anxiety over time.

- School did not predict the initial status or rate of growth of mathematical anxiety over time.

Chapter 5- The relationship between mathematical anxiety and mathematical performance for the key stage one children.

Chapter contents:

The previous chapter discussed the development of mathematical anxiety in detail. It outlined the specific longitudinal group differences of mathematical anxiety over time using repeated measures ANOVAS and Latent growth curve modelling. It then investigated the individual trajectories of mathematical anxiety for all the participants. Finally using time invariant predictors (year, gender, and school) within latent growth curve modelling outlined whether they were significant predictors of the children's initial and rate of growth of mathematical anxiety. This chapter begins to look at the relationship between mathematical anxiety and mathematical performance over time. This chapter will describe these relationships with reference to the Key Stage one (KS1), the younger children within the sample at each time point. The chapter is divided into the following subsections:

- Introduction
- Aims
- Hypotheses
- Method: Participants, Materials and Procedure.
- Results
    - Descriptive Statistics
    - Analyses
    - Question A) what is the relationship between mathematical anxiety and mathematical performance?
    - Question B) Is the relationship between mathematical anxiety and mathematical performance significant above a child's general anxiety and cognitive levels?
- Chapter Discussion.
- Chapter summary.

5.1 Introduction

The focus of this chapter is to examine the relationship between mathematical anxiety and mathematical performance over time. In particular this relationship is being studied within the Primary stage of Education within the UK, which is divided in to three age ranges, Foundation (children under 5 years of age), Infant (children aged between 5 and 7) and Junior (children aged between 8 and 11). This distinction then links to the Curriculum for each age range, with children being taught the Early years Foundation stage (EYFS) statutory framework (birth to 5 years of age) and then moving onto the National Curriculum, which is subdivided into Key Stage one (5 to 7 years of age) and Key stage two (8 to 11 years of age).

Primary Education within the UK sets out to provide children with a good level of understanding in the core subjects of English, Mathematics and Science along with a foundational level of understanding in the foundation subjects, art and design, computing, design and technology, physical education, history, geography, and music (Department of Education, 2014).

From the National Curriculum standards are set for children to achieve at the end of each key stage. In Key Stage 1 these standards are working towards the expected standard, working at the expected standard, and working at greater depth within the expected standard. The standards are described as a series of "pupil can" statements, which teachers assess the children against and to achieve a standard the children must meet all the statements within a standard. In English reading and mathematics, the teachers' judgements of a child's ability must be linked to their performance on the KS1 SATs (Standards and Teaching Agency, 2018).

In particular, this thesis will examine this relationship between mathematical anxiety and mathematical performance in the younger children from the year before their national testing and then at key points in the year of National Testing. The UK uses Standard Attainment Tests (SATs) in year two (age 7) to assess children nationally. They were devised as end of Key Stage Tests to assess children's knowledge and understanding of the specific contents of the National Curriculum, introduced as part of the Education Reform Act in 1988 (DfES, 1988). They were initially devised as a measurement of the individual abilities of each child and were intended to provide useful indicators of the child's next steps in learning. Subsequently they are being used as a means of accountability for teachers, schools, and local authorities (West, 2010), with the introduction of the publication of results nationally in 1991.

Assessment is an important feature in education as it provides a means of collecting, analysing, and interpreting information about children's performance at different stages to aid decision making (Black & Wiliam, 1998). Assessment can be divided into formative (where ongoing assessment informs teachers of the next steps needed for children to progress) and summative (where a score or value is given at the end of a program of study). High stakes tests are a particular form of summative assessment. They are tests that are administered, where there are rewards or sanctions that are conditional on the results from these tests (Harlen, 2007). The SATs are high stakes as the children's results from these tests are then used to hold to account teachers, schools, local authorities and even governments for their performance (Regan-Stansfield, 2017).

KS1 SATS are significant high stakes tests in infant schools (schools that provide education to children from five to seven years of age) in assessing the attainment of children at the end of KS1. As these SATs results can have consequences for infant schools, through their subsequent classification after an OFSTED visit, due to the national benchmarking of KS1 SATS (Segal, Snell & Lefstein, 2016). For primary schools (schools providing education for children from five to eleven years of age) covering both KS1 and KS2, they are also significant high stakes tests as they provide a baseline for the progress measure at the end of KS2. For the children in KS1 themselves, these tests are not presented to them as "High Stakes" tests. As the approach promoted when administering KS1 SATS is that the tasks are as far as possible assimilated into the normal everyday classroom tasks. The tasks are administered in small groups, within normal lesson time with no time limits imposed. The tasks within the SATs are closely supervised by the children's own class teachers and the aim whilst supervising them is for the children not too realise that they are being tested (STA, 2020a). Therefore, everything is done within the school to try to reduce the pressure on the children with a much more low-key mode of administration. The tests at this age are administered by the class teacher in order to make it a less stressful experience for the children but the children still know that they are being tested. Researchers have shown that even with the attempts made to keep the testing within the normal school routine for the children, some children do experience stress from the situation. (Connor, 2003).

In KS1, the children are required to demonstrate that they have good knowledge and skills to solve age-appropriate arithmetic and word problems successfully (DFE, 2013b). They need to demonstrate three types of knowledge. Factual knowledge which is their understanding of the numbers and the types of operations e.g., ability to read and write numbers to 100, and know the four main operations, addition, subtraction, multiplication, and division (DFE, 2013b). Procedural knowledge which is the knowledge of the processes that the different operations perform on the numbers e.g., to perform addition and subtraction on two-digit numbers and understand the 2, 5 and 10-times tables in order to solve simple problems (DFE, 2013b). Conceptual knowledge the principles behind the operations, for example where in addition the sum of two numbers is always a larger number e.g., 5 + 6 =11 (Leferve, Wells and Sowinski, 2015). Equally, that the effect of subtraction is to produce an answer that is less than the first number e.g., 18 - 8 =10. Another principle is the understanding of commutativity, where numbers in addition and multiplication can be moved around in any order and you still get the same answer e.g., 6 + 4=10 and 4 + 6 = 10 or 5 x 3 =15 and 3 x 5 =15. They also have to demonstrate a good level of mathematical fluency, that is their ability to answer arithmetic questions quickly and correctly using whole numbers (whole numbers are numbers that are not expressed as fractions or decimals) (DFE 2013b; McClure, 2014). Mathematical Fluency demonstrates that the children have committed these facts to memory and no longer need to work them out each time they meet the question e.g., their number bonds to 20 and their two, five and ten-times tables (Vukovic et al., 2010). Researchers have indicated arithmetic facts in a form of "verbal code" (Deheane, 1992) are stored within the long-term memory of individuals (Ashcraft, 1987; Verguts & Fias, 2005). Thus, it is thought that younger children are still developing the skill of automatic retrieval of facts and verbal codes and will most likely rely on other strategies to help them recall the simple arithmetic facts in order to answer basic arithmetic and word problems. To support this, children of this age will rely on concrete apparatus such as blocks, cubes or even their fingers to support them in recalling these facts (Jordan, Kaplan, Ramineni & Locuniak, 2008; Laski, Jor'dan, Daoust, & Murray, 2015). These younger children are still developing the mathematical knowledge and skills, but it may be that emotional factors may hinder this development.

Mathematical anxiety, which is described as feelings of insecurity in one's ability to perform mathematical tasks well (Witt, 2012) is a significant emotional factor affecting mathematical performance in children. Mathematical anxiety affects individuals in everyday situations, where working with number is required, as well as in their school and academic lives. (Richardson & Suinn, 1972). This negative effect is significant for this research as it seems to develop from an early age, having been reported in children as young as 6 or 7 years of age (Thomas & Dowker, 2000; Krinzinger et al., 2009; Namkung, Peng & Lin, 2019; Ramirez et al., 2013). Recent qualitative work with children has found that children as young as four years of age describe their anxiety around mathematics (Petronzi, Staples, Sheffield, Hunt & Fitton-Widle, 2017). This research identified four main themes that the children had around their experience of mathematics, emotional responses to numeracy, coping strategies, teachers/teaching, and influence/ perception of others (Petronzi et al, 2017). The children were able to discuss in some detail their mathematical experiences within the four main themes.

Mathematical performance, the ability of children to solve mathematical tasks is measured in several different ways by researchers. The mathematical tasks require children to solve arithmetic, reasoning and word problems. Researchers (Krinzinger et al., 2009; Ramirez et al., 2015; Sorvo et al., 2017; Thomas & Dowker, 2000; Vukovic et al., 2013; Wu et al., 2012) lack agreement regarding the relationship between mathematical anxiety and the particular type of mathematical performance in children. Some researchers have identified significant negative relationships with mathematical anxiety, for advanced problem-solving strategies (Ramirez et al., 2015), calculation problems (Vukovic et al., 2013) complex verbal reasoning (Wu et al., 2012) and mathematical fluency (Sorvo et al., 2017) in younger children. Whilst others reported no significant relationships specifically with calculation ability (Krinzinger et al., 2009; Thomas & Dowker, 2000) in younger children. Therefore, the studies in this research were devised to investigate the relationship between mathematical anxiety and mathematical performance, using varying measures of mathematical performance:

- Mathematical fluency, their ability to solve arithmetical questions at speed.

- Mathematical complexity, their ability to solve age-appropriate arithmetic and word problems with no time limit.

It was important to establish whether there was a relationship between mathematical anxiety and mathematical performance, cross sectionally at each time point for the younger children.

5.2 Aims

The aim of all four studies was to investigate the specific nature of the relationship between mathematical anxiety and mathematical performance at each time point**.** Mathematical performance was defined in two ways their mathematical fluency and their mathematical complexity. Mathematical fluency was measured through their ability to correctly solve a series of basic addition, subtraction, and multiplication questions in a specific time. Mathematical complexity was measured through their ability to correctly solve arithmetic and word problems, like problems from the age-appropriate Standard Attainment tests.

The aim of studies one and three were to investigate the specific nature of children's self-reported mathematical anxiety and the association with their mathematical performance considering emotional and cognitive properties of the children. The aim of studies two and three were to provide data for the association between children's self- reported mathematical anxiety and their mathematical performance at the beginning and the end of their SATs year.

In this chapter the following questions are examined to fully understand the pattern of the relationship between mathematical anxiety and mathematical performance for the younger children.

Question A) What is the association between mathematical anxiety and mathematical performance over time?

Question B) Is the relationship between mathematical anxiety and mathematical performance significant above a child's general anxiety levels and general cognitive levels?

5.3 Hypotheses

All four studies have the following hypothesis:

The first hypothesis was that mathematical anxiety would negatively associate with mathematical performance. From previous research, it was predicted that there would be mathematical anxiety present in the younger children (Harari et al, 2013; Jamieson & Ross, 2011; Petronzi, Staples, Sheffield, & Hunt, 2019) (see chapter four for the pattern of mathematical anxiety in the younger children). It was also predicted that the association between mathematical anxiety and mathematical performance would be equal for all the mathematical performance measures for the younger children. As all the measures of mathematical performance would require greater cognitive resources for the younger children as their mathematical performance is not yet automatic. They are still learning the arithmetical facts and beginning to develop the ability for automatic recall. In line with The Processing Efficiency Theory (Eysenck & Calvo, 1992) a theory developed to explain how performance is affected by worry, children's ability to solve problems is hindered by their worrisome thoughts. This theory when applied to mathematical anxiety proposes that the mathematical performance of children is affected because the children become preoccupied with worrisome thoughts rather than concentrating on the task in hand. A consequence of this preoccupation with worrisome thoughts is a depletion of working memory resources (Ashcraft & Kirk, 2001; Ramirez et al., 2016). Therefore, the more mathematically anxious children find it harder to concentrate on the mathematical tasks, due to the depletion of their available working memory resources being consumed by worrying thoughts.

> H1- High levels of mathematical anxiety will be significantly associated with lower levels of mathematical performance.

Studies 1 and 3 enable a more detailed hypothesis incorporating the cognitive and emotional variables.

2) The second hypothesis was that the negative relationship between mathematical anxiety and mathematical performance would still be present after controlling for the negative association with general anxiety (as measured by Trait and State anxiety) and the positive association with cognitive variables (as measured by non-verbal intelligence and working memory). As previous researchers have indicated that there is a negative association between general anxiety and mathematical performance in college students (Aronen et al., 2005; Grezo & Sarmany-Schuller, 2018; Heppner, Willy & Dixon, 2004), but that

mathematical anxiety is a separate construct it is important to be able to control for the children's general anxiety.

Equally, it is important to control for the cognitive variables such as non-verbal intelligence (Kyatta & Lehto, 2008; Nunes et al., 2007) and working memory (Bull & Scerif, 2001; Cowan & Alloway, 2008; Swanson& Sachse-Lee, 2001) which researchers have indicated provides a significant positive relationship with mathematical performance.

> H2- High levels of mathematical anxiety will be associated with lower levels of mathematical performance after controlling for general anxiety (Trait and State) and specific cognitive skills (non-verbal intelligence and working memory).

5.4 Method

The methodology of this longitudinal study is described in detail in Chapter 3.

5.4.1 Participants

At time one, the year before their SATs, sixty-seven year one children (M=75 months of age, SD= 3.7) were originally recruited from two schools in the Nottingham area. This cohort was followed up at time point two, the beginning of the SATs year (n=64, M = 80 months of age, SD=3.7), then time point three, just before their SATs (n= 61, m= 85 months of age, SD= 3.5) and finally at time point four, after the SATs (n =59, m = 88months of age, SD= 3.2). (See chapter 3 for more details about the participants).

5.4.2. Materials

At time point one and three the children were assessed on all the emotional (Interest in mathematics, Trait, State and mathematical anxiety), Cognitive (Non-verbal intelligence, Reading and Working Memory) and Mathematical Performance (Fluency, Arithmetic and Word problem solving) measures. At time points two and four the children were only assessed on State Anxiety, Mathematical anxiety, and the measures of mathematical performance (see chapter three for specific details of the different measures).

5.4.3. Procedure

As described in chapter three, testing took place over several sessions, with assessments being administered on a one-to-one basis with each child and the researcher in a small quiet space within the school. Apart from the mathematical fluency test which was administered in small group sessions with no more than six children at a time.

Testing was carried out four times over an eighteen-month period from summer of school year one (April-July 2017), autumn term of school year two (Sept-Dec 2017), Spring/summer term of school year two (March-May 2018) and summer term of school year two (June-July 2018).

All testing was carried out by the author and general praise and encouragements were the only feedback given.

5.5 Results

5.5.1 Descriptive Statistics.

The means and standard deviations of the all the measures for the younger cohort for each time point are provided in table 5.1.

Younger children	Study 1 Mean (SD) (N=67)	Study 2 Mean (SD) (N=64)	Study 3 Mean (SD) (N=61)	Study 4 Mean (SD) (N=59)
Emotional				
Mathematical Anxiety	37.3 (11.7)	37.7 (12.2)	37.6 (13.3)	39.1 (11)
Trait Anxiety	32.5 (6.7)		32.2 (8.5)	
State Anxiety	30.9 (5.1)	32.6 (4.9)	31.4 (6.4)	32.5 (5.4)
Interest in Mathematics	43.4 (12.6)		43.5 (12.2)	
Cognitive				
Non-verbal Intelligence	18.2 (0.25)		22.8 (5.7)	
Reading	19.9 (9.3)		29.7 (10.6)	
Working Memory	1.5 (0.70)		2.1 (0.77)	
Mathematical Performance				
Mathematical Fluency	22.8 (10.3)		34.1 (17.2)	37.1 (7.2)
Arithmetic	3.9 (3.9)	2.4 (2.3)	4.4 (2.8)	4.9 (2.6)
Word Problem Solving	2.3 (2.3)	1.1 (1.3)	1.8 (1.8)	2.8 (2.6)

Table 5.1: Means and Standard deviations for emotional, cognitive, and mathematical performance measures for the younger children for each study.

5.5.1 Assessing Normality: Looking for outliers in the data.

At time one outliers were found in the data for the measures of state anxiety and interest in mathematics, as well as mathematical fluency. At time point two outliers were found in the data for the measures of mathematical anxiety. state anxiety and word problem performance. At time point three, outliers were found in the data for the measures of working memory, state anxiety, interest in mathematics and mathematical fluency. At time point four, outliers were found in the data for the measures of state anxiety and mathematical fluency.

No data was excluded from all the participants as once the trimmed means were checked they were found to be similar to the mean for each variable. (Pallant, 2013).

5.5.2 Analyses.

Analyses were undertaken to ensure no violation of assumptions including normality, linearity, and homoscedasticity. Therefore, the analyses chosen were parametric in nature including Correlations and Hierarchical Regressions. Pearson product-moment correlations coefficients were reported in the correlational analyses. Throughout statistical significance was set at $p<.05$. Prior to conducting the series of hierarchical multiple regressions, the relevant assumptions of this statistical analysis were tested. Firstly, the sample sizes were considered acceptable given that there were five independent variables to be included in the analysis (Khamis & Kepler, 2010, Tabachnick & Fidell, 2014). The assumption of singularity was also met as the independent variables (Working memory, non-verbal intelligence, trait, state, and mathematical anxiety) were not a combination of other independent variables. An examination of correlations (see Correlation tables in chapter 5 appendix) revealed that no independent variables were highly correlated, as none of the predictors correlated at .80 or above. However, the assumption of multicollinearity was accepted as the collinearity statistics of Tolerance and VIF were all within acceptable limits, (Coakes, 2005; Hair, Black, Babin, Anderson &Tatham, 2006). Univariate outliers identified in initial data screening in the extreme range were kept, as the trimmed means were similar to the means in all variables (Pallant, 2013). Residual and scatter plots indicated the assumptions of normality, linearity and homoscedasticity were all satisfied (Hair et al., 2006; Pallant, 2013).

5.5.3 Question A) What is the relationship between mathematical anxiety and mathematical performance?

In answering this question, the association between mathematical anxiety was investigated with each measure of mathematical performance.

Correlations coefficients with Mathematical Anxiety	Study 1	Study 2	Study 3	Study 4
Mathematical Fluency	-.28*		-.40**	-.3
Arithmetic	-.16	-.3*	-.38**	-.14
Word Problem Solving	-.05	-.4*	-.40**	-.21

Table 5.2: Correlation coefficients for mathematical anxiety and all measures of mathematical performance for each of the studies for the younger children (“**p* < .05, ***p* < .01”).

5.5.3.1 Mathematical Fluency.

The association between Mathematical Anxiety and the measure of mathematical fluency was investigated using Pearson product-moment correlations coefficients at three of the time points (time 1, time 3 and time 4). At time point one, there was a negative correlation between the two variables, r= -.3, n= 67, p = .024. At time point three, there was also a negative correlation between the two variables, r= -.4, n= 61, p = .001. Indicating that at time one and three high levels of mathematical anxiety were associated with lower levels of mathematical fluency. At time point four, there was no significant correlation between the two variables, r= -.3, n= 59, p = .084. indicating that there was no association between mathematical fluency and mathematical anxiety at this time point (see table 5.2).

5.5.3.2 Arithmetic performance.

The relationship between Arithmetic scores and Mathematical Anxiety was investigated using Pearson product-moment correlations coefficient. At time point one, the negative correlation between the two variables, r= -.16, n= 67, p =.21, was not significant. At time point two, there was a negative correlation between the two variables, r= -.3, n= 64, p = .017 and at time point three, there was a negative correlation between the two variables, r= -.38, n= 61, p = .00. Indicating that high levels of mathematical anxiety were associated with lower levels of arithmetic performance.

At time point four, there was no significant correlation between the two variables, r= -.14, n= 59, p =.28 (see table 5.2).

5.5.3.3 Word problem solving performance*.*

The relationship between Word problem- solving scores and Mathematical Anxiety was investigated using Pearson product-moment correlations coefficient. At time point one, the negative correlation between the two variables, r= -.05, n= 67, p = .68 was not significant. At time point two, there was a negative correlation between the two variables, r= -.38, n= 64, p = .002. Also, at time point three, there was a negative correlation between the two variables, r= -.4, n= 61, p = .001, with high levels of mathematical anxiety associated with lower levels of word problem solving performance. At time point four, there was no significant correlation between the two variables, r= -.21, n= 59, p = .104

Hypothesis one is met as there is a negative association between mathematical anxiety and measures of mathematical performance, but this is dependent on the type of performance and the time at which they were measured. At time point one, this significant negative association is only for one measure of mathematical performance namely, mathematical fluency. At time point two, there is a significant negative association between mathematical anxiety and arithmetic and word problem solving performance. At time point three, there is a significant negative association between mathematical anxiety and all the measures of mathematical performance. At time point four there are no significant negative associations between mathematical anxiety and mathematical performance. Therefore, the significant negative associations between mathematical anxiety and mathematical performance changes over time for the younger children.

5.5.4 Question B) Is the relationship between mathematical anxiety and mathematical performance significant above a child's general anxiety and cognitive levels?

In answering this question, the relationship between mathematical anxiety and mathematical performance was investigated for each measure of mathematical performance at time point one and three along with the emotional and cognitive variables.

Two-step hierarchical multiple regressions were conducted with the measure of mathematical performance as the dependent variable. Working memory and non-verbal Intelligence were entered at step one of the hierarchical multiple regression, to adjust statistically for cognitive abilities. These two predictors were entered in step one as previous research have found positive associations between working memory (Caviola, Mammarella, Cornoldi & Lucangeli, 2012; Korhonen, J., Nyroos, M., Jonsson & Eklof, 2017) and non –verbal Intelligence (Kyttala & Lehto,

2008) with mathematical performance. The emotional variables (Trait, state and mathematical anxiety) were entered at step two as general anxiety has been found to have a negative association with mathematical performance in previous research (Aronen et al., 2005; Crezo & Sarmany-Schuller, 2018; Heppner, Willy & Dixon, 2004). The means and SDs for each variable at each time point can be seen in Table 5.1. Intercorrelations between the multiple regression variables at each time point and with each of the measures of mathematical performance can be found in chapter 5 appendix.

5.5.4.1 Mathematical Fluency.

At time point one, the overall relationship was highly significant at step two, (F (5,61) = 8.823, p < .001) with a good fit (multiple R = .65). Analysing the un-standardised coefficients showed that Non-verbal intelligence (B = 1.1, t (66) =5.3, p<.001) was the only significant predictor of mathematical fluency (R^2 = 0.42). The standardised coefficients showed that non-verbal intelligence was a positive predictor of mathematical fluency (β = .55), therefore higher scores on the non- verbal intelligence test indicated higher mathematical fluency scores (see table 5.3).

	β	t	p	R	R^2	Δ R^2
Step 1				**.63**	**.39**	**.39**
Working memory	.13	1.3	.20			
Non-verbal Intelligence	.60	6.0	P<.001***			
Step 2				**.65**	**.42**	**.03**
Working memory	.12	1.3	.20			
Non- verbal Intelligence	.60	6.1	P<.001***			
Trait Anxiety	.15	1.4	.17			
State Anxiety	-.06	-.48	.63			
Mathematical Anxiety	-.13	-.99	.33			

Table 5.3: Summary of Hierarchical Regression Analysis for Variables predicting Mathematical Fluency at time point one. (N =67; *p < .05, **p < .01, ***p< .001).

At time point three, the overall relationship was highly significant at step two, (F (5,55) = 4.5, p = .002) with a good fit (multiple R = .54). Analysing the un-standardised coefficients showed that Non-verbal Intelligence (B = .90, t (60) =2.3, p=.028) was the only significant predictor of mathematical fluency (R^2 = 0.30) The standardised coefficients showed that Non-verbal Intelligence was a positive predictor of mathematical fluency (β = .30), therefore higher scores on the non- verbal intelligence test indicated higher mathematical fluency scores (see table 5.4).

	β	t	*p*	R	R^2	Δ R^2
Step 1				**.47**	**.22**	**.22**
Working memory	.13	1.1	.28			
Non-verbal Intelligence	.41	3.4	P<.001**			
Step 2				**.54**	**.30**	**.07**
Working memory	.14	1.1	.27			
Non-verbal Intelligence	.30	2.3	.03*			
Trait Anxiety	-.01	-.07	.95			
State Anxiety	-.07	-.57	.57			
Mathematical Anxiety	-.25	-1.8	.082			

Table 5.4: Summary of Hierarchical Regression Analysis for Variables predicting Mathematical Fluency at time point three (N =61; *p < .05, **p < .01, ***p< .001).

For the younger children mathematical anxiety is not a significant predictor of mathematical fluency at either time point, it is the non-verbal Intelligence of the child that is the strongest predictor.

5.5.4.2 Arithmetic performance.

At time point one, the overall relationship was highly significant at step 2, (F (5,61) = 8.2, p < .001) with a good fit (multiple R = .63). Analysing the un-standardised coefficients showed that non-verbal Intelligence (B = .2, t (66) =5.5, p<.001) was the only significant predictor of arithmetic performance (R^2 = 0.40). The standardised coefficients showed that non-verbal intelligence was a positive predictor of arithmetic performance (β = .58), therefore higher scores on the non-verbal Intelligence test indicated higher arithmetic scores (see table 5.5).

	β	t	p	R	R^2	Δ R^2
Step 1				**.61**	**.38**	**.38**
Working memory	.17	1.7	.094			
Non-verbal Intelligence	.57	5.7	P<.001***			
Step 2				**.63**	**.40**	**.03**
Working Memory	.20	1.9	.06			
Non- verbal Intelligence	.58	5.5	P<.001***			
Trait Anxiety	.13	1.2	.23			
State Anxiety	.11	.94	.35			
Mathematical Anxiety	-.07	-.54	.59			

Table 5.5: Summary of Hierarchical Regression Analysis for Variables predicting Arithmetic performance at time point one. (N =67; *p < .05, **p < .01, ***p< .001).

At time point three, the overall relationship was highly significant at step two (F (5,55) = 5.9, p < .001) with a good fit (multiple R = .59). Analysing the un-standardised coefficients showed that both non-verbal intelligence (B= .22, t (60) =3.5, p=.001) was the only significant predictor of arithmetic performance (R^2 =0.35). The standardised coefficients showed that non- verbal intelligence was a positive predictor of arithmetic performance (β = .44) therefore higher scores on the non-verbal intelligence test indicated higher arithmetic scores (see table 5.6).

	β	t	*p*	R	R^2	ΔR^2
Step 1				**.56**	**.31**	**.31**
Working memory	.10	.86	.39			
Non-verbal intelligence	.52	4.6	P<.001***			
Step 2				**.59**	**.35**	**.04**
Working memory	.11	.91	.37			
Non-verbal Intelligence	.43	3.5	P<.001***			
Trait Anxiety	-.03	-.25	.80			
State Anxiety	-.07	-.59	.56			
Mathematical anxiety	-.16	-1.2	.23			

Table 5.6: Summary of Hierarchical Regression Analysis for Variables predicting Arithmetic performance at time point three (N =61; *p < .05, **p < .01, ***p< .001).

For the younger children mathematical anxiety is not a significant predictor of arithmetic performance, once again it is the non-verbal Intelligence of the child that is the strongest predictor.

5.5.4.3 Word Problem-solving performance.

At time point one, the overall relationship was highly significant at step two (F (5,61) = 5.0, p = .001) with a good fit (multiple R = .54). Analysing the un-standardised coefficients showed that both non- verbal intelligence (B= .15, t (66) =4.2, p<.001) and working memory (B = .56, t (66) =2.2, p=.030) were significant predictors of word problem solving performance ($R^2 = 0.29$). The standardised coefficients showed that non-verbal intelligence (β = .48) was a slightly stronger predictor of word problem solving scores than working memory (β = .25). As both predictors were positive this indicates that higher scores on the non-verbal intelligence and working memory tests indicate higher word problem solving scores (see table 5.7).

	β	t	*p*	R	R^2	ΔR^2
Step 1				**.51**	**.26**	**.26**
Working memory	.21	1.9	.053			
Non-verbal Intelligence	.44	4.1	P<.001***			
Step 2				**.54**	**.29**	**.03**
Working memory	.25	2.2	.030*			
Non-verbal Intelligence	.48	4.2	P<.001***			
Trait Anxiety	.05	.44	.66			
State Anxiety	.11	.86	.39			
Mathematical Anxiety	.05	.33	.75			

Table 5.7: Summary of Hierarchical Regression Analysis for Variables predicting Word Problem Solving performance at time point one. (N =67; *p < .05, **p < .01, ***p< .001).

At time point three, the overall relationship was highly significant at step two (F (5,55) = 6.4, p < .001) with a good fit (multiple R = .61). Analysing the un-standardised coefficients showed that both non-verbal intelligence (B = .11, t (55) =2.8, p=.006) and state anxiety (B = -.07, t (55) =-2.1, *p*=.041) were significant predictors of word problem solving performance (R^2 = 0.38). The standardised coefficients showed that non-verbal intelligence (β = .35) was a positive predictor of word problem solving scores and was slightly stronger than the negative predictor state anxiety (β = -.25) (see table 5.8).

	β	t	*p*	R	R^2	Δ R^2
Step 1				**.51**	**.26**	**.26**
Working memory	.14	1.2	.23			
Non-verbal Intelligence	.45	3.8	P<.001***			
Step 2				**.61**	**.38**	**.12**
Working memory	.10	.80	.43			
Non-verbal Intelligence	.35	2.8	.006**			
Trait Anxiety	.11	.9	.37			
State Anxiety	-.25	-2.1	.041*			
Mathematical Anxiety	-.20	11.5	.14			

Table 5.8: Summary of Hierarchical Regression Analysis for Variables predicting Word Problem Solving performance at time point three. (N =61; *p < .05, **p < .01, ***p< .001).

For the younger children mathematical anxiety is not a significant predictor of arithmetic performance, once again it is the non-verbal intelligence of the child that is the strongest predictor.

Hypothesis two is not met as mathematical anxiety is not a significant predictor of any of the measures of mathematical performance when taking account of the children's general anxiety (trait and state) and their non-verbal intelligence and working memory.

5.6 Chapter Discussion.

The relationship between mathematical anxiety and mathematical performance was investigated in the younger children over four time points. These time points were specifically designed to test children before (time point one), during (time points two and three) and after (time point four) their high stakes testing, KS1 SATs. Correlational data between mathematical anxiety and each measure of mathematical performance (fluency, arithmetic, and word problems) was investigated at each time point. Mathematical fluency significantly negatively correlated with mathematical anxiety at time point one (before the SATs year) and three (just before the SATs). Arithmetic and word problem solving performance significantly correlated with mathematical anxiety at time points two and three (during the SATs year). Correlations between mathematical anxiety and mathematical performance were stronger during the SATs year. To further investigate the relationship between mathematical anxiety and mathematical performance hierarchical regressions, were undertaken that accounted for the children's general anxiety (state and trait anxiety) and cognitive (non-verbal intelligence and working memory) factors. These were undertaken at time point one (year before the SATs) and time point three (just before the SATs) when all measures were tested (see chapter three for more details, table 3.4 for testing timetable). These analyses revealed that there were no significant negative relationships between mathematical anxiety and mathematical performance at either time point one or three. Moreover, that the most significant relationship was between non-verbal intelligence and mathematical performance, with non-verbal intelligence being a positive predictor of mathematical performance at both times.

The correlational results surrounding the association between mathematical anxiety and mathematical performance suggest several areas for discussion which relate to the ages of the children, the type of mathematical performance, and the time at which the tasks were administered.

Firstly, the correlational data shows that the negative association between mathematical anxiety and mathematical performance is dependent on the age of the children. As the results indicated a significant negative association in both year one (children aged five to six) and two (children aged six to seven). Therefore, this negative association was found in these young children, this finding is in accord with previous studies who found significant negative correlations with children aged six to seven (Harari et al., 2013) and children aged seven to nine (Vukovic et al., 2013).

Secondly, the correlational data shows that this negative association between mathematical anxiety and mathematical performance is dependent on the type of mathematical performance. Mathematical fluency, measured at three time points, was found to negatively correlate with mathematical anxiety at time one and three but not at time four. Longitudinal studies have found significant negative correlations between mathematical anxiety and mathematical fluency. Cargnelutti et al., 2017, found significant negative correlations between mathematical fluency and mathematical anxiety at two time points six months apart. They tested children in the second term of second grade (children aged seven to eight) and in the first term of grade three (children aged eight to nine). Sorvo et al., 2019, found significant negative correlations between mathematical fluency and mathematical anxiety at two time points approximately a year apart. They tested children in different grades (year groups) from grade two (children aged seven to eight), grade three (children aged eight to nine) grade four (children aged nine to ten) and grade five (children aged ten to eleven). Cross sectional research using just one time point has equally found significant negative correlations between mathematical fluency and mathematical anxiety. Harari et al, 2013, tested children aged six to seven at one time point and found significant negative correlations between mathematical fluency and mathematical anxiety. Thus, the correlational results within this thesis provides more evidence of the association between mathematical anxiety and mathematical fluency in younger children.

These significant negative associations between mathematical anxiety and mathematical performance could be linked to the fact that mathematical fluency was a test delivered whilst the children were given a time pressure in which to complete it. Ashcraft and Moore (2009) describe this negative association as an “affective drop” in performance. This drop-in performance is thought to only appear during timed high stakes conditions. Therefore an “affective drop” in performance was evident at times one and three, but not apparent at time point four. This could indicate that these children were more relaxed at school after the SATs. It also might link to their increase in confidence and ability at completing the mathematical fluency tasks, as this was their third time completing them.

Alternatively, for arithmetic performance measured at all four time points, it was only found to negatively correlate with mathematical anxiety at time point two (beginning of SATs year) and time point three (just before the SATs). This significant negative association could indicate that during these two time periods the children felt under pressure to perform. Other cross-sectional studies have reported significant negative associations between mathematical anxiety and arithmetic tasks. Vukovic et al., (2013), found significant negative correlations between arithmetic performance and mathematical anxiety at one time point. They tested children in the spring term of either their second grade (children aged seven to eight) or their third grade (children aged eight to nine). Wu et al., (2012) found significant negative correlations between arithmetic performance and mathematical anxiety with children aged seven to nine. Therefore, this thesis provides more evidence of the association between mathematical anxiety and arithmetic performance in the younger children.

Equally for problem solving performance there were significant negative correlations at times two and three. Other researchers have found negative associations between mathematical anxiety and problem-solving performance, in children of a similar age (Vukovic et al., 2013). Therefore, the type of mathematical performance affects the association with mathematical anxiety.

Thirdly, that the negative association between mathematical anxiety and mathematical performance is dependent on the time of testing. This was an important feature of this research, the timing of each of the studies was planned to follow the journey of the children through their SATs year. Study one was conducted the year before the SATs with an assumption that the pressure on the pupils to perform mathematically would be less. Study two, three and four were all timed within the SATs year, the beginning, just before and after with an assumption that during this year the pressure would increase the nearer the children got to the SATs and then decline after the SATs. The finding that the strongest negative association between mathematical anxiety and mathematical performance was at time three, just before the SATs, adds support to the increasing pressure of the SATs on mathematical performance (Connor, 2001; Connors et al., 2009; McDonald, 2001; Putwain et al., 2012; Tymms & Merrell, 2007; Ward & Quennerstedt, 2018). The children could feel under more pressure to succeed in mathematics the nearer to their SATS, from themselves as they compare to their peers, and from their teachers and their parents (Berliner, 2011; Connor, 2003; Harlen, 2007; Ozga, 2009; Putwain, Connors, Woods, & Nicholson, 2012; Segal, Snell & Lefstein, 2016; Segool, Carlson, Goforth, Van der Embse & Barterian, 2013). This stronger negative association with all types of mathematical performance nearer to high stakes testing reflects the higher cognitive demands placed on children at this time even when every attempt has been made to reduce the pressure in the younger children (Connors, 2003: Dowker, 2019a). This could be linked to the fact that there is a learning environment around meeting performance expectations (Beilock & Ramirez, 2011) and children's ability to learn from their mistakes (Dowker et al., 2019a). The longitudinal nature of this research allows for a more detailed look at the association between mathematical anxiety and mathematical performance at each specific time point.

In order to investigate how this negative relationship between mathematical anxiety and mathematical performance changes in more detail, consideration was given to how it might be affected by the child's general anxiety and individual cognitive abilities. From a review of previous literature (see chapter one and two), it was hypothesised that high levels of mathematical anxiety would be associated with lower levels of mathematical performance after controlling for general anxiety (Aronen et al., 2005; Grezo & Sarmany-Schuller, 2018; Heppner, Willy & Dixon, 2004) and cognitive skills (Bull & Scerif,2001; Cowan & Alloway, 2008; Kyatta & Lehto, 2008; Nunes et al., 2007; Swanson & Sachse-Lee, 2001). Cross sectionally, looking at the findings from studies one and three, there were no significant negative relationships between mathematical anxiety and mathematical performance for the younger children when controlling for general anxiety (state and trait anxiety) and cognitive (non-verbal intelligence and working memory) measures. This finding could reflect the children's more relaxed approach to mathematics, through less pressure being placed on the children. This is an indication that the teachers of this sample of children were following the instructions to ensure that children do not feel under pressure around their SATs (STA, 2020A).

In fact, what was found was that the younger children's non-verbal intelligence was the strongest predictor of their mathematical performance (fluency, arithmetic and word problem solving). That is children with a high non-verbal intelligence performed better mathematically, a year before and just before the SATs. As the hierarchical regressions at time point one and three revealed that non-verbal intelligence contributed unique positive variance for all measures of mathematical performance for the younger children. This finding agrees with previous research which indicated that measures of general intelligence are predictors of mathematics achievement (Deary, Strand, Smith, & Fernandes, 2007; Geary, 2011; Hale, Fiorello, Kavanaugh, Hoepprer & Gathercole, 2001;). Specifically, it has been demonstrated that non-verbal Intelligence, namely the ability to reason and think logically is a strong predictor of mathematical performance (Fuchs, Fuchs, Hamlett, Lambert, Stuebing, & Fletcher, 2008; Kyttala & Lehto, 2008). This significant positive relationship found in studies one and three between non-verbal intelligence and mathematical performance, then supports previous findings in that children with a good non-verbal intelligence perform better at mathematics.

Additionally, it was found that the younger children's working memory was a predictor of their mathematical performance, but only for word problem solving performance at time point one. Therefore, at time point one a year before the SATs, the younger children with high working memory scores demonstrated a positive association with their ability to solve the word problems. It is thought that solving mathematical problems places additional demands on working memory, especially when those problems are in sentences rather than just numerical notation (Cowan & Powell, 2014; Fuchs et al., 2008). As solving mathematical word problems, requires an interpretation of the specific problem in identifying the mathematical operation required before being able to develop a solution to the problems (Andersson, 2010). Therefore, for the younger children it is only those children with a better working memory, that allows them to hold more information whilst they read and interpret the problem, who perform better. Younger children may struggle with the language of the word problem and therefore need a greater working memory capacity to cope with the cognitive load and the mathematical needs of the problem. Additionally, younger children who do not yet have access to the automatic recall of arithmetic facts to help them solve the problems rely on counting using concrete apparatus, such as cubes within the normal classroom environment to solve problems (DFE, 2013b; Ofsted, 2012). Concrete apparatus was not available to the younger children during testing; therefore, they would need to have a good working memory to solve the word problems. As working memory was no longer a significant predictor of word problem- solving performance at time three, this could indicate that the children are now more familiar with word problems, coping better with the language of them and beginning to rely more on automatic recall of arithmetical facts.

A limitation within this study is the fact that mathematical anxiety was not measured at the point at which they completed their SATs, as this would not have been appropriate and likely schools would not have granted access to the children at this sensitive time. In order to accommodate these limitations, we measured their anxiety as close to their SATs as possible and ensured that the tasks of mathematical performance especially the arithmetic and word problem solving were similar in structure to those that the children would encounter in their SATS.

5.7 Chapter Summary

Question A) What is the association between mathematical anxiety and mathematical performance over time?

Correlational analyses indicated that the negative associations between mathematical anxiety and mathematical performance were dependent on the measure of mathematical performance and the time of testing.

- At time point one there were significant negative correlations between mathematical anxiety and mathematical fluency.
- At time point two it was between mathematical anxiety and arithmetic and word problem solving.
- At time point three with all measures of mathematical performance.
- At time point four there were no significant negative relationships with any of the measures of mathematical performance.

Therefore, as the children got nearer to taking their SATs there were significant negative associations between mathematical anxiety and all measures of mathematical performance, but this relationship was no longer significant after the SATs.

Question B) Is the relationship between mathematical anxiety and mathematical performance significant above a child's general anxiety levels and general cognitive levels?

- Hierarchical analyses indicated that there were no significant negative relationships between mathematical anxiety and mathematical performance at either time one or time three.
- Conversely the most significant positive relationships between non-verbal intelligence and mathematical performance.
- At time one there was a positive relationship between working memory and problem solving indicating that the children with a better working memory were better problem solvers.

Therefore, for the younger children as they got nearer to taking their SATs mathematical anxiety was not a significant predictor of their mathematical performance.

Chapter 6-The relationship between Mathematical anxiety and mathematical performance for the Key Stage 2 children.

Chapter contents:

This chapter follows on from the previous chapter and explores the relationship between mathematical anxiety and mathematical performance for the older children over time. The relationship between mathematical anxiety and mathematical performance was investigated using correlations and hierarchical regressions analyses at each time point.

The chapter is divided into the following subsections:

- Introduction
- Aims
- Hypotheses
- Method: Participants, Materials and Procedure
- Results
  - Descriptive Statistics
  - Analyses
  - Question A) what is the relationship between mathematical anxiety and mathematical performance?
  - Question B) Is the relationship between mathematical anxiety and mathematical performance significant above a child's general anxiety and cognitive levels?
- Chapter discussion.
- Chapter summary.

6.1 Introduction

The focus of this chapter is to examine the relationship between mathematical anxiety and mathematical performance over time. In particular this relationship is being studied within the Primary stage of Education within the UK, which is divided in to three age ranges, Foundation (children under 5 years of age), Infant (children aged between 5 and 7) and Junior (children aged between 8 and 11). This distinction then links to the Curriculum for each age range, with children being taught the Early years Foundation stage (EYFS) statutory framework (birth to 5 years of age) and then moving onto the National Curriculum, which is subdivided into Key Stage one (5 to 7 years of age) and Key stage two (8 to 11 years of age).

Primary Education within the UK sets out to provide children with a good level of understanding in the core subjects of English, Mathematics and Science along with a foundational level of understanding in the foundation subject’s art and design, computing, design and technology, physical education, history, geography and music with the introduction of a foreign language at KS2 (Department of Education, 2014).

From the National Curriculum standards are set for children to achieve at the end of each key stage. In Key stage 2 these standards are working towards the expected standard, working at the expected standard, and working at greater depth for English writing and Science. The standards are described as a series of “pupil can” statements, which teachers assess the children against and to achieve a standard the children must meet all the statements within a standard (Standards and Teaching Agency, 2018). Alongside the teacher assessments in English writing and science, the children sit SATS in mathematics, English reading, punctuation, and spelling. The raw scores from these tests are converted into scaled scores as a means of comparing the results year by year, this process allows for any variation in difficulty between the tests from year to year (GOV.UK, 2019). Children with a scaled score of 100 will be deemed to have met the standard for the test. Children with a scaled score of 99 or less has not met the expected standard for the test. Children with a scaled score of 110+ indicates that the child is working at greater depth.

In particular it will examine this relationship between mathematical anxiety and mathematical performance in the older children from the year before their national testing and then at key points in the year of National Testing. In the UK Standard Attainment Tests (SATs) in year six, are used to assess all eleven-year-old children nationally. They were devised as end of Key Stage Tests to assess children’s knowledge and understanding of the specific contents of the KS2 National Curriculum introduced as part of the Education Reform Act in 1988 (DfES, 1988). They were initially devised as a measurement of the individual abilities of each child and were supposed to provide some useful indicators of the child’s next steps in learning. With the introduction of nationally published results (1991), they were then used as a means of accountability for teachers, schools, and local authorities (West, 2010).

As discussed earlier (chapter 5), assessment is an important feature in education. It is the means within schools of collecting, analysing, and interpreting information about children's performance at different stages for teachers to appropriately adjust their teaching (Black & Wiliam, 1998). Assessment is divided into formative (where ongoing assessment informs teachers of the next steps needed for children to progress) and summative (where a score or value is given at the end of a program of study). High Stakes tests such as SATs are a particular form of summative assessment. These are tests that are administered, where there are rewards or sanctions that are conditional on the results from these tests (Harlen, 2007). The children's results from these tests are then used to hold to account teachers, schools, local authorities and even governments to account (Regan-Stansfield, 2017). Many countries within the world use high stakes tests to make judgments on the state of their education systems such as England, United States, Australia, and Denmark. In an ever-increasing global world, the state of a countries education system is assessed and compared with other countries (Provasnik, Kastberg, Ferraro, Lemanski, Roey & Jenkins 2012; OECD, 2014).

The KS2 tests are classed as "High Stake" tests, as the results of these tests are used on a yearly basis to influence the future of pupils, teachers, and schools (West, 2010). They provide a measure of pupil performance which is linked to many accountability outcomes. For pupils it has a direct influence on their predictions of academic performance in secondary schools and in some cases reflects the education they receive. For teachers with the advent of performance management in 2008 (DfCSF, 2008), the outcomes of the pupils that they teach is used to demonstrate the positive impact of their teaching, leading to rewards such as promotion and financial gain (DFEE, 1999). Equally there is a significant need for Head teachers to be able to demonstrate the positive impact of education within their schools, through internally monitoring the teaching standards in their schools (Burnitt, 2016; Ozga 2009). More importantly they must ensure that the school's results meet the National Standard for attainment in the SATS and that individual children make the required progress from their KS1 SATs. As an inability to demonstrate this can have quite significant negative impact on the school through OFSTED inspections leading to schools being classed as "failing" "coasting" or "requiring improvement" (Segal, Snell & Lefstein, 2016).

The mode of administration of the KS2 tests also adds to the element of "high stakes" as they are paper and pencil tests administered on the same day to all children within the UK. The children's teachers or school are not allowed to provide any input to the children during testing or give feedback after the SATS. This puts pressure on the children to perform on a particular day and for a particular length of time. The test papers are commercially produced and sent to the schools, where they must be kept under lock and key until the actual scheduled day of the test. The tests are then administered under formal testing conditions with strict guidelines (STA, 2020b). Once completed the tests are then sent away for external marking.

The KS2 SATS are designed to assess and demonstrate the children's knowledge and skills to solve arithmetic and word problems successfully (STA, 2016). They need to be able to demonstrate three types of knowledge. Factual knowledge which is their understanding of the numbers and the types of operations e.g., ability to say, read, write, order, and compare numbers to 10,000,000 including negative numbers, recognise the value of each digit, and use effectively the four main operations, addition, subtraction, multiplication, and division (DFE, 2013b). Procedural knowledge which is the knowledge of the processes that the different operations perform on the numbers e.g., perform addition, subtraction, multiplication, and division on four-digit numbers and understand all the times tables in order to solve number problems (DFE, 2013b). Conceptual knowledge the principles behind the operations e.g., understanding that multiplication and division are inverse operations (Robinson & Dube, 2009a) and understanding the inversion principle for arithmetic operations (Bisanz & LeFevre, 1992; Robinson & Dube, 2009b). They also must demonstrate a good level of mathematical fluency, that is their ability to answer arithmetic questions quickly and correctly (Hulme, Brigstocke &Moll, 2016). This demonstrates that the children have committed these facts to memory and no longer need to work them out each time they meet the question e.g., number bonds to 100 and their times tables (DFE, 2013b; McClure, 2014). Researchers have indicated arithmetic facts in the form of a "verbal code" (Deheane, 1992) are stored within an individual's long-term memory (Ashcraft, 1987; Verguts & Fias, 2005) Thus, it is thought that older children use this automatic retrieval of facts more effectively as they have had more experience through schooling to develop this skill of automatic retrieval (Meyer et al., 2010). Children develop their mathematical knowledge and skills at different rates, but it may be that emotional factors may hinder this development in particular mathematical anxiety.

Mathematical anxiety described as feelings of insecurity in one's ability to perform mathematical tasks well (Witt, 2012) is a significant emotional factor affecting the mathematical performance of children. Mathematical anxiety affects individuals in everyday situations, where working with number is required, as well as in their school and academic lives. (Richardson & Suinn, 1972). Negative relationships between mathematical anxiety and mathematical performance have been found in older primary aged children (Justica-Galiano et al., 2017; Ho et al., 2000; Sorvo et al., 2017; Wu et al.,2014). Meta- analyses have consistently found negative correlations between mathematical anxiety and mathematical performance for children in the later years of primary and into secondary education (Hembree, 1990; Ma, 1999; Namkung et al, 2019).

Mathematical performance, the ability of children to solve mathematical tasks is measured in several different ways by researchers. These tasks require children to solve arithmetic, reasoning and word problems. Researchers have consistently identified significant negative relationships with mathematical anxiety, for calculations (Carey et al., 2017b), mathematical fluency (Justica-Galiano et al., 2017; Sorvo et al., 2017) and mathematical achievement tests (Henschel & Roick, 2017; Ho et al., 2000) in older children. Therefore, the studies in this research were devised to investigate the relationship between mathematical anxiety using varying measures of mathematical performance:

- Mathematical fluency, their ability to solve arithmetical questions at speed.

- Mathematical complexity, their ability to solve age-appropriate arithmetic and word problems with no time limit.

It was important to establish whether there was a relationship between mathematical anxiety and each mathematical performance, cross sectionally at each time point for the older children.

6.2 Aims:

The aim of all four studies was to investigate the specific nature of the relationship between mathematical anxiety and mathematical performance at each time point. Mathematical performance was defined in two ways their mathematical fluency and their mathematical complexity. Mathematical fluency was measured through their ability to correctly solve a series of basic addition, subtraction, and multiplication questions. Mathematical complexity was measured through their ability to correctly solve arithmetic and word problems, similar to problems from the age-appropriate Standard Attainment tests.

The aim of studies one and three was to investigate the specific nature of children's self- reported mathematical anxiety and the association with their mathematical performance considering cognitive and emotional properties of the children. The aim of studies two and were to provide data for the association between children's self- reported mathematical anxiety and their mathematical performance at the beginning and the end of their SATs year.

In this chapter the following questions are examined to fully understand the pattern of the relationship between mathematical anxiety and mathematical performance for the older children.

Question A) What is the association between mathematical anxiety and mathematical performance over time?

Question B) Is the relationship between mathematical anxiety and mathematical performance significant above a child's general anxiety levels and general cognitive levels?

6.3 Hypotheses:

All four studies have the following hypothesis:

The first hypothesis was that Mathematical anxiety would negatively associate with mathematical performance. From previous research, it was predicted that there would be mathematical anxiety present in the older children. It was also predicted that the association between mathematical anxiety and mathematical performance would be stronger for word problem solving performance than mathematical fluency (Vukovic et al., 2013). This was predicted as children would need to access more cognitive resources when solving word problems (Namkung et al., 2019). In line with The Processing Efficiency Theory (Eysenck & Calvo, 1992) a theory developed to explain how performance is affected by worry. This theory when applied to mathematical anxiety proposes that the mathematical performance of children is affected because the children become preoccupied with worrisome thoughts rather than concentrating on the task in hand. This preoccupation with worrisome thoughts then consequently depletes their working memory resources (Ashcraft & Kirk, 2001; Ramirez et al., 2016). Therefore, the more anxious children would find it harder to concentrate on the more challenging word problems due to the depletion of their available working memory resources being consumed by worrying thoughts.

> H1- High levels of mathematical anxiety will be significantly associated with lower levels of mathematical performance.

Studies 1 and 3 enable a more detailed hypothesis incorporating the emotional and cognitive variables.

3) The second hypothesis was that the negative relationship between mathematical anxiety and mathematical performance would still be present after controlling for the negative association with general anxiety (as measured by trait and state anxiety) and the positive association with cognitive variables (non-verbal intelligence and working memory). As previous researchers have indicated that there is a negative association between general anxiety and mathematical performance in college students (Aronen et al., 2005; Grezo & Sarmany-Schuller, 2018; Heppner, Willy & Dixon, 2004) but that mathematical anxiety is a separate construct it is important to be able to control for the children's general anxiety (Ashcraft & Moore, 2009; Vukovic et al., 2013).
   Equally, it is important to control for the cognitive variables such as non-verbal intelligence (Kyatta & Lehto, 2008; Nunes et al., 2007) and working memory (Bull & Scerif,2001; Cowan & Alloway, 2008; Swanson& Sachse-Lee, 2001) which researchers

have indicated provides a significant positive relationship with mathematical performance.

H2- High levels of mathematical anxiety will be associated with lower levels of mathematical performance after controlling for general anxiety (trait and state) and specific cognitive skills (non-verbal intelligence and working memory).

6.4 Method

The methodology of this longitudinal study is described in detail in Chapter 3.

6.4.1 Participants

At time point one, the year before their SATs, seventy-three year five children (M=123 months of age, SD= 3.5) were originally recruited from two schools in the Nottingham area. This cohort was followed up at time point two, the beginning of the SATs year (n=72, M = 128 months of age, SD=3.8), then time point three, just before their SATs (n= 72, m=133 months of age, SD= 3.5) and finally at time point four, after the SATs (n =71, m = 136 months of age, SD= 3.4)(See chapter 3 for more details about the participants).

6.4.2. Materials

At time point one and three the children were assessed on all the emotional (interest in mathematics, trait, state, and mathematical anxiety), Cognitive (non-verbal intelligence, reading and working memory) and mathematical performance (fluency, arithmetic and word problem solving) measures. At time points two and four the children were only assessed on state anxiety, mathematical anxiety, and the measures of mathematical performance. (See chapter three for specific details of the different measures).

6.4.3 Procedure

As described in chapter three, testing took place over several sessions, with assessments being administered on a one-to-one basis with each child and the researcher in a small quiet space within the school. Apart from the mathematical fluency test which was administered in small group sessions with no more than six children at a time.

Testing was carried out four times over an eighteen-month period from summer of school 5 (April-July 2017), autumn term of school year six (Sept-Dec 2017), Spring/summer term of school year six (March-May 2018) and summer term of school year six (June-July 2018).

All testing was carried out by the author and general praise and encouragements were the only feedback given.

6.5. Results

6.5.1 Descriptive Statistics.

The means and standard deviations of the measures for the older cohort for each time point are provided in table 6.1.

older children	Study 1 Mean (SD) (N=73)	Study 2 Mean (SD) (N=72)	Study 3 Mean (SD) (N=72)	Study 4 Mean (SD) (N=71)
Emotional				
Mathematical Anxiety	39.3(11)	37.8 (11.1)	39.7 (11.7)	39(12)
Trait Anxiety	3.1(6.9)		31.7(7.0)	
State Anxiety	31.8(4.6)	34.1(5.5)	32.4(4.7)	31.6(6.5)
Interest in Mathematics	44.1(9.3)		42.5(12.3)	
Cognitive				
Non-verbal Intelligence	28.8(4.3)		30.8 (3.8)	
Reading	46.7(9.4)		50.3(8.3)	
Working Memory	3.2(1.2)		4.1(.95)	
Mathematical Performance				
Mathematical Fluency	107.7(39)		135.58(49.66)	139(52)
Arithmetic	10(12)	11.5(2.6)	12.5(1.94)	12.5 (2.3)
Word Problem Solving	7.4(2.1)	8.3(3.4)	9.1 (3.11)	9.4(3.3)

Table 6.1: Means and Standard deviations for emotional, cognitive, and mathematical performance measures for the older children for each study.

6.5.1.1. Assessing Normality: Looking for outliers in the data.

At time point one, outliers were found in the data for the measures of trait anxiety, reading and Interest in mathematics, as well as all three measures of mathematical performance. At time point two, outliers were found in the data for the measures of state anxiety and arithmetic performance. At time point three, outliers were found in the data for the measures of non-verbal intelligence, reading, trait anxiety, state anxiety, interest in mathematics, mathematical fluency, and arithmetic performance. At time point four, outliers were found in the data for the measures of state anxiety, mathematical fluency, and arithmetic performance.

No data was excluded from all the participants as once the trimmed means were checked they were found to be similar to the mean for each variable. (Pallant, 2013).

6.5.2 Analyses.

Initial analyses were undertaken to ensure no violation of assumptions, including normality, linearity, and homoscedasticity. Therefore, the analyses chosen were parametric in nature including Correlations and Hierarchical Regressions. Pearson product-moment correlations coefficients were reported in the correlational analyses. Throughout statistical significance was set at $p<.05$. Prior to conducting the series of hierarchical multiple regressions, the relevant assumptions of this statistical analysis were tested. Firstly, the sample sizes were considered acceptable given that there were five independent variables to be included in the analysis (Khamis & Kepler, 2010, Tabachnick & Fidell, 2014). The assumption of singularity was also met as the independent variables (Working memory, non-verbal intelligence, trait, state, and mathematical anxiety) were not a combination of other independent variables. An examination of correlations (see Correlation tables in chapter 6 appendix) revealed that no independent variables were highly correlated, as none of the predictors correlated at .80 or above. Moreover, the assumption of multicollinearity was accepted as the collinearity statistics of Tolerance and VIF were all within acceptable limits, (Coakes, 2005; Hair, Black, Babin, Anderson &Tatham, 2006). Univariate outliers identified in initial data screening in the extreme range were kept, as the trimmed means were similar to the means in all variables (Pallant, 2013). Residual and scatter plots indicated the assumptions of normality, linearity and homoscedasticity were all satisfied (Hair et al., 2006; Pallant, 2013).

6.5.3 Question A) What is the association between mathematical anxiety and mathematical performance?

In answering this question, the relationship between mathematical anxiety was investigated with each measure of mathematical performance.

Correlations coefficients with Mathematical Anxiety	Study 1	Study 2	Study 3	Study 4
Mathematical Fluency	-.24*		-.40**	-.40**
Arithmetic	-.3*	-.4**	-.39**	-.39**
Word Problem Solving	-.22	-.3*	-.41**	-.42**

Table 6.2: Correlation coefficients for mathematical anxiety and all measures of mathematical performance for each of the studies for the older children ("*p < .05, **p < .01").

6.5.3.1 Mathematical Fluency

The associations between mathematical anxiety and the measure of mathematical fluency were investigated using Pearson product-moment correlations coefficients at three of the time points (time 1, time 3 and time 4). At time point one, there was a negative correlation, r= -.24, n= 73, p = .038. At time point three, there was a negative correlation between the two variables, r= -.4, n= 72, p<.001. At time point four, there was a medium, negative correlation between the two variables, r= -.44, n= 71, p <.001. Therefore, at all three time points high levels of mathematical anxiety were associated with lower of mathematical fluency (see table 6.2).

6.5.3.2 Arithmetic Performance.

The association between arithmetic scores and mathematical anxiety was investigated using Pearson product-moment correlations coefficient. At time point one, there was a negative correlation between the two variables, r= -.3, n= 73, p = .017. At time point two, there was a negative correlation between the two variables, r= -.35, n= 72, p = .002. At time point three, there was a negative correlation between the two variables, r= -.39, n= 72, p = .001. At time point four, there was a negative correlation between the two variables, r= -.40, n= 71, p = .001. At all four time points, high levels of mathematical anxiety were associated with lower levels of arithmetic performance for the older children (see table 6.2).

6.5.3.3 Word Problem Solving Performance.

The association between word problem solving scores and mathematical anxiety was investigated using Pearson product-moment correlations coefficient. At time point one, the negative correlation between the two variables, r= -.22, n= 73, p = .07 was not significant. At time point two, there was a negative correlation between the two variables, r= -.3, n= 72, p = .011. At time point three, there was a negative correlation between the two variables, r= -.34 n= 72, p <.001. At time point four, there was a medium, negative correlation between the two variables, r= -.42, n= 71, p <.001. These results indicate that during the SATs year high levels of mathematical anxiety were associated with lower levels of problem-solving performance (see table 6.2).

Hypothesis one is met as there is a significant negative association between mathematical anxiety and measures of mathematical performance, but this is dependent on the type of performance and the time at which they were measured. At time point one, this significant negative association is for two measures of mathematical performance namely, mathematical fluency and arithmetic performance. At time point two, there is a significant negative association between mathematical anxiety and arithmetic and word problem solving performance. At times points three and four, there are significant negative associations between mathematical anxiety and all the measures of mathematical performance. Therefore, the significant negative association between mathematical anxiety and mathematical performance changes over time for the older children.

6.5.4 Question B) Is the relationship between mathematical anxiety and mathematical performance significant above a child's general anxiety levels and cognitive levels?

In answering this question, the relationship between mathematical anxiety was investigated with each measure of mathematical performance at time point one and three along with the emotional and cognitive variables.

Two-step hierarchical multiple regressions were conducted with the measure of mathematical performance as the dependent variable. Working memory and non-verbal intelligence were entered at step one of the hierarchical multiple regression, to adjust statistically for cognitive abilities. These two predictors were entered in step one as previous research have found positive associations between working memory (Caviola, Mammarella, Cornoldi & Lucangeli, 2012; Korhonen, J., Nyroos, M., Jonsson & Eklof, 2017) and non –verbal intelligence (Kyttala & Lehto, 2008) with mathematical performance. The emotional variables (trait, state, and mathematical anxiety) were entered at step two as general anxiety has been found to have a negative association with mathematical performance in previous research (Aronen et al., 2005; Crezo & Sarmany-Schuller, 2018; Heppner, Willy & Dixon, 2004). The means and SDs for each variable at each time point can be seen in Table 6.1. Intercorrelations between the multiple regression variables at each time point and with each of the measures of mathematical performance can be found in chapter 6 appendix.

6.5.4.1. Mathematical Fluency.

At time point one, the overall relationship was highly significant (*F* (5,67) = 5.57, $p < .001$) with a good fit (multiple *R* = .54). Analysing of the un-standardised coefficients showed that both non-verbal intelligence (B= 2.2, *t* (72) =2.2, *p*=.034) and working memory (B = 8.9, *t* (72) =2.5, *p*=.015) were significant predictors of mathematical fluency (R^2 = 0.29). The standardised coefficients showed that working memory (β = .27) was a slightly stronger predictor of mathematical fluency scores than non-verbal Intelligence (β = .24). Both predictors were positive therefore higher scores on the non-verbal Intelligence and working memory tests indicated higher mathematical fluency scores (see table 6.3).

	β	t	*p*	R	R^2	Δ R^2
Step 1				**.45**	**.20**	**.20**
Working memory	.29	2.5	.014*			
Non-verbal Intelligence	.26	2.3	.022*			
Step 2				**.54**	**.29**	**.10**
Working memory	.27	2.5	.015*			
Non-verbal Intelligence	.24	2.2	.034*			
Trait Anxiety	-.13	-1.1	.26			
State Anxiety	-.25	-1.9	.065			
Mathematical Anxiety	-.01	-.09	.93			

Table 6.3: Summary of Hierarchical Regression Analysis for Variables predicting Mathematical Fluency at time point one (N =73; *p < .05, **p < .01, ***p< .001).

At time point three, the overall relationship was highly significant at step two (*F* (5,71) = 3.3, *p* = .011) with a good fit (multiple *R* = .45). Analysing the un-standardised coefficients showed that mathematical anxiety (CAMS) (Beta = -.12, *t* (71) =-2.02, *p*=.048) was the only significant predictor of mathematical fluency (R^2 = 0.20). The standardised coefficients showed that mathematical anxiety (CAMS) (Beta = -.29) was a negative predictor of mathematical fluency, therefore high levels of mathematical anxiety indicate poor levels of mathematical performance (see table 6.4).

	β	t	*p*	R	R^2	ΔR^2
Step 1				**.28**	**.08**	**.05**
Working memory	.07	.60	.58			
Non-verbal Intelligence	.25	1.9	.051			
Step 2				**.45**	**.20**	**.14**
Working memory	-.007	-.06	.95			
Non-verbal Intelligence	.14	1.2	.25			
Trait Anxiety	.02	.11	.91			
State Anxiety	-.15	-1.7	.29			
Mathematical Anxiety	-.29	-2.0	.05*			

Table 6.4: Summary of Hierarchical Regression Analysis for Variables predicting Mathematical Fluency at time point three (N =72; *p < .05, **p < .01, ***p< .001).

For the older children mathematical anxiety was not a significant predictor of mathematical fluency at time point one, it was the non-verbal Intelligence and working memory of the child that were the strongest predictors. Alternatively, at time point three, just before the SATs, mathematical anxiety is a significant predictor of mathematical fluency.

6.5.4.2 Arithmetic Performance.

At time point one, the overall relationship was highly significant at step two (F (5,67) = 6.63, p < .001) with a good fit (multiple R = .58). Analysing the un-standardised coefficients showed that both non-verbal intelligence (B = .12, t (72) =3.4, p=.001) and trait anxiety (B = -.062, t (72) =-2.7, p=.009) were significant predictors of arithmetic performance (R^2 = 0.33). The standardised coefficients showed that non-verbal intelligence (β = .36) was a positive and slightly stronger predictor of arithmetic performance scores than the negative predictor of trait anxiety (β = -.30). Non-verbal intelligence was a positive predictor, therefore higher scores on the non-verbal intelligence test (Ravens) indicated higher arithmetic scores. Trait anxiety was a negative predictor, therefore higher scores on the trait anxiety test indicated lower arithmetic scores (see table 6.5).

	β	t	*p*	R	R^2	Δ R^2
Step 1				**.44**	**.20**	**.20**
Working memory	.14	1.3	.22			
Non-verbal Intelligence	.37	3.3	.002**			
Step 2				**.58**	**.33**	**.14**
Working memory	.10	1.0	.34			
Non-verbal Intelligence	.36	3.3	.001***			
Trait Anxiety	-.29	-2.7	.009**			
State Anxiety	-1.4	-1.1	.28			
Mathematical Anxiety	-.04	-.33	.74			

Table 6.5: Summary of Hierarchical Regression Analysis for Variables predicting Arithmetic performance at time point one (N =73; *p < .05, **p < .01, ***p< .001).

At time point three, the overall relationship was highly significant at step two (F (5,66) = 4.5, p = .001) with a good fit (multiple R = .50). An analysis of the un-standardised coefficients showed that both non-verbal intelligence (B = .13, t (71) =2.2, p=.032) was the only significant predictor of arithmetic performance (R^2 = 0.25). The standardised coefficients showed that non-verbal intelligence (Beta = .26) was a positive predictor of arithmetic performance, therefore higher scores on the non-verbal intelligence test (Ravens) indicates higher scores of arithmetic performances (see table 6.6).

	β	t	*p*	R	R^2	Δ R^2
Step 1				**.41**	**.17**	**.17**
Working memory	.14	1.2	.25			
Non-verbal Intelligence	.34	2.9	.005**			
Step 2				**.50**	**.25**	**.08**
Working memory	.08	.65	.52			
Non-verbal Intelligence	.26	2.2	.032*			
Trait Anxiety	-.04	-.33	.74			
State Anxiety	-.15	-1.1	.27			
Mathematical Anxiety	-.19	-1.4	.18			

Table 6.6: Summary of Hierarchical Regression Analysis for Variables predicting Arithmetic performance at time point three (N =72; *p < .05, **p < .01, ***p< .001).

For the older children mathematical anxiety is not a significant predictor of arithmetic performance, in this case it is the non-verbal intelligence of the child that is the strongest predictor.

6.5.4.3. Word Problem-solving performance.

At time point one, the overall relationship was highly significant (F (5,67) = 7.9, $p < .001$) with a good fit (multiple $R = .61$). Analysing the un-standardised coefficients showed that non-verbal intelligence (B = .27, t (72) =4.4, p<.001) was the only significant predictor of word problem solving performance ($R^2 = 0.37$). The standardised coefficients showed that non-verbal intelligence was a positive predictor of word problem solving (β = .45), therefore higher scores on the non-verbal intelligence test (Ravens) indicated higher word problem solving scores (see table 6.7).

	β	t	*p*	R	R^2	ΔR^2
Step 1				**.50**	**.25**	**.25**
Working memory	.10	.90	.37			
Non-verbal Intelligence	.46	4.1	P<.001***			
Step 2				**.56**	**.32**	**.07**
Working memory	.05	.48	.64			
Non-verbal Intelligence	.39	3.4	P=.001**			
Trait Anxiety	.05	.39	.70			
State Anxiety	-.03	-.20	.84			
Mathematical Anxiety	-.28	-2.2	.83			

Table 6.7: Summary of Hierarchical Regression Analysis for Variables predicting Word Problem Solving performance at time point one (N =73; *p < .05, **p < .01, ***p< .001).

At time point three, overall relationship was highly significant at step two (F (5,66) = 6.2, p < .001) with a good fit (multiple R = .56). Analysing the un-standardised coefficients showed that both non-verbal intelligence (B= .32, t (71) =3.4, p=.001) and mathematical anxiety (Beta =-.07, t (71) =2-2, p=.037) were significant predictors of word problem solving performance (R^2 = 0.32). The standardised coefficients showed that Non-verbal Intelligence (β = .39) was a slightly stronger predictor of word problem solving scores than Mathematical Anxiety (β = -.28) (see table 6.8).

At time point three, mathematical anxiety is a significant negative predictor of word problem solving performance. Therefore, hypothesis two was met as children who are more anxious about mathematics perform less well in word problem solving. Although, non-verbal intelligence is still a stronger significant positive predictor of word problem solving performance.

	β	t	*p*	R	R^2	ΔR^2
Step 1				**.54**	**.30**	**.30**
Working memory	.16	1.5	.14			
Non-verbal Intelligence	.47	4.4	p<.001***			
Step 2				**.61**	**.37**	**.08**
Working memory	.14	1.4	.18			
Non-verbal Intelligence	.45	4.4	p<.001***			
Trait Anxiety	-.17	-1.6	.11			
State Anxiety	-.21	-1.7	.10			
Mathematical Anxiety	.03	.22	.037*			

Table 6.8: Summary of Hierarchical Regression Analysis for Variables predicting Word Problem Solving performance at time point three (N =72; *p < .05, **p < .01, ***p< .001).

Hypothesis two is only met at time point three as there is a negative relationship between mathematical anxiety and specific measures of mathematical performance, when considering a child's general anxiety (trait and state) and their non-verbal intelligence and working memory. This negative relationship is dependent on the type of performance and the time at which they were measured. At time point one, there were no significant negative relationships between mathematical anxiety and any of the measures of mathematical performance. At time point three, there are significant negative relationship between mathematical anxiety with two of the measures of mathematical per performance, mathematical fluency and word problem solving. Therefore, the significant negative relationship between mathematical anxiety and mathematical performance is only present for the older children at time point three just before the SATs.

6.6 Chapter Discussion:

The relationship between mathematical anxiety and mathematical performance was investigated in the older children over four time points. These time points were specifically designed to test the children on their high stakes' SATs journey, in the year before (time point one) during the year (time point two and three) and at the end of the year (time point four). Correlational data between mathematical anxiety and each measure of mathematical performance (fluency, arithmetic, and word problems) was investigated at each time point. Mathematical fluency significantly negatively correlated with mathematical anxiety at time points one, three and four. Arithmetic performance significantly correlated with mathematical anxiety at all the time points. Whilst word problem solving performance significantly correlated with mathematical anxiety at time points two, three and four. Correlations between mathematical anxiety and mathematical performance were stronger during the SATs year, compared to the previous year. To further investigate the relationship between mathematical anxiety and mathematical performance hierarchical regressions, were undertaken that accounted for the children's general anxiety (state and trait anxiety) and cognitive (non-verbal intelligence and working memory) factors. These were undertaken at time point one (year before the SATs) and time point three (just before the SATs) when all measures were tested (see chapter three for more detail, table 3.4 for testing timetable). These analyses revealed that at time point one there were no significant negative relationships between mathematical anxiety and mathematical performance (fluency, arithmetic and word problem solving). Moreover, the most significant relationship was between non-verbal intelligence and mathematical performance, with non-verbal intelligence being a positive predictor of mathematical performance. There were other significant relationships, a negative one between trait anxiety and arithmetic performance and a positive one between working memory and mathematical fluency. At time point three (just before the SATs) there were significant negative relationships between mathematical anxiety with two of the mathematical performance measures, mathematical fluency, and word problem solving performance. There were also significant positive relationships between non-verbal intelligence and two of the mathematical performance measures, arithmetic and word problem solving.

The correlational results surrounding the association between mathematical anxiety and mathematical performance suggest several areas for discussion which relate to the ages of the children, the type of mathematical performance, and the time at which the tasks were administered.

Firstly, the correlational data shows that the negative association between mathematical anxiety and mathematical performance is dependent on the age of the children. As the results indicated a significant negative association in both year five (children aged nine and ten) and year six (children aged ten and eleven). Therefore, this association is found in the older children, this finding agrees with previous studies, which found significant negative correlations with children aged eight to nine (Carey et al., 2017b), children aged ten to eleven (Justica-Galiano et al., 2017) and children aged nine to eleven (Henschel & Roick, 2017).

Secondly, the data shows that this negative association is dependent on the type of mathematical performance. Mathematical fluency measured at three time points was found to negatively correlate with mathematical anxiety at all three time points. Longitudinal studies have found significant negative correlations between mathematical anxiety and mathematical fluency. Cargnelutti et al., (2017), found significant negative correlations between mathematical fluency and mathematical anxiety at two time points six months apart. They tested children in the second term of second grade (children aged seven to eight) and in the first term of grade three (children aged eight to nine). Sorvo et al., (2019), found significant negative correlations between mathematical fluency and mathematical anxiety at two time points approximately a year apart. They tested children in different grades (year groups) from grade two (children aged seven to eight), grade three (children aged eight to nine) grade four (children aged nine to ten) and grade five (children aged ten to eleven). Cross sectional research using just one time point has equally found significant negative correlations between mathematical anxiety and mathematical fluency, Justica-Galiano et al., (2017), tested children aged ten to eleven at one time point and found significant negative correlations between mathematical fluency and mathematical anxiety. Hunt, Bhardwa & Sheffield, (2017), tested children aged nine to eleven and found that a significant negative association between mathematical anxiety and mathematical fluency for the more complicated three-digit problems. Thus, the correlational results within this thesis provides more evidence of the association between mathematical anxiety and mathematical fluency in older children.

This significant negative associations as stated previously could be linked to the fact that mathematical fluency was a test delivered whilst the children were given a time pressure in which to complete it. Ashcraft and Moore (2009) describe this as an “affective drop” in performance. This drop-in performance is thought to only appear during timed high stakes conditions. Therefore, an “affective drop” in performance was evident for mathematical fluency at all three time points (time one, three and four).

Equally, for arithmetic performance measured at all four time points, it was found to negatively correlate with mathematical anxiety at all the four time points. This significant negative association could indicate that all the time points the children felt under pressure to perform. Previous cross-sectional research (Carey et al., 2017b; Henschel & Roick, 2017), using just one time point found significant negative correlations between arithmetic performance and mathematical anxiety. For example, Carey et al., (2017b) tested arithmetic performance in children aged eight to nine, they found a significant negative correlation between mathematical anxiety and arithmetic performance. Henschel & Roick, (2017), tested arithmetic performance in children aged nine to eleven, they found significant negative correlations for both cognitive and affective mathematical anxiety. Therefore, the correlational results within this thesis provides more evidence of the association between mathematical anxiety and arithmetic performance in older children.

Alternatively, for problem solving performance there was a significant negative correlation at times two, three and four but not a time point one. Previous cross-sectional research (Justica-Galiano et al., 2017), found significant negative correlations between mathematical anxiety and word problem solving performance. For example, Justica- Galiano et al., (2017), tested mathematical problem solving of eight to twelve-year old children. They found that mathematical anxiety predicted the mathematical outcomes. The lack of a significant correlation between mathematical anxiety and problem-solving performance at time one could be explained through the difficulty of the word problems. The word problems had been designed to match the questions the children would meet in the SATs a year later. Therefore, there is the possibility that children accepted the fact that they might not be able to solve the word problems leading to no significant relationship between mathematical anxiety and word problem solving performance at this time. As they progressed through their SATs year with more pressure to perform, there was a negative association between mathematical anxiety and word problem solving performance. Therefore, this provides evidence, that the type of mathematical performance affects the association with mathematical anxiety.

Thirdly, that the negative association between mathematical anxiety and mathematical performance is dependent on the time of testing. This was an important feature of this research, as the timing of each of the studies was planned in order to follow the journey of the children through their SATs year. Study one was conducted the year before the SATs with an assumption that the pressure on the pupils to perform mathematically would be less. Study two, three and four were all timed in the SATs year, the beginning, just before and after with an assumption that during this year the pressure would increase the nearer the children got to the SATs and then decline after the SATs. The finding for the older children that the strongest negative association between mathematical anxiety and mathematical performance was during the whole of their SATs year, adds support to the increasing pressure of the SATs on mathematical performance (Connor, 2001; Connors et al., 2009; McDonald, 2001; Putwain et al., 2012; Tymms & Merrell, 2007; Ward & Quennerstedt, 2018). The children could feel under more pressure to succeed in mathematics throughout the whole year from themselves as they compare to their peers, and from their teachers and parents (Berliner, 2011; Connor, 2003; Harlen, 2007; Ozga, 2009; Putwain, Connors, Woods, & Nicholson, 2012; Segal, Snell & Lefstein, 2016; Segool, Carlson, Goforth, Van der Embse & Barterian, 2013). This stronger negative association with all types of mathematical performance nearer to high stakes testing reflects the higher cognitive demands placed on children at this time (Connors, 2003: Dowker, 2019a). Researchers have suggested that children aged eleven do experience anxiety around their SATs (Connors et al., 2009; Putwain et al., 2012) and that they are fully aware of the consequences for their schools of the SATs results (McDonald, 2001). Therefore, it is likely that the children feel under pressure to perform, leading to the strong association between mathematical anxiety and mathematical performance. The longitudinal nature of this research allows for a more detailed look at the journey of this negative association between mathematical anxiety and mathematical performance at each time point over this SATs year.

In order to investigate how this relationship between mathematical anxiety and mathematical performance changes in more detail, consideration was given to how it might be affected by the child's general anxiety and individual cognitive abilities. From a review of previous literature (see chapter one and two), it was hypothesised that high levels of mathematical anxiety would be associated with lower levels of mathematical performance after controlling for general anxiety (Aronen et al., 2005; Grezo & Sarmany-Schuller, 2018; Heppner, Willy & Dixon, 2004) and cognitive skills (Bull & Scerif, 2001; Cowan & Alloway, 2008; Kyatta & Lehto, 2008; Nunes et al., 2007; Swanson & Sachse-Lee, 2001). Cross sectionally, looking at the findings from studies one and three, there were significant negative relationships between mathematical anxiety and mathematical performance for the older children when controlling for general anxiety (trait and state) and cognitive (non-verbal intelligence and working memory) measures. These significant relationships were dependent on the type of mathematical performance and the time at which the data was collected. Therefore, there is some evidence of an "affective drop" in performance for the older children (Ashcraft & Moore, 2009).

In contrast to the findings for the younger children, the hierarchical regressions with the older children indicated that there was a significant negative relationship between mathematical anxiety with two of the measures of mathematical performance namely, mathematical fluency and word problem solving at time point three (just before SATs). This finding is in line with other cross- sectional studies with older primary aged children. Justica-Galiano et al., (2017), found that mathematical anxiety predicted mathematical outcomes (fluency and problem solving) above and beyond trait anxiety in children aged eight to eleven. Henschel & Roick, (2017), found a significant negative relationship between cognitive mathematical anxiety and mathematical performance (mathematics achievement test including arithmetic and word problems) in children aged nine to ten. Van Mier et al., (2019), found a significant relationship between mathematical anxiety and mathematical fluency, but only for girls. Possible reasons for this significant negative relationship between mathematical anxiety and mathematical performance, could be the mathematical performance condition (timed or untimed) and pressure to perform.

The mathematical performance condition, such as whether the task is timed or untimed, could be a possible reason for the significant negative relationship. Researchers have indicated significant negative relationships for timed tasks (Carey et al., 2017b; Hunt, Bhardwa, & Sheffield, 2017; Justica- Galiano et al., 2017; Sorvo et al., 2017). The present results indicated a significant negative relationship between mathematical anxiety and mathematical fluency (timed test). This significant negative relationship could be explained as an "affective drop" in performance (Ashcraft & Moore, 2009), where the children's anxiety influences their mathematical performance negatively. This affective drop is thought to be more evident in mathematical tasks subjected to time restrictions (Ashcraft & Moore, 2009).

Moreover, a significant negative relationship was found between mathematical anxiety and word problem solving (not timed) indicating an "affective drop" in performance. As this affective drop only occurred at time point three (just before the SATs), this could be taken to suggest that there might be another reason. That of pressure to perform, as this has been found to be a negative side effect of SATs (Connor, 2001; Connors et al., 2009; McDonald, 2001; Putwain et al., 2012; Tymms & Merrell, 2007; Ward & Quennerstedt, 2018). It could be explained that at this time just before the SATS, the children were under more pressure to succeed in their maths tasks. Therefore, this significant negative relationship between mathematical anxiety and word problem solving performance could reflect the children's more anxious approach to mathematics, through pressure to perform being placed on the children (Beilock & Ramirez, 2011).

However, the hierarchical regressions also indicated positive relationships for non-verbal intelligence with arithmetic and word problem solving at time point three (just before SATs). Therefore, children with a high non-verbal intelligence performed better mathematically at time three. Previous research has indicated that measures of general intelligence are predictors of mathematics achievement (Hale, Fiorello, Kavanaugh, Hoepprer & Gathercole, 2001; Deary, Strand, Smith, & Fernandes, 2007; Geary, 2011). Specifically, it has demonstrated that non-verbal intelligence, namely the ability to reason and think logically has been found to be a strong predictor of mathematical performance (Fuchs et al., 2008; Kyttala & Lehto, 2008). This positive relationship found in this study between non-verbal intelligence and mathematical performance then supports previous findings in that children with a good non-verbal intelligence perform better at mathematics. This positive association continues in older children, with children as old as 16 years of age demonstrating that their intelligence predicts 60% of the variation in National mathematics tests (Deary et al., 2007).

At time point one (year before SATs) there were no significant negative relationships between mathematical anxiety and mathematical performance (fluency, arithmetic and word problem solving) for the older children. The hierarchical regressions for all measures (fluency, arithmetic and word problem solving) revealed that the most significant predictor of mathematical performance was in fact non-verbal intelligence, like the findings for the younger children at time point one. As this was a positive relationship, children with a higher non-verbal intelligence perform better mathematically a year before their SATs (see previous paragraph for more explanation).

Another positive predictor of mathematical performance was identified for mathematical fluency at time point one (year before SATs). That of working memory which contributed a significant positive variance in mathematical performance. Therefore, older children with high working memory scores performed better at tasks which required quick recall of arithmetic facts. Working memory skills have been linked to the recalling of arithmetic facts (Cragg, Richardson, Hubber, Keeble & Gilmore, 2017). As it is thought that those with low working memory use other strategies for solving arithmetic problems rather than automatic retrieval (Barrouillet & Lepine, 2005; Geary, Hoard, Nugent, & Bailey, 2012) and that they are less likely to get the right answers (Andersson, 2010; Geary, Hoard, Byrn-Craven, Nugent & Numtee, 2007). Equally, other researchers have indicated arithmetic facts are stored in the form of a "verbal code" (Dehaene, 1992) within long-term memory (Ashcraft, 1987, Verguts & Fias, 2005) and it is the working memory that activates this information (Barrouillet, Bernadin, & Camos, 2004; Cowan, 1999; Engle, Kane & Tuholski, 1999; Unsworth & Engle, 2007). As the older children used automatic retrieval of facts more effectively with much higher scores than the younger children, they would need a good working memory in order to activate this information from their long-term memory (Barrouillet et al., 2004; Cowan, 1999; Engle et al., 1999; Unsworth & Engle, 2007). As working memory was no longer a significant predictor of word problem- solving performance at time point three, this could indicate that the children's working memory was occupied with their anxious thoughts (Ashcraft & Krause, 2007). As mathematical anxiety was the strongest predictor of mathematical fluency at time point three (just before the SATs).

As with the younger children, a limitation within this study is the fact that mathematical anxiety was not measured at the point at which they completed their SATs, as this would not have been appropriate and likely schools would not have granted access to the children at this sensitive time. To accommodate these limitations, we measured their anxiety (mathematical and general) as close to their SATs as possible and ensured that the tasks of mathematical performance especially the arithmetic and word problem solving were similar in structure to those that the children would encounter in their SATS.

6.7 Chapter summary

Question A) What is the association between mathematical anxiety and mathematical performance over time?

Correlational analyses indicated that the negative associations between mathematical anxiety and mathematical performance were dependent on the measure of mathematical performance and the time of testing.

- At time point one there were significant negative correlations between mathematical anxiety and mathematical fluency and arithmetic.
- At time point two it was between mathematical anxiety and arithmetic and word problem solving.
- At time point three with all measures of mathematical performance.
- At time point four with all measures of mathematical performance.

Therefore, as the children got nearer to taking their SATs there were significant negative associations between mathematical anxiety and all measures of mathematical performance and this continued after the children had completed their SATs.

Question B) Is the relationship between mathematical anxiety and mathematical performance significant above a child's general anxiety levels and general cognitive levels?

Hierarchical analyses also indicated that the significant negative relationships between mathematical anxiety and mathematical performance were dependent on the measure of mathematical performance and the time of testing.

- At time point one, there were no significant negative relationships between mathematical anxiety and mathematical performance.
- At time point one, the strongest predictor of mathematical performance was non-verbal intelligence.
- At time point one, there was a significant positive relationship with working memory for mathematical fluency only.
- At time point three there were significant negative relationships between mathematical anxiety and mathematical performance in two of the measures namely mathematical fluency and word problem solving.
- At time point three there were positive relationships between non-verbal intelligence and mathematical performance for arithmetic and word problem solving.

Therefore, as the children got nearer to taking their SATs mathematical anxiety was a predictor of two types of mathematical performance, mathematical fluency and word problem solving.

Chapter 7- Longitudinal development of mathematical anxiety and mathematical performance and the longitudinal relationship of mathematical anxiety and mathematical performance.

Chapter contents: This chapter follows on from the previous chapters which looked at the relationship between mathematical anxiety and mathematical performance for the younger (Key Stage One) and older (Key Stage two) children. In this chapter, the development of both mathematical anxiety and mathematical performance over time are investigated. Then the directional nature of the relationship between mathematical anxiety and mathematical performance is looked at longitudinally, this is especially important because only using data from cross sectional studies does not allow questions about directionality to be answered (Curran, 2000). This chapter specifically looks at answering the following questions, as to how stable both mathematical anxiety and mathematical performance are over time and as to whether there is a directional relationship between mathematical anxiety and mathematical performance over time and in which direction. The chapter is divided into the following subsections:

- Introduction
    - Development of mathematical anxiety
    - Development of mathematical performance
    - Relationship between mathematical anxiety and mathematical performance
    - Structural Equation modelling (SEM)
    - Autoregressive modelling
    - Cross lagged panel models
    - Simultaneous Latent growth curve modelling.
- Aims
- Hypotheses
- Method: Participants, Materials and Procedure
- Results
    - Descriptive
    - Question A) Does mathematical anxiety develop over time?
    - Question B) Does mathematical performance develop over time?

- Question C) Is there a directional relationship between mathematical anxiety and mathematical performance?
- Question C1) Is there a directional relationship between mathematical anxiety and mathematical fluency?
- Simultaneous Latent growth modelling with mathematical fluency performance as a predictor
- Question C2) Is there a directional relationship between mathematical anxiety and arithmetic performance?
- Simultaneous Latent growth modelling with arithmetic performance as a predictor
- Question C3) Is there a directional relationship between mathematical anxiety and word problem solving performance?
- Simultaneous Latent growth modelling with word problem solving performance as a predictor

- Chapter Discussion.
- Conclusion.
- Chapter summary.

7.1 Introduction

The focus of this chapter is to understand the longitudinal development and relationship of mathematical anxiety and mathematical performance over key points around National testing periods within primary schools. This will be achieved using Structural Equation modelling (SEM). In particular autoregressive modelling, which allows for an exploration of the “causal” relationships of both mathematical anxiety and mathematical performance with each other over time.

7.1.1. Development of Mathematical Anxiety.

Mathematical anxiety has been described as an emotional construct that changes over time, where some researchers have indicated that it increases with age (Dowker, Sarkar & Looi, 2016) especially in later school years (Carey et al., 2017b; Devine et al., 2012; Hill et al. 2016; Ma & Xu, 2004; Wigfield & Meece, 1988) and into adulthood (Hembree,1990). Most of the research into the changes in mathematical anxiety have been cross- sectional in nature. Where mathematical anxiety was measured at a particular time point and therefore the change in mathematical anxiety was compared across age groups, therefore providing data that is not truly developmental (Gierl & Bisanz, 1995; Gunderson et al, 2018; Sorvo et al., 2017). A more developmental design would be to measure the change in mathematical anxiety in the same individuals over time. This is provided through longitudinal research which looks to follow the developmental trajectory in constructs over time. There have been a few notable longitudinal studies looking at the change in mathematical anxiety over time for the same participants. Krinzinger et al, (2009), looked at the stability of mathematical anxiety around failure, in younger children from third to fifth grade. They found using SEM that mathematical anxiety demonstrated moderate developmental stability over their four time points. They also found a significant increase in mathematical anxiety with age. Ma and Xu, (2004), looked at the stability of mathematical anxiety in older children from grade seven (children aged twelve to thirteen) to grade twelve (adolescent aged seventeen to eighteen). They investigated stability with the use of longitudinal panel models which demonstrated that mathematical anxiety was stable over the time period, but in the study reported by MA and Xu, (2004), mathematical anxiety was more stable from grade eight (children aged thirteen to fourteen) onwards.

Within this thesis (Chapter 4) it was found that mathematical anxiety at the group level demonstrated no significant rate of growth over the time period but that at an individual level there was significant variability in the rate of growth, as demonstrated through latent curve modelling.

7.1.2 Development of Mathematical Performance.

Equally important within this thesis is the change in mathematical performance over time. Mathematical performance is known to increase with age due to the continuing development of mathematical skills, knowledge and understanding (Kikas et al., 2009). Researchers have investigated the developmental trajectories of children's mathematical performance over time and found that at a group level there is a significant increase in skills, knowledge and understanding (Aunola et al., 2004; Vanbinst et al, 2018). Whereas at an individual level there are significant differences in the rates of change and the developmental trajectories (Brown et al., 2003; Jordan, Mulhern, & Wylie, 2009). As expected within this thesis both the younger and older children' mathematical performance (mathematical fluency, arithmetic and word problem solving) significantly increased over the study time period (see chapter 7 appendix).

Therefore, with mathematical anxiety remaining statistically stable at a mean level and the growth of mean mathematical performance established over time, the key question to answer within this thesis is how this affects the relationship between mathematical anxiety and mathematical performance.

7.1.3 Relationship between Mathematical anxiety and mathematical performance.

This relationship between mathematical anxiety and mathematical performance and its directional influence is an important issue for researchers, educationalists, and governments (DFE, 2016; DFE, 2019; OECD, 2013b). As an understanding of this directional relationship over time would support the drive within research and education to increase mathematical performance in children (Every Child a Chance Trust, 2009).

Previous research has proposed two models that suggest that the directional nature is from increased mathematical anxiety that leads to poor mathematical performance (Hembree, 1990; Lyons & Beilock, 2012). First, the disruption account model, which explains that mathematical anxiety works by disrupting mathematical performance through a reduction of an individual's working memory resources (Ramirez et al., 2018a). Second the Debilitating Anxiety Model, which proposes that mathematical anxiety impacts mathematical performance during the processing and retrieval stages (Lyons & Beilock, 2012). Whilst two other models propose that the directional nature of the relationship is from initial poor mathematical performance leading to mathematical anxiety (Maloney, 2016; Tobias, 1986). The Deficit model (Tobias, 1986) assumes that an individual's memories of their inability to succeed at mathematical tasks leads to an increasing anxiety in the future. Another interpretation of this directional relationship is the reduced competency model. This model suggests that it is an individual's poor numerical and spatial ability that causes their poor mathematical performance, which in turn causes their mathematical anxiety (Maloney, 2016). A further model proposes that there is a bidirectional nature to this relationship that works in a cyclic nature, that as individuals experience poor mathematical performance this then leads to increased mathematical anxiety that in turn then leads to poor performance (Ashcraft et al, 2007; Carey et al., 2016). All the above models link the actual poor mathematical performance scores of participants with their levels of mathematical anxiety to explain the directional relationship between mathematical anxiety and mathematical performance.

Alternatively, the Interpretation account of the relationship between mathematical anxiety and mathematical performance proposes that it is how the individual interprets their mathematical performance that effects their mathematical anxiety (Ramirez, Shaw & Maloney, 2018). Therefore, individuals with high mathematical performance may have high mathematical anxiety because their own interpretation of their mathematical performance is that it is not good enough.

Researchers have found significant relationships between mathematical anxiety and mathematical performance through cross sectional designs studies (Devine et al., 2012; Harari et al, 2013; Hunt et al., 2017; Justica- Galiano et al., 2017; Ramirez et al., 2013; Ramirez et al., 2016; Sorvo et al., 2017; Wu et al., 2012; Wu et al., 2014). These studies investigated the relationship in children at a specific time and therefore only captured a snapshot of this relationship. In these studies, significant negative relationships have been found between mathematical anxiety and particular forms of mathematical performance namely computation (Harari et al., 2013), problem solving (Ramirez et al., 2013; Ramirez et al., 2016), measures of mathematical composite using numerical operations and mathematical reasoning (Wu et al., 2012; Wu et al., 2014) and mathematical fluency (Devine et al., 2012; Hunt et al., 2017; Justica-Galiano et al., 2017; Sorvo et al., 2017). Harari et al, (2013), used the timed arithmetic, counting and mathematical background skills of first grade children (aged six to seven) to investigate the relationship with mathematical anxiety. They found a significant negative relationship with all measures of mathematical performance and suggested that because they were testing very young children with little exposure to school mathematics that they were predisposed to mathematical anxiety. Ramirez et al., (2013), used the Applied problems subtest from the Woodcock- Johnson III, standardised test (Woodcock, McGrew & Mather, 2001), which contains an increasingly difficult set of word problems for the children to solve. They tested children in first (aged six to seven) and second (aged seven to eight) grade and found a significant negative relationship between mathematical anxiety and performance, but only for the children with high working memories. They equally suggested that early mathematical anxiety would lead to poor mathematical performance. Wu et al., (2012.) tested older children in grades two and three (seven to nine years of age) in both numerical operations (write and count numbers alongside some simple arithmetic) and mathematical reasoning (single and multi- step word problems) from the Weschler Individual Achievement test (WAIT-II) (Weschler, 1949). They found a significant negative relationship between mathematical anxiety and mathematical performance, with more effect for the mathematical reasoning word problems. All of these studies were with children from the early stages of their primary education and the researchers suggest that they offer support to early mathematical anxiety leading to later poor mathematical performance, lending support to the Disruption and Debilitating anxiety models of the relationship. Although all these studies only found this negative relationship between early mathematical anxiety and mathematical performance at a snapshot in time comparing groups of children at different ages.

Other researchers investigated the relationship between mathematical anxiety and mathematical performance with children at a later stage in their primary education. Sorvo et al., (2017), tested children's mathematical fluency (timed tests of simple addition, subtraction, multiplication, and division questions). They found significant negative relationships with children up to grade five (aged ten to eleven). Hunt et al., (2017), tested the mental arithmetic skills of children in year five and six (nine to eleven years of age) using arithmetic questions with 2-digit and 3-digit numbers, like SAT questions, displayed on a computer. They found that the children with higher levels of mathematical anxiety had longer response times for solving the 3-digit arithmetic questions. These two studies demonstrate that children in the later years of primary education have a significant negative relationship between mathematical anxiety and mathematical performance. Other researchers used cross sectional designs with older children, children in secondary education, equally investigating the relationship between mathematical anxiety and mathematical performance at a particular point in time. Devine et al., (2012), tested the mental mathematics of children in years seven, eight and ten (aged twelve to fifteen) in UK secondary education. They found a negative correlation between mathematical anxiety and mathematical performance. Justica- Galiano et al., (2017), tested mathematical fluency (simple addition, subtraction, and multiplication questions) and mathematical problem solving of eight to twelve-year old children. They found that mathematical anxiety predicted the children's mathematical outcomes.

Equally, all these cross-sectional studies with older children have indicated significant negative relationships between mathematical anxiety and varying measures of mathematical performance at a snapshot in time. None of these studies with younger and older age groups followed through with these children to investigate how the relationship between mathematical anxiety and mathematical performance changed at the group and individual level.

There have been very few researchers who have looked at the relationship between mathematical anxiety and mathematical performance using a longitudinal design (Krinzinger et al., 2009; Ma & Xu, 2004; Vukovic et al., 2013). In a longitudinal design the research is extended over time allowing the directional relationship to be studied for each participant. Two studies have looked at the relationship in younger children, that is those in primary education (Schooling from 3 -11 years of age). Krinzinger et al., (2009), looked at the relationship between mathematical anxiety and calculation ability in children aged six to nine. They assessed calculation ability using small (answers less than 10) and large (answers greater than 10) addition and subtraction questions that children were asked to solve orally as fast as they could. Using SEM, they found no significant relationship between mathematical anxiety and calculation ability over this three-year period. Alternatively, Vukovic et al., (2013), looked at the relationship between mathematical performance and mathematical anxiety in children aged seven to nine They used a range of mathematical performance measures including calculation skills, through a 25-minute test of children's addition and subtraction facts and mathematical applications (mathematical problems set in story format, algebraic, data handling, probability, and geometry problems). Through a series of regression analyses, they found a negative correlation between mathematical anxiety and mathematical performance over this one-year period. The directional relationship between mathematical anxiety and mathematical performance has been studied with older children, those attending secondary education (Schooling from 11-18 years of age). Ma & Xu, (2004), looked at the relationship between mathematical anxiety and mathematical performance as measured by tasks of basic number skills, algebraic, geometrical, and quantitative literacy problems from grade seven to twelve (students aged twelve to eighteen). Through longitudinal panel analysis, they found that there was a significant relationship between mathematical anxiety and mathematical performance with prior low mathematics achievement significantly related to later high mathematics anxiety over this five-year period. This relationship increased significantly from grade eight (adolescents aged thirteen to fourteen) onwards, they explained this considering the increasing difficulty of the mathematical content and proximity to National Tests. A factor of importance within this thesis is how the proximity to National Testing impacts the directional relationship between mathematical anxiety and mathematical performance.

Therefore, it can be seen from previous research that the relationship between mathematical anxiety and mathematical performance can be affected by the type of mathematical performance, period of study, and the age of children.

Importantly in this thesis the longitudinal nature of this relationship between mathematical anxiety and mathematical performance was a key component enabling the directional influence of this relationship to be studied. The research questions to be answered here were whether mathematical anxiety causes poor mathematical performance or whether poor mathematical performance results in increased mathematical anxiety:

- Do children have mathematical anxiety that then leads to poor performance or is it the poor performance that leads to mathematical anxiety, or is it a combination of both?

To answer these questions SEM was the method used to explore whether there was evidence of a directional relationship between mathematical anxiety and mathematical performance.

7.1.4 Structural Equation Modelling (SEM).

SEM is a multivariate form of statistical analysis used to analyse the relationship between variables over time. SEM provides a statistical way of modelling which explores the "causal" relationships between the chosen observed variables, in this thesis mathematical anxiety and mathematical performance (Byrne, 2016). This type of modelling is achieved through a series of structured regression equations (Byrne, 2016). In this thesis it was used to produce the path diagrams of the structural relations between the observed variables to depict more clearly the hypothesised model (see figure 7.1). As this data was longitudinal, autoregressive modelling a particular form of SEM was used to investigate whether there was a directional relationship.

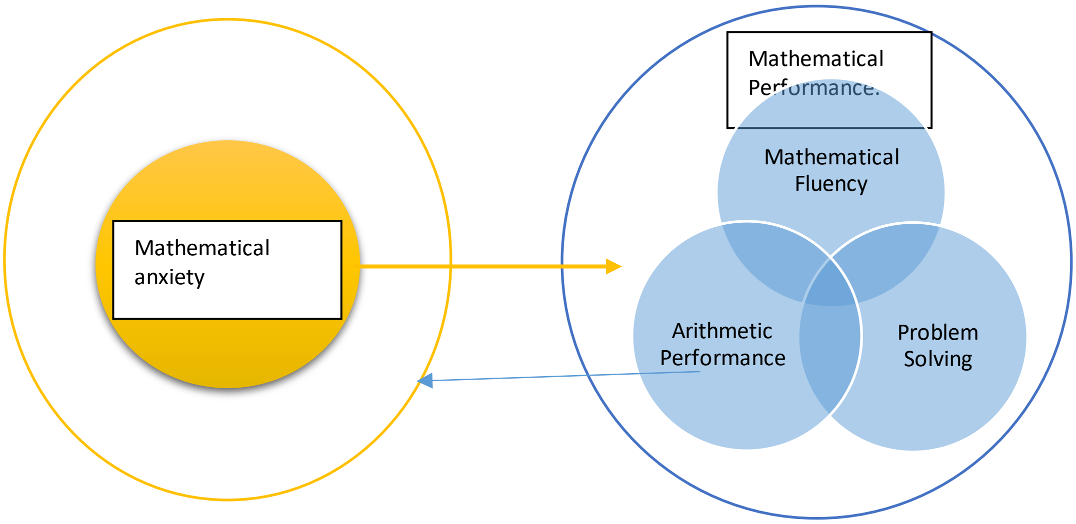

Figure 7 .1: Hypothesised model of the relationship between the observed variables, mathematical anxiety and mathematical performance.

7.1.5. Autoregressive Modelling

Autoregressive modelling is a form of SEM that creates time series regression models. In these models of change, the values of the observed variables measured at the previous time points will be used to predict the values of the same variables measured later (Liu, 2017). This type of modelling enables statistical account to be taken of earlier values for each of the observed variables. Figure 7.2 shows a simplex autoregressive model (AR1). The pathways between each variable measured at different time points (e.g., X1, X2, X3, X4) are identified as auto-lagged pathways. These pathways capture the relationship between the adjacent measures of the variable as a set of repeated measures. Thus, allowing for the fact that any given variable when measured at a time point will correlate with itself when measured at subsequent time points t + 1, t +2 etc. This allows for an understanding to be modelled of the statistical stability of the variable over time. If these auto-lagged pathways have large coefficients then the variable can be described as stable, whereas smaller coefficients means that the variable is less stable over time.

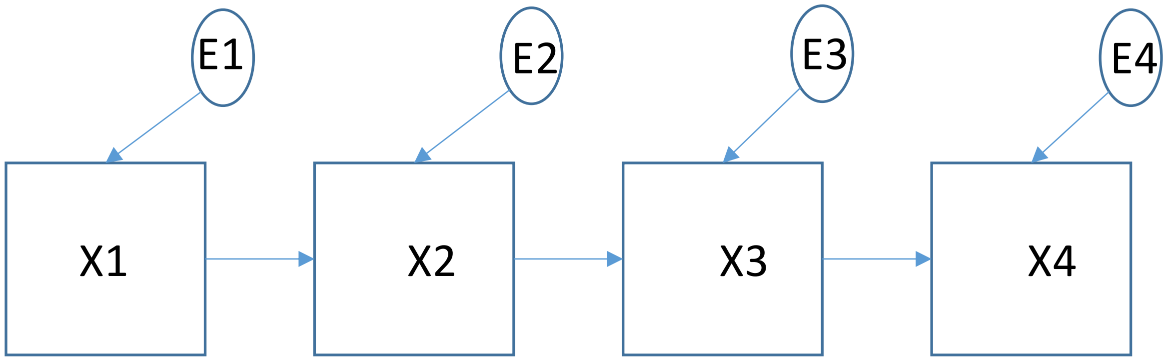

Figure 7.2: Autoregressive model (AR1) Simplex pattern (X= Observed Variable, E=measurement error value).

These autoregressive models are called panel models, which use the observations at each time point to examine the change at the level of participant. This then provides a focus on the individual differences in the scores over time. Autoregressive models can be extended to include other variables and enables the researcher to look at the relationship of each variable over time whilst at the same time looking at the relationship between these variables.

As within this thesis it is important to look at the individual differences (between participants) to examine the direction of influence in the changing process between mathematical anxiety and mathematical performance. A more sophisticated form of panel models, namely cross-lagged panel models were used. These models allow two observed variables, in this thesis mathematical anxiety and mathematical performance to be modelled at the same time.

7.1.6. Cross Lagged Panel Models.

Cross lagged panel models allowed modelling of the directional relationship between mathematical anxiety and mathematical performance (see figure 7.3). This type of modelling allowed the relationship between the two variables to be modelled over time e.g., modelling the pathway between variable X at time 1 and variable Y at time 2, and the pathway between variable Y at time 1 with variable X at time 2, at the same time (see figure 7.3). This modelling continues for the number of times that data has been collected. Previously, cross lagged panel models have been used to look for directional and reciprocal effects between two variables, for example parenting sensitivity and children's behaviour problems. (Belsky, Pasco Fearon & Bell, 2007). Equally, at the same time it allows the auto-lagged pathways to be modelled to provide an understanding of the relationship of the individual variable over time i.e., variable Y at time 1 with variable Y at time 2 etc.

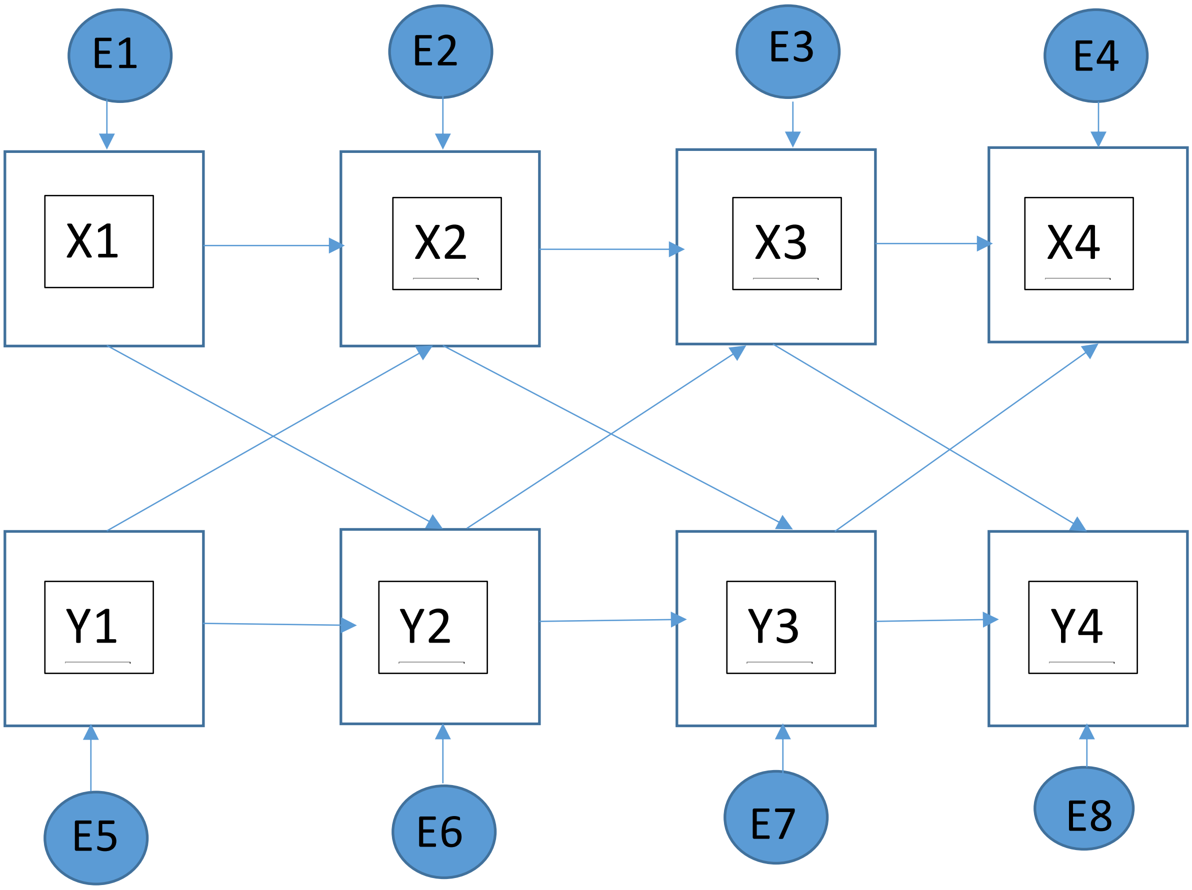

Figure 7.3: Autoregressive model: Cross lagged panel model depicting the directional relationship between two variables (X and Y) and the relationship of individual variables over time (Y1-Y2-Y3-Y4) (X= Observed Variable 1, Y=Observed Variable 2, E=measurement error value).

7.1.7. Simultaneous Latent growth curve modelling.

Another SEM approach to investigate the directional relationship between mathematical anxiety and mathematical performance was also used namely Latent growth curve modelling (see previous chapter four for a more detailed description of Latent growth curve modelling). In Simultaneous Latent growth curve models, change over time of observed variables is modelled with covariates/predictors that are time varying. In this thesis the time varying predictors used were the measures of mathematical performance (Mathematical fluency, arithmetic and word problem solving). These models are given the title simultaneous because both the outcome and predictor variables are being modelled at the same time (Byrne, 2008).

These two SEM approaches allow for the directional nature of the relationship between mathematical anxiety and mathematical performance to be explored more fully. Therefore, in order to add more information to this discussion of the directional relationship between mathematical anxiety and mathematical performance, cross lagged panel models and simultaneous growth curve models were constructed for each type of mathematical performance (fluency, arithmetic and word problem solving).

The focus of this chapter is to understand the longitudinal development and directional relationship of mathematical anxiety and mathematical performance over key points around National testing periods within primary schools. This will be achieved using Structural Equation modelling (SEM). In particular autoregressive modelling, which allows for an exploration of the "causal" relationships of both mathematical anxiety and mathematical performance with each other over time.

7.2 Aims

The aims of this chapter are to investigate the development of mathematical anxiety and mathematical performance and the directional relationship between mathematical anxiety and mathematical performance over time with the use of autoregressive modelling.

The auto lagged pathways of the cross lagged panel models were used to investigate the statistical stability of mathematical anxiety and mathematical performance. It was hypothesised that prior values of mathematical anxiety would predict later values of mathematical anxiety. That prior values of mathematical performance would predict later values of mathematical performance. This would indicate the relative statistical stability of mathematical anxiety and mathematical performance over time. It was also hypothesised that the rank-order of mathematical performance would be more stable than the rank order of mathematical anxiety. As previous research has identified that individual differences in mathematical anxiety are less stable than in mathematical performance measures (Ma & Xu, 2004; Sorvo et al., 2019). Therefore, two research questions were proposed:

Question A) Is mathematical anxiety stable over time?

Question B) Is mathematical performance stable over time?

The cross lagged pathways from the autoregressive modelling and the pathways in the simultaneous growth curve models were used to investigate the relationship between mathematical anxiety and mathematical performance over time. These pathways enabled the possibility of a directional relationship within this sample to be investigated. As previous research has indicated reciprocal relations (Cargnelutti et al., 2017; Gunderson et al., 2018), where prior mathematical anxiety predicts later mathematical performance and prior mathematical performance predicts later mathematical anxiety with children in primary education. Therefore, it was important within the thesis to establish whether there was a directional relationship for this sample. These statistical models enabled the following research question to be explored:

Question C) Is there a directional relationship between mathematical anxiety and mathematical performance?

- Does the poor mathematical performance in children predict their later level of mathematical anxiety?
- Do high levels of mathematical anxiety in children predict their later level of mathematical performance?
- Is there a reciprocal relationship between mathematical anxiety and mathematical performance?

7.3 Hypotheses

This chapter has the following hypothesis:

1) Examine the relationship between a child's prior mathematical anxiety (measured as self-reported mathematical anxiety) and their subsequent mathematical anxiety over time. Previous research has indicated the stability of development of mathematical anxiety over time (Gunderson et al., 2018; Krinzinger et al., 2009; Ma & Xu, 2004).

    H1- prior levels of mathematical anxiety will be significantly associated with subsequent levels of mathematical anxiety over time.

2) Examine the relationship between a child's prior mathematical performance (measured as mathematical fluency, arithmetic, and word problems) and their subsequent mathematical performance over time. Previous research has indicated that previous mathematical performance predicts later mathematical performance (Gunderson et al., 2018; Krinzinger et al., 2009; Ma & Xu, 2004).

    H1- prior levels of mathematical performance will be significantly associated with subsequent levels of mathematical performance over time.

3) Compare the individual development of mathematical anxiety and mathematical performance over time. Previous research has identified that the statistical stability effects are stronger for mathematical performance than mathematical anxiety, with good mathematical performance at time one predicting good performance at subsequent times (Gunderson et al., 2018; Krinzinger et al., 2009: Ma & Xu, 2004).

    H3- That mathematical performance will be more statistically stable than mathematical anxiety.

4) Examine the relationship between mathematical anxiety and mathematical performance over time to identify whether there was a directional relationship. Previous research indicates significant negative relationships between mathematical anxiety and mathematical performance. Some researchers found that high mathematical anxiety predicted low levels of mathematical performance at a later time point (Vukovic et al., 2013). Whilst others suggest that it is low mathematical performance that predicts mathematical anxiety at a later time point (Ma & Xu, 2004). Whereas others suggest that it is a reciprocal relationship with low mathematical performance predicting mathematical anxiety which in turn leads to further poor mathematical performance (Cargnelutti et al., 2017; Gunderson et al., 2018).

    H4- High levels of mathematical anxiety will significantly predict lower levels of mathematical performance over time.

    H5- low levels of mathematical performance will significantly predict higher levels of mathematical anxiety over time.

7.4 Method

The methodology of this longitudinal study is described in detail in chapter 3.

7.4.1. Participants

The participants in the longitudinal analysis were the children who had taken part at all four of the time points (see tables 3.1 and 3.2 in chapter 3).

7.4.2. Materials

Mathematical anxiety was measured with the use of The Children's Anxiety in Maths Scale (Jameson, 2013a, 2013b) at all four time points. Mathematical fluency was measured at three time points (time one, three and four). Arithmetic and problem-solving performance were measured at all four time points. These measures are described in chapter 3.

7.4.3 Procedure

Data were collected from all four studies (see chapter three for methodology) and analysed using SPSS VERSION 24. Cross lagged panel models were created in IBM SPSS AMOS 24.5. Throughout the analyses the maximum-likelihood estimation (MLE) was used. The fit of all the models was evaluated using the following indices: chi- square test (χ^2), comparative fit index (CFI) and root mean error of approximation (RMSEA). As the chi square test is known to be sensitive to sample size the other fit indices were used to assess the models (Hu & Bentler, 1998; Kline, 2005). For the CFI, the cut off criteria used was that values were close to .95, which previous researchers have indicated denotes a superior fit, (Hu & Bentler, 1999). Values >.90 were considered as acceptable (Kline, 2005). For the RMSEA values the cut off criteria used were that values less than .05 indicated a good fit (MacCallum et al., 1996) (Cited in Byrne, 2016.) Values that were as high as .08 were accepted as "reasonable errors of approximation in the population" (Browne & Cudeck, 1993).

A series of cross lagged panel models were conducted using IBM AMOS version 24.5. Each model investigated the relationship between mathematical anxiety and each measure of performance. For arithmetic and problem solving this meant that there were four time points included within the panel model as scores were collected at all four time points. For mathematical fluency there were three time points within the model as scores were collected at three time points. Each model started with the basic model, where the auto-lagged paths were drawn from each time point to the next (see figure 7.3) and then modification indices were used in order to check where the model could be improved each time. Measurement errors were included for measures of each variable taken at the same time point.

7.5 Results

7.5.1 Descriptive Statistics

In total 130 children (59 in school year two, 71 in school year six) participated in the study. There were 65 (50%) males and 65 (50%) females in the study. The means and standard deviations for mathematics anxiety and all measures of mathematical performance by study are in table 7.1.

Whole sample	Study 1	Study 2	Study 3	Study 4
(N=130)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Emotional				
Mathematical Anxiety	38.7(11.5)	38 (11.3)	39 (12.4)	39(11.3)
Mathematical Performance				
Mathematical Fluency	69(51.4)		89(64)	93(65
Arithmetic	7.2(3.4)	7.3(5.2)	8.8(4.7)	9 (4.5)
Word Problem Solving	5.1(3.3)	5.0(4.5)	6 (4)	6.4(4.3)

Table 7.1: Means and standard deviations for mathematical anxiety and mathematical performance measures for the whole sample.

7.5.2 Question A) Does mathematical anxiety develop over time?

In looking at the development of mathematical anxiety over time, the auto lagged pathways were assessed. The adjacent measures of mathematical anxiety all had significant regression pathways providing confirmation of hypotheses one. The adjacent pathways demonstrated significant effects for mathematical anxiety ranging from (.12 to .75) see tables 7.3, 7.4 and 7.5. The non-subsequent pathways within each of the cross lagged models were significant except for the pathway from mathematical anxiety at time point one to time point four in the model for mathematical anxiety and arithmetic performance (see figures 7.5, 7.7 and 7.9). In all the models, prior values of mathematical anxiety predicted later values of mathematical anxiety.

7.5.3. Question B) Does mathematical performance develop over time?

In looking at the development of mathematical performance over time the auto lagged pathways were assessed. The adjacent measures of mathematical performance all had significant regression pathways providing confirmation of hypotheses two. The significant effects ranged between (.92 to 1.2) for mathematical fluency (see table 7.2), (.17 to 1.3) for arithmetic (see table 7.3) and between (.41 to 1.2). for problem solving performance (see table 7.4). The non- subsequent pathways within each of the cross lagged models were significant except for the pathway for all measures of mathematical performance at time point one to time point four (see figures 7.5, 7.7 and 7.9). In all the models, prior values of mathematical performance predicted later values of mathematical performance.

In all the models, prior mathematical performance impacts on later mathematical performance in a much stronger manner than prior mathematical anxiety on later mathematical anxiety (see figures 7.5, 7.7 and 7.9). Confirming hypothesis three, that mathematical performance is more stable than mathematical anxiety.

7.5.3 Question C) Is there a directional relationship between mathematical anxiety and mathematical performance?

In answering the question is there a directional relationship between mathematical anxiety and mathematical performance, cross lagged panel models were constructed with each measure of mathematical performance.

7.5.5. Question C1) Is there a directional relationship between mathematical anxiety and mathematical fluency?

This question was investigated through a series of models which statistically constructed the relationship between mathematical anxiety and mathematical fluency over time. Initially, model one the basic model, (see figure 7.4), did not fit well with the Linear fit for this model:

$\chi^2(5) = 15.6$, $p = .008$, with an RMSEA = .128 and a CFI =.988 (see figure 7.4).

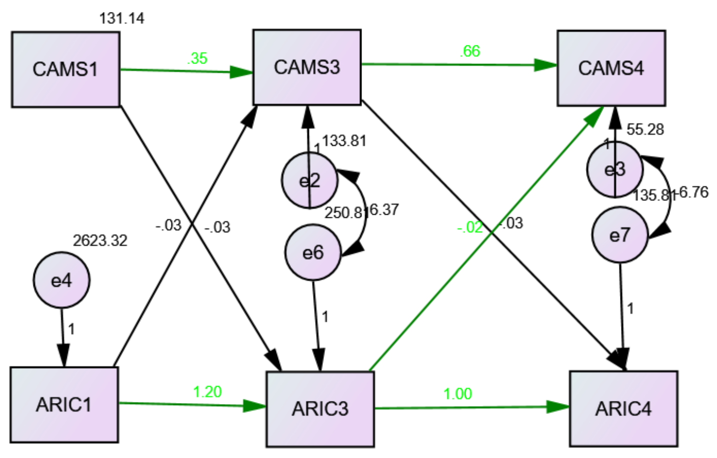

Figure 7.4: Cross Lagged panel model 1 for the relationship between mathematical anxiety (CAMS) with mathematical performance (ARIC) at each time point (significant pathways showed in green, all significant at the p<.001 level except ARIC3 to CAMS4 p=.042, e=measurement error).

Modification indices from model one, were used to improve the fit of subsequent models. These modification indices indicated that auto lagged pathways needed to be added from mathematical anxiety at time one (CAMS1) to mathematical anxiety at time four (CAMS4). Also, that auto lagged pathways needed to be added from mathematical fluency at time one (ARIC1) to mathematical fluency at time four (ARIC 4) (Model three). These modifications link to the assumptions that previous mathematical anxiety and mathematical fluency might predict their value of at non-subsequent later times.

Model three proved to be a good fit, and the Linear fit for this model can be described as:

$\chi^2(3) = .31$, p =.96, with an RMSEA = .000 and a CFI =1 (see figure 8.5).

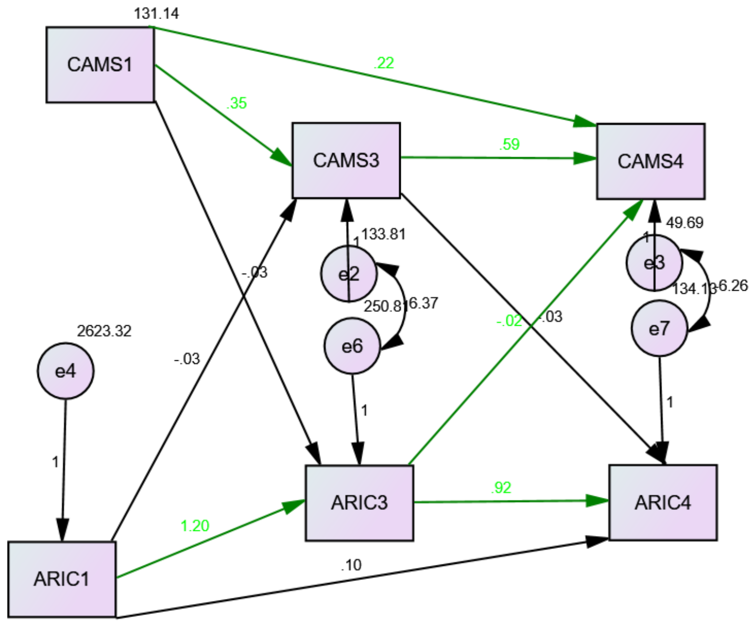

Figure 7.5: Cross Lagged panel model three for the relationship between mathematical anxiety (CAMS) with mathematical fluency (ARIC) at each time point (significant pathways showed in green, all significant at the p<.001 level except ARIC3 to CAMS4 p=.031, e=measurement error).

Effect	Coefficient	SE	CR	Standardized
Auto lagged pathways				
CAMS1→CAMS3	.35**	.09	3.9	.32
CAMS1→CAMS4	.22**	.06	3.8	.22
CAMS3→CAMS4	.59**	.05	11	.65
ARIC1→ARIC3	1.2**	.03	44	.97
ARIC1→ARIC4	.10	.08	1.2	.08
ARIC3→ARIC4	.92**	.06	14	.91
Cross lagged pathways.				
CAMS1→ARIC3	-.03	.12	-.22	-.005
CAMS3→ARIC4	-.03	.08	-.31	-.005
ARIC1→CAMS3	-.03	.02	-1.5	-.13
ARIC3 →CAMS4	-.02*	.01	-2.2	-.12

Table 7.2: Structural model parameters estimates, standard errors and standardized estimates for cross lagged panel model three for the relationship between mathematical anxiety (CAMS) with mathematical performance (ARIC) at each time point (** significant at the p<.001 level * at the p<.05).

Cross lagged unidirectional paths between mathematical anxiety and mathematical fluency specify the causal contribution from the previous time to changes at the next time from mathematical anxiety to mathematical fluency and conversely from mathematical fluency to mathematical anxiety (see figure 7.5). The only significant pathway is the one between mathematical fluency at time three (just before the SATS) and mathematical anxiety at time four (after the SATS) (see table 7.2). Therefore, children's mathematical fluency score at time three was a significant predictor of their mathematical anxiety score at time four. Evidence that in specific circumstances hypothesis five is met, as low levels of mathematical fluency significantly predict higher levels of mathematical anxiety. None of the other pathways from mathematical fluency to mathematical anxiety were significant indicating that this relationship appears to only occur between these two time points. Looking at the pathways from mathematical anxiety to mathematical fluency none of the pathways are significant therefore for the children in this sample mathematical anxiety does not predict their subsequent performance on mathematical fluency tests. Therefore, hypothesis four is not met as high levels of mathematical anxiety do not significantly predict lower levels of mathematical fluency over time.

7.5.6. Simultaneous Latent growth curve modelling with Mathematical Fluency performance as a predictor.

A model was created with Mathematical Fluency as a time varying predictor of mathematical anxiety.

The Linear fit for this model can be described as:

$\chi^2(8) = 10$, $p = .27$, with an RMSEA = .04 and a CFI =.99.

Goodness of fit indices, e.g., Chi squared (χ^2), RMSEA and CFI indicate that this is a good fit model. Although estimates d1 and d3 have negative values which is classed as an inadmissible solution (see appendix 7 for output). Therefore, this model can be described as a Heywood case (Kline, 2015), which is where a Latent growth curve model has inadmissible solutions. Heywood cases have been described as models with too small a sample size or not enough waves of data. In the case of mathematical fluency there were only three waves of data collected at time points one, three and four, this may be why this model has inadmissible solutions. Therefore, no conclusions can be made with this model as to the directional relationship between mathematical fluency and mathematical anxiety for this sample.

7.5.7 Question C2) Is there a directional relationship between mathematical anxiety and arithmetic performance?

A series of models were constructed to look at the relationship between mathematical anxiety and arithmetic performance. Model one, the basic model, did not fit well with the Linear fit for this model:

$\chi^2(13) = 67.4$, $p < .001$, with an RMSEA = .180 and a CFI =.945 (see figure 7.6).

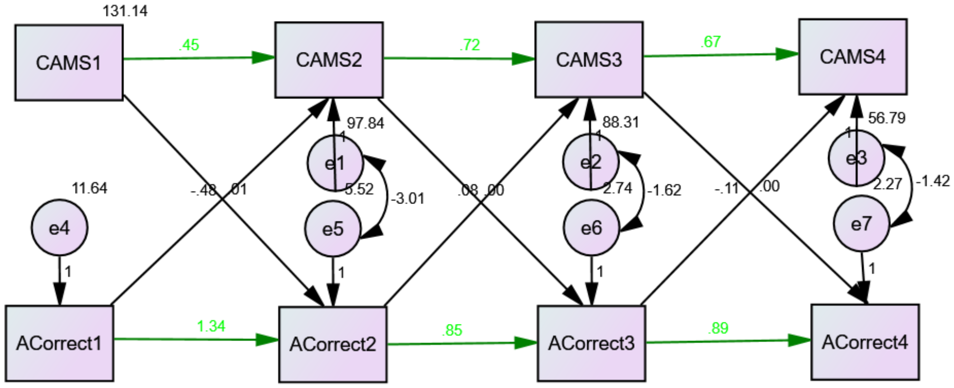

Figure 7.6: Cross Lagged panel model one for the relationship between mathematical anxiety (CAMS) with arithmetic performance (ACorrect) at each time point (significant pathways showed in green, all significant at the p<.001 level, e =measurement error).

Modification indices from model one, were used to improve the fit of subsequent models. These modification indices indicated that auto lagged pathways needed to be added from mathematical anxiety at time one (CAMS1) to mathematical anxiety at time four (CAMS4) and mathematical anxiety at time two (CAMS 2) to mathematical anxiety at time four (CAMS 4) (model two). Further modification indices indicated that that auto lagged pathways needed to be added from arithmetic performance at time one (ACorrect 1) to arithmetic performance at time four (ACorrect 4), arithmetic performance at time one (ACorrect 1) to arithmetic performance at time three (ACorrect 3) and arithmetic performance at time two (ACorrect 2) to arithmetic performance at time four (ACorrect 4) (model three- see figure 7.7). These modifications link to the assumptions that previous mathematical anxiety and arithmetic performance might predict their value at non-subsequent later times.

This modified model proved to be a good fit and the Linear fit for this model can be described as:

$\chi^2(8) = 11.2$, p =.191, with an RMSEA = .056 and a CFI =.997 (see figure 7.7).

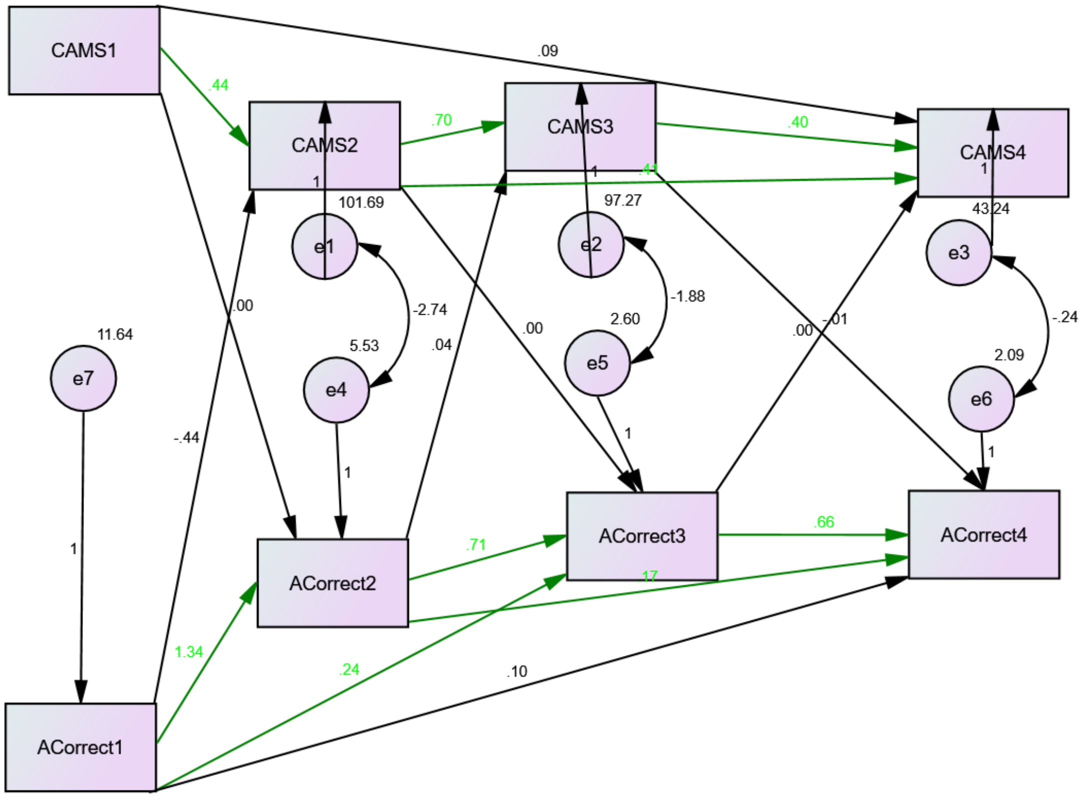

Figure 7.7: Cross Lagged panel model three for the relationship between mathematical anxiety (CAMS) with arithmetic performance (ACorrect) at each time point (significant pathways showed in green, all significant at the p<.001 level, e=measurement error).

Effect	Coefficient B	SE	CR	Standardized β
Auto lagged pathways				
CAMS1→CAMS2	.44**	.08	5.6	.44
CAMS1→CAMS4	.09	.06	1.6	.09
CAMS2→CAMS3	.70**	.08	9.0	.63
CAMS2→CAMS4	.41**	.07	5.8	.41
CAMS3→CAMS4	.40**	.06	6.9	.45
ACorrect1→ACorrect2	1.3**	.06	22	.90
ACorrect1→ACorrect3	.24*	.09	2.7	.18
ACorrect1→ACorrect4	.10	.08	1.2	.08
ACorrect2→ACorrect3	.71**	.06	11.7	.78
ACorrect2→ACorrect4	.17*	.08	2.1	.19
ACorrect3→ACorrect 4	.66**	.08	8.3	.69
Cross lagged pathways.				
CAMS1→ACorrect2	.003	.02	.14	.006
CAMS2→ACorrect 3	.000	.01	.03	.001
CAMS3→ACorrect4	-.007	.01	-.70	-.02
ACorrect1→CAMS2	-.44	.26	-1.7	-.13
ACorrect2→CAMS3	.04	.17	.22	.015
ACorrect3→CAMS4	.003	.13	.02	.001

Table 7.3: Structural model parameters estimates, standard errors and standardized estimates for cross lagged panel model three for the relationship between mathematical anxiety (CAMS) with arithmetic performance (ACorrect) at each time point (** significant at the p<.001 level * at the p<.05).

Cross lagged unidirectional paths between mathematical anxiety and arithmetic performance specify the causal contribution between the previous time to changes at the next time specifically mathematical anxiety to arithmetic performance and conversely from arithmetic performance to mathematical anxiety (see figure 7.7). None of the pathways from arithmetic performance to mathematical anxiety were significant indicating that for this sample there is no directional relationship between arithmetic performance predicting mathematical anxiety. Looking at the pathways from mathematical anxiety to arithmetic performance none of these pathways are significant either therefore for the children in this sample mathematical anxiety is not a predictor of their subsequent performance on arithmetic performance tasks. Therefore, neither hypothesis four nor five are met when the measure of mathematical performance is arithmetic performance.

7.5.8 Simultaneous Latent Growth Curve Model with Arithmetic performance as a predictor.

A model was created with Mathematical Fluency as a time varying predictor of mathematical anxiety. The Linear fit for this model can be described as:

$\chi^2(22) = 106.2$, $p = .000$, with an RMSEA = .1972 and a CFI =.92 (see figure and table in appendix 7).

This therefore was not a good fit model. Therefore, no conclusions can be made with this model as to the directional relationship arithmetic performance and mathematical anxiety.

7.5.9 Question C3) Is there a directional relationship between mathematical anxiety and word problem solving performance?

To provide evidence for this question a set of cross lagged panel models were constructed to model the relationship between mathematical anxiety and problem-solving performance. Model one, the basic model, did not fit well with the Linear fit for this model:

$\chi^2(13) = 93.72$, $p < .001$, with an RMSEA = .219 and a CFI =.910 (see figure 8.8).

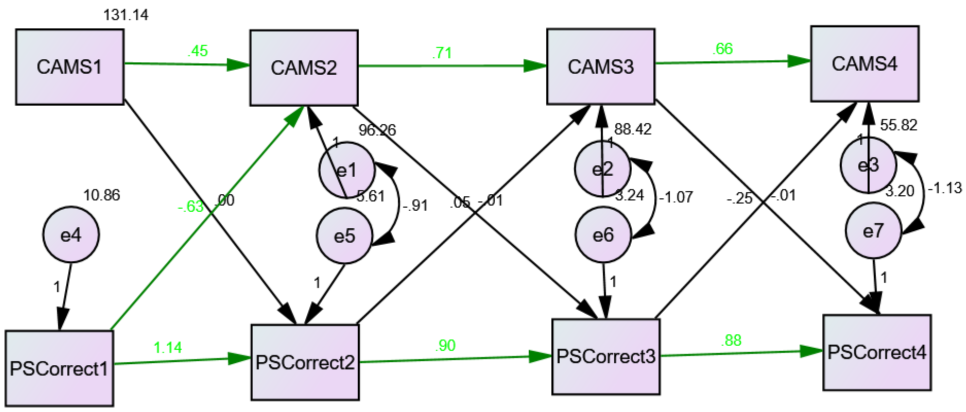

Figure 7.8: Cross Lagged panel model one for the relationship between mathematical anxiety (CAMS) with mathematical performance (PSCorrect) at each time point (significant pathways showed in green, all significant at the p<.001 level except PSCorrect1 to CAMS2 p=.017, e =measurement error).

Model two, this model used the information from the modification indices of the previous model indicating that auto lagged pathways needed to be added from each variable at time point one to time point three and four as well as from time point two to time point four so that all possible variations of the pathways could be included. These modifications link to the assumptions that previous mathematical performance or mathematical anxiety would predict their value at later times.

This modified model proved to be a good fit and the Linear fit for this model can be described as:

$\chi^2(9) = 16.1$, p =.066, with an RMSEA = .078 and a CFI =.992 (see figure 7.9).

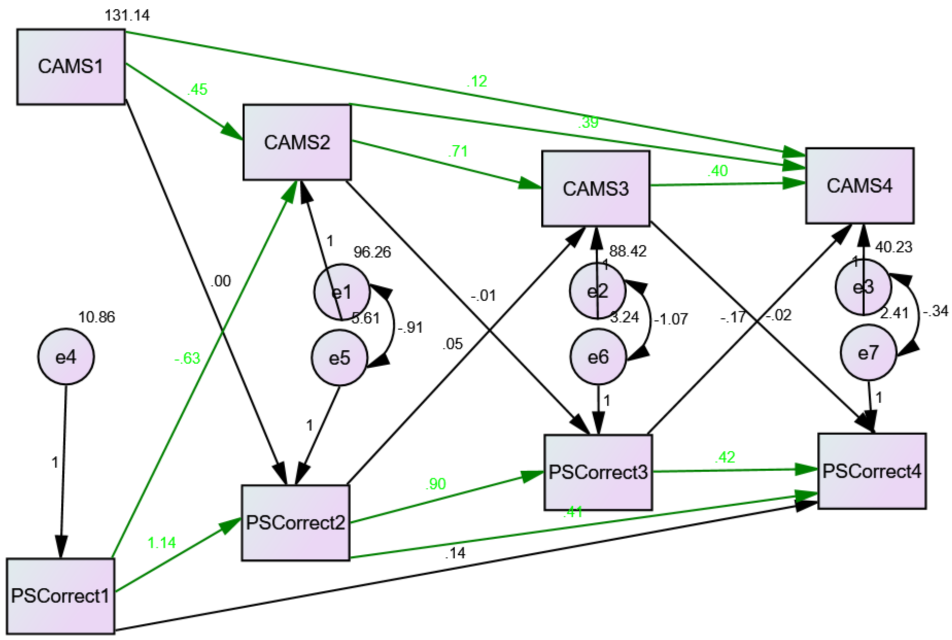

Figure 7.9: Cross Lagged panel model two for the relationship between mathematical anxiety (CAMS) with mathematical performance (PSCorrect) at each time point (significant pathways shown in green, all significant at the p<.001 level except PSCorrect1 to CAMS2 p=.017, e =measurement error).

Effect	Coefficient B	SE	CR	Standardized β
Auto lagged pathways				
CAMS1→CAMS2	.45**	.08	5.9	.45
CAMS1→CAMS4	.12*	.06	2.1	.12
CAMS2→CAMS3	.72**	.08	9.6	.65
CAMS2→CAMS4	.39**	.07	5.5	.39
CAMS3→CAMS4	.4**	.06	6.8	.44
PSCorrect1→PSCorrect2	1.2**	.06	18.1	.85
PSCorrect1→PSCorrect4	.14	.08	1.8	.11
PSCorrect2→PSCorrect3	.90**	.04	24.9	.91
PSCorrect2→PSCorrect4	.41**	.09	4.5	.42
PSCorrect3→PSCorrect4	.42**	.08	5.5	.43
Cross lagged pathways.				
CAMS1→PSCorrect2	-.002	.02	-.15	-.007
CAMS2→PSCorrect 3	-.011	.01	-.74	-.03
CAMS3→PSCorrect 4	-.02	.01	-1.4	-.07
PSCorrect1→CAMS2	-.63*	.26	-2.4	-.18
PSCorrect2 →CAMS3	.05	.19	.26	.02
PSCorrect3→CAMS4	-.17	.13	-1.3	-.07

Table 7.4: Structural model parameters estimates, standard errors and standardized estimates for cross lagged panel model two for the relationship between mathematical anxiety (CAMS) with word problem solving performance (PSCorrect) at each time point (** significant at the p<.001 level * at the p<.05).

Cross lagged unidirectional paths between mathematical anxiety and problem-solving performance specified the causal contribution between the previous time to changes at the next time specifically mathematical anxiety to problem solving performance and conversely from problem solving performance to mathematical anxiety (see figure 7.9). The only significant pathway is the one between problem solving at time point one (year before the SATS) and mathematical anxiety at time point two (the beginning of the year of SATS) see table 7.4. Therefore, children's problem-solving performance score at time point one was a predictor of their mathematical anxiety score at time point two. Evidence that in specific circumstances hypothesis five is met, as low levels of word problem solving performance significantly predicts higher levels of mathematical anxiety. None of the other pathways from problem solving performance to mathematical anxiety were significant indicating that this relationship appears to only occur between these two time points. Looking at the pathways from mathematical anxiety to problem solving performance none of the pathways are significant therefore for the children in this sample mathematical anxiety does not predict their subsequent performance on problem solving tasks. Therefore, hypothesis four is not met as high levels of mathematical anxiety do not significantly predict lower levels of word problem solving performance over time.

7.5.10 Simultaneous Latent Growth Curve Model with Problem Solving performance as a predictor.

This simultaneous latent growth curve analysis modelled the trends in mathematical anxiety across the whole project for the four time points adding problem solving performance as latent predictor variables. The problem-solving latent variables were added to attempt to explain the variability of the intercept and slope factors of mathematical anxiety as seen in figure 7.10. In figure 7.10 the intercept and slope factors of problem solving are being used to predict the intercept and slope of mathematical anxiety. This type of model enables the use of time varying predictors i.e., allows the use of the problem-solving scores from each time point. The detailed specification of the iterations of this model can be found in the appendices.

The Linear fit for this model was:

$\chi^2(17) = 12.3$, $p = .783$, with an RMSEA = .000 and a CFI =1.0 (see figure 7.10).

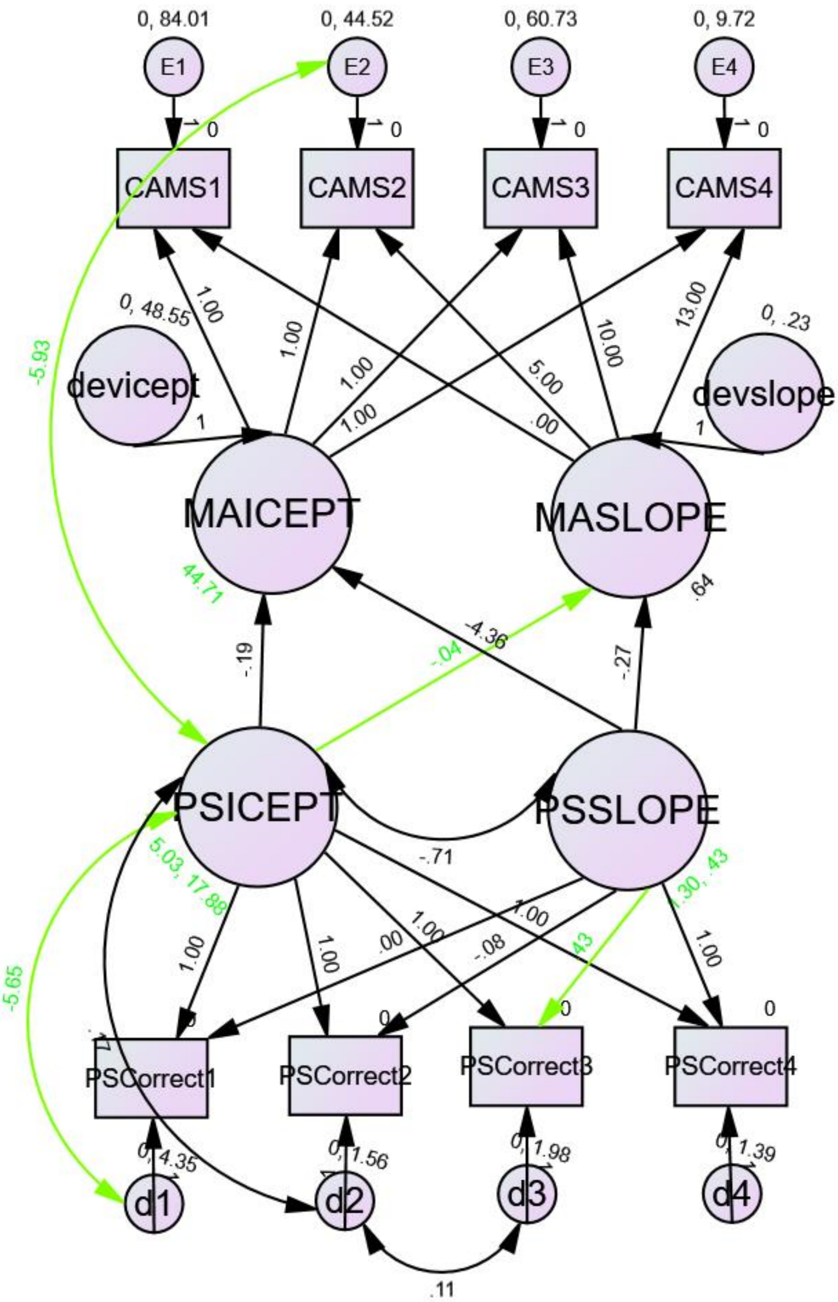

Figure 7.10: A path diagram of simultaneous latent growth curve modelling for the variables mathematical anxiety (CAMS) and mathematical performance problem solving (PSCorrect) over time with specified factor loadings on the slopes with means, unstandardized variances and covariance estimates displayed (circles = latent variables, rectangles = observed variables, e and d= measurement errors of observed variables).

Parameter	Coefficient	SE	CR	P value
Problem Solving Intercept mean	5.03	.29	17.7	p<.001
Problem Solving Intercept variance	17.9	2.5	7.2	p<.001
Problem Solving Slope mean	1.3	.22	5.9	p<.001
Problem Solving Slope variance	.43	.52	.84	p=.40
Mathematical anxiety Intercept mean	44.7	7.7	5.8	p<.001
Mathematical anxiety Slope mean	.64	.47	1.4	p=.169
Covariance Problem Solving Intercept-Problem Solving Slope.	-.71	.763	-.93	p=.35

Table 7.5: Parameter estimates for simultaneous latent growth curve model with problem solving as a predictor.

The intercepts for this model indicated that the average participant starts at a value of 44.7 for mathematics anxiety and 5.03 for problem solving performance. The average rate of change over the project for mathematical anxiety was 0.64, but this was not significant. Whereas the average rate of change for problem solving was 1.3 and was significant. In looking at the variances there was no significant covariance with a B= -.71 (β=- .26) as the significance level was p=.35.

Regression weights	Estimate	SE	CR	P value
Mathematical anxiety Intercept ← Problem solving Intercept	-.19	.29	-.65	.52
Mathematical anxiety Slope ← Problem Solving Intercept	-.04	.02	-2.1	.037
Mathematical anxiety Intercept ← Problem solving Slope	-4.4	5.5	-.80	.42
Mathematical anxiety Slope ← Problem Solving Slope	-.27	.32	-.83	.41

Table 7.6: Regression weights for simultaneous latent growth curve model with problem solving performance as a predictor.

The regression paths of interest for this model are those between the predictor and outcome variables. The regression path from problem solving intercept (predictor) to mathematical anxiety intercept (outcome) was not significant, meaning that the average mean in initial scores in problem solving performance does not predict the average mean score in mathematical anxiety. The regression path from problem solving slope to mathematical anxiety slope was not significant, meaning that the rate of change in problem solving scores is not related to the rate of change in mathematical anxiety. The problem-solving slope to mathematical anxiety intercept was also not significant meaning that the average rate of change in problem solving scores is not related to the average initial mean score in mathematical anxiety. The only significant regression path between the outcome and predictor factors was the regression path between problem solving intercept and mathematical anxiety slope. This negative path from the intercept of the problem-solving factor to the slope factor for mathematical anxiety suggests that the higher initial scores in problem solving the slower the rate of change in mathematical anxiety over time. Therefore, children with higher scores in problem solving performance have slower increases in mathematical anxiety. Also, those with lower ability scores in problem solving performance exhibit greater increases in mathematical anxiety. These results support hypothesis five, that poor levels of mathematical performance as measured by word problem solving, will significantly predict higher levels of mathematical anxiety over time.

7.6 Discussion.

The main aims of this chapter were to investigate the research questions as to whether mathematical anxiety and mathematical performance develop and whether there was a significant directional relationship between mathematical anxiety and mathematical performance over time. Both mathematical anxiety and mathematical performance were found to be statistically stable over time as the auto lagged pathways in all of the models found that both mathematical anxiety and all three forms of mathematical performance (Mathematical fluency, arithmetic and problem solving) were significant predictors from the previous time point to the next time point. The cross lagged pathways in these models indicated that there were no significant unidirectional pathways between mathematical anxiety and any of the measures of mathematical performance but that there were two significant unidirectional pathways from measures of mathematical performance to mathematical anxiety.

The cross lagged panel modelling in this thesis was used to investigate the autoregressive effect of both mathematical anxiety and mathematical performance as it allowed the adjacent measures of variables to be investigated over time, through interpreting the coefficients assigned to the auto lagged pathways. The finding that all the unidirectional auto lagged pathways for mathematical anxiety in each of the cross lagged panel models were significant, with coefficients between adjacent time measurements of mathematical anxiety ranging from .12 to .72., further supports the results from chapter 4 around the change in mathematical anxiety over time in this sample of children. The largest significant coefficient was between mathematical anxiety measured at time 2 (the beginning of the SATS year) to time 3 (just before the SATS). This indicates that the children's mathematical anxiety and their relative standings on mathematical anxiety were the most stable during this period. This effect in close proximity to SATs is important as it indicates that those children who are high in mathematical anxiety during this time continue to report high mathematical anxiety and those who are low in mathematical anxiety continue to report low mathematical anxiety.

Equally the direct unidirectional auto lagged pathways for mathematical performance in each of the cross lagged panel models were significant. For the first measure of performance namely mathematical fluency all direct auto lagged pathways were significant, two were significant with large coefficients (ARIC1- ARIC3 = 1.2, p<.001 and ARIC 3 – ARIC 4 = .92, p<.001) (see figure 7.5). These findings indicate that there is little variance in mathematical fluency over time and that there is increasing influence from the previous time points of mathematical fluency scores to the next time point. The children's relative standings on mathematical fluency change little over time. Therefore, those children who are better at mathematical fluency continue to be better at mathematical fluency and those children who are poorer at mathematical fluency continue to be poorer at mathematical fluency between adjacent time points.

For arithmetic performance there was a similar pattern of significant auto lagged pathways as far mathematical fluency. Three of the auto-lagged pathways were significant with large coefficients (ACorrect1 – Acorrect2 = 1.3, p<.001; ACorrect2- ACorrect3 = .7, p,.001; ACorrect3 – Acorrect4 = .66, p<.001) (see figure 7.7). Like mathematical fluency there is little variance in arithmetic performance over time. Therefore, those children who are better at arithmetic performance continue to be better at arithmetic performance and those children who are poorer at arithmetic performance continue to be poorer at arithmetic performance between adjacent time points.

In comparison to mathematical fluency there are two indirect pathways with significant coefficients (ACorrect1- ACorrect3= .24, p<.05; ACorrect2 – Acorrect4 = .17, p<.05) (see figure 7.7). These indirect pathways indicate that the children's standings on their arithmetic performance from time point one (year before SATs) to time point three (just before SATs) and from time point two (beginning of SATs year) to time point four (after the SATs). Therefore, there are some changes in those who are better or poorer at arithmetic performance linked to the proximity to the SATs.

Word problem solving the third measure of mathematical performance is like mathematical fluency and arithmetic in that the direct auto-lagged pathways are significant. Four of the auto-lagged pathways were significant with large coefficients (PSCorrect1 – PScorrect2 = 1.2, p<.001; PSCorrect2- PSCorrect3 = .9, p<.001; PSCorrect3 – PScorrect4 = .42, p<.001; PSCorrect1 – PScorrect4 = .41, p<.001) (see figure 7.9). These findings indicate that there is little variance in word problem solving over time and that there is more influence from the previous time points word problem solving scores to the next time point. The children's relative standings on word problem solving changes little over time on these direct pathways. Therefore, those children who are better at problem solving performance continue to be better at problem solving performance and those children who are poorer at problem solving performance continue to be poorer at problem solving performance between adjacent time points.

The relationship between prior mathematical performance and later mathematical performance was stronger in all three types of mathematical performance than the relationship between prior mathematical anxiety and later mathematical anxiety. This effect was similar to those found by Ma & Xu, (2004), for older children aged twelve to eighteen and Krinzinger et al., (2009) for younger children aged six to nine, whereby the mathematical anxiety remained relatively stable although not as stable as performance in mathematics. Krinzinger et al., (2009), found this stronger stability in mathematical calculation ability and Ma & Xu, 2004 found it for a combination of mathematical performance measures (basic number skills, algebraic problems, geometry tasks and quantitative literacy tasks). In this thesis mathematical anxiety stays relatively statistically stable over the period but not as statistically stable as for all the measures of mathematical performance (Fluency, arithmetic and word problem solving). Of interest here is that this developmental statistical stability of mathematical anxiety through the SATs year. This developmental statistical stability indicates that children who are more anxious at the beginning stay more anxious throughout.

From the longitudinal panel modelling the research questions as to whether the children with high levels of mathematical anxiety subsequently have poor performance or whether children with low levels of mathematical performance subsequently develop high levels of mathematical anxiety or is it that there is a combination of both directions at play were investigated. This directional relationship was of particular importance during the children's SATs year, as it is important to understand this relationship in order to support the children in increasing their mathematical performance. The results from this longitudinal study support the view that there is a significant relationship between mathematical anxiety and mathematical performance and that the dominating direction of this relationship is from prior mathematical performance to later mathematical anxiety (Carey et al., 2016; Tobias, 1986). There is no evidence of any significant relationship from prior mathematical anxiety to later mathematical performance (Ashcraft et al., 2007; Hembree, 1990; Lyons & Beilock, 2012), or of any reciprocal relationship (Carey et al., 2016; Hembree, 1990; Ramirez, Shaw & Maloney, 2018a).

Evidence was found for two specific cross lagged pathways where there was a significant negative relationship to suggest that lower levels of mathematical performance predicted higher levels of mathematical anxiety at the next time of testing. The first significant pathway was within the cross lagged panel model between mathematical anxiety and mathematical fluency. This pathway was the one from mathematical fluency at time point three (Just before the SATS) and time point four (just after the SATS).) This negative relationship indicates that children who are struggling with their mathematical fluency at time point three are then higher in mathematical anxiety at time point four. Time point three was of importance within this research, as it was the time closest to the children completing their SATs, therefore the time assumed where the children would be under most pressure to perform. Equally the measure of mathematical fluency was the only task within this research that required the children to perform under a time limit, a known factor that is thought to lead increased mathematical anxiety (Boaler, 2014; Engle, 2002). Previous research has found significant negative associations between mathematical fluency and mathematical anxiety (Devine et al., 2012: Justica-Galiano et al., 2017; Sorvo et al., 2017) in adolescents and children of a similar age cross-sectionally. Sorvo et al., (2019), in their longitudinal study with children from second grade to fifth grade (aged seven to eleven), found that prior lower mathematical fluency performance was linked to later high mathematical anxiety. Therefore, this significant pathway is consistent with previous cross sectional and longitudinal research investigating the relationship between mathematical anxiety and mathematical fluency.

The second significant pathway was within the cross lagged panel model between mathematical anxiety and problem-solving performance. This pathway was from problem solving performance at time one (a year before the SATS) and mathematical anxiety at time two (the beginning of the SATS year). This negative relationship indicates that children, who are struggling with their problem solving at time point one, are subsequently higher in mathematical anxiety at time point two. Previous research has found significant negative associations between problem-solving performance and mathematical anxiety (Ramirez et al., 2013; Ramirez et al., 2016; Wu et al., 2012; Wu et al., 2014) in children of a similar age cross-sectionally. Equally this finding is supported by other researchers who have found that adolescents and adults with prior poor problem-solving performance, report higher mathematical anxiety at a later time (Ma & Xu, 2004; Maloney et al., 2010; Maloney, Ansari & Fugelsang, 2011; Meece et al., 1990; Nunez-Pena & Suarez- Pellicioni, 2014). This significant pathway is consistent with previous longitudinal research, Gunderson et al., (2018), using similar cross lagged panel modelling with children aged from six to eight. They found children with poor mathematical performance reported higher mathematical anxiety six months later (Gunderson et al., 2018). This finding therefore offers limited support to the Deficit model (Carey et al., 2016; Tobias, 1986), which proposes that the memories that an individual has of their poor performance to succeed at previous mathematical tasks leads to an increasing mathematical anxiety in the future. Reasons suggested for this directional relationship in adults are, that those with high levels of mathematical anxiety appear to have some numerical processing deficits, which could be linked to poor performance but equally could be the result of mathematical avoidance earlier in life (Maloney et al., 2011). As the cross lagged panel modelling involved the whole sample and the children were not assigned to categories of mathematical ability e.g., high, low ability or mathematical learning disability this finding could not be linked to underlying numerical processing deficits. Rather it is more likely to be linked to the fact that the word problems, participants initially met at time point one, had been devised to assess the mathematical skills of the children in their SATs years. Therefore, the children would have found these word problems unfamiliar and quite challenging at time point one. Supporting this interpretation is the fact that previous research has indicated that the significant negative relationship with mathematical anxiety is more pronounced when children are required to complete more demanding mathematical tasks (Wu et al., 2012).

The Cross lagged pathways in all the models indicated that there was no evidence to suggest that higher levels of mathematical anxiety predicted poorer mathematical performance for any of the types of mathematical performance or time of testing. This finding therefore does not support either the Disruption model (Ramirez et al., 2018a) or the Debilitating Anxiety Model (Lyons & Beilock, 2012), as they both propose that it is previous mathematical anxiety that leads to poor mathematical performance. These models build on the theory of processing efficiency (Eysenck & Calvo, 1992) which proposes that the worry individuals experience when feeling anxious about mathematics reduces working memory resources which leads to a decline in performance. Previous research supporting this model has mainly used adults and adolescents as their participants and have linked the negative emotions linked with mathematical anxiety as the reason for their subsequent avoidance of mathematical tasks and courses (Ashcraft, Kirk & Hopko, 1998; Hembree, 1990). Other research with adults has added support to this theory by applying it to mathematical learning and problem solving (Ashcraft & Kirk, 2001; Ashcraft & Ridley, 2005; Eysenck & Calvo, 1992). Therefore, this result of no significant negative pathways could be linked to the fact that the participants in this thesis are children, attending primary school and learning about mathematics every day as part of their curriculum, they do not have the opportunity to avoid mathematics.

Thirdly, the cross lagged panel models were used to investigate whether the relationship between mathematical anxiety and mathematical performance is reciprocal. Researchers (Ashcraft et al., 2007: Carey et al, 2016), suggested that it is a cyclical relationship with poor performance leading to higher levels of mathematical anxiety, which in turn leads to poor performance or the other way around that high levels of mathematical anxiety leads to poor performance which then leads to higher levels of mathematical anxiety. Either way this cyclical relationship has negative consequences at school and in later life for individuals. In this research there were no significant reciprocal pathways in any of the cross lagged pathways. This finding therefore does not support, the reciprocal theory (Ashcraft et al., 2007: Carey et al, 2016), where the relationship is a cycle of influence whereby poor mathematical performance leads to mathematical anxiety and that this then leads to a decline in mathematical performance and increases mathematical anxiety (Jansen, Louwerse, Straatemeir, Van de Ven, Klinkenberg, & Van der Mass, 2013).

The relationship between mathematical anxiety and mathematical performance was also investigated through the inclusion of time varying predictors of mathematical performance into the simultaneous latent growth curve models. These models attempted to explain whether children's mathematical performances at each time point, predicted the initial status of their mathematical anxiety, the longitudinal rate of growth and the individual difference in that growth. The simultaneous latent growth curve model that included the measure of performance, mathematical fluency, as a predictor revealed no further information about this relationship. This modelling produced inadmissible solutions and could be explained as a "Heywood case" in that there were too few waves of data collected (Kline, 2015). The simultaneous latent growth curve model that included arithmetic performance as a predictor equally revealed no further information about this relationship as the model was not a good fit. The simultaneous latent growth curve model that included problem solving as a predictor was the only model which revealed some information about the relationship between mathematical anxiety and mathematical performance. A significant negative regression path ($\beta = -.35$, $p = .037$) from the intercept of the problem-solving factor to the mathematical anxiety slope factor was found. This negative path suggests that that the higher the children's initial scores in problem solving performance were then the slower their rate of change in mathematical anxiety. Conversely, it suggests that the lower the children's initial scores in problem solving performance were the higher the rate of change in mathematical anxiety. Therefore, those children who are good at problem solving a year before their mathematical anxiety increases slower than those who were not as good at problem solving a year before. This link between initial problem-solving ability and mathematical anxiety could be expected as children with stronger problem-solving ability at the beginning will continue to find problem solving easier over time and consequently be less mathematically anxious. This is an important finding for teachers and educationalists as it identifies the need to support children's problem-solving skills early to reduce the rate of growth in mathematical anxiety. Therefore, teaching and interventions supporting the development of problem-solving skills a year before SATs could reduce the children's mathematical anxiety increases (see chapter 9 for more discussion of the educational implications of this research).

Another important aspect to consider in the finding of a directional relationship between mathematical performance and mathematical anxiety is the fact that this may in part be explained by the impact of the high stakes testing environment. The children within the study were all within their SATs year, so were within an environment where their mathematical performance was of high importance and likely to impact their anxiety and stress levels. In a recent survey "83% of headteachers agreed that SATs have a negative impact on pupils' well-being" with concerns about the anxiety and stress these children are experiencing (Bradbury, Braun & Quick, 2019). Another negative aspect of a high stakes' regimes is the fact that children from a very early age are being told that they have not reached the age-related expectations, and this then identifies these children as "failures" (Bradbury, Braun & Quick, 2019) and increases their awareness of this "failure" (Hutchings, 2015). As it has been suggested that schools create a learning environment that strengthens children's general anxiety. (Szcygiel, 2020a), it can be assumed that it would also increase their mathematical anxiety too. Specifically, within the UK this testing regime of very young children has been identified as being a cause of stress and anxiety in children, requiring them to perform at a level at which they are not actually ready for developmentally (Hutchings, 2015). Thus, these children were within an environment where they would have been strongly aware of their performance levels in mathematics, and this would be highly likely to impact on their mathematical anxiety.

7.7. Conclusion

The auto lagged pathways in these models found that both mathematical anxiety and all three forms of mathematical performance (Mathematical fluency, arithmetic and problem solving) were significant predictors from the previous time point to the next time point. The relationship between prior mathematical performance and later mathematical performance was stronger in all three types of mathematical performance than the relationship between prior mathematical anxiety and later mathematical anxiety.

The cross lagged pathways in these models indicated that there were no significant unidirectional pathways between mathematical anxiety and any of the measures of mathematical performance. Therefore, in this sample children's mathematical anxiety scores did not predict their later mathematical performance. Conversely, there were two significant unidirectional pathways from measures of mathematical performance to mathematical anxiety. The first was from mathematical fluency at time point three to time point four and secondly from problem solving performance at time point one to time point two. All other cross lagged pathways were not significant. Therefore, this predictive relationship between mathematical performance and mathematical anxiety is specific to type of mathematical performance (fluency and word problem solving) and time of measurement. This lends support to the Deficit model (Tobias, 1986), which assumes that the memories that an individual has of their inability to succeed at mathematical tasks leads to an increasing anxiety in the future.

The simultaneous latent growth curve modelling added to the understanding of the directional relationship between mathematical anxiety and mathematical performance in the specific instance of word problem solving. As results indicated that the initial status of problem-solving performance did predict the rate of growth of mathematical anxiety over this study period. This negative path suggests that the children with higher initial scores in problem solving had a slower rate of change in mathematical anxiety over time. Also, those children with lower ability scores in problem solving performance exhibited greater increases in mathematical anxiety.

7.8 Chapter summary

7.8.1 Auto lagged pathways.

There was evidence that the children's relative standings on mathematical anxiety changes little over time for adjacent time points

- All auto-lagged pathways for adjacent measures of mathematical anxiety were significant.

There was evidence that the children's relative standings on mathematical fluency changes little over time for adjacent time points.

- All auto-lagged pathways for adjacent measures of mathematical fluency were significant, with large autoregressive effects (ranging from .92-1.2).

There was evidence that the children's relative standings on arithmetic performance changes little over time for adjacent time points but there is some change in the relative standings between time point one and time point three and time point two and time point four.

- All auto-lagged pathways for adjacent measures of arithmetic performance were significant, with large autoregressive effects (ranging from .65-1.3).

There was evidence that the children's relative standings on problem solving performance changes little over time for adjacent time points.

- All auto-lagged pathways for adjacent measures of problem-solving performance were significant, with large autoregressive effects (ranging from .42-1.2).

All autoregressive effects for the auto-lagged pathways for mathematical performance were stronger than for mathematical anxiety.

7.8.2 Cross lagged pathways:

- There was some evidence of a directional relationship from prior poor performance leading to higher mathematical anxiety.
  - significant cross lagged pathway between mathematical fluency at time point three (just before the SATS) and mathematical anxiety at time point four (after the SATS).

    - significant cross lagged pathway between problem solving performance at time pint one (a year before the SATS) and mathematical anxiety at time point two (the beginning of the SATS year).
    - no significant cross lagged pathways from arithmetic performance to their subsequent measure of mathematical anxiety

- There was no evidence of a directional relationship from prior mathematical anxiety leading to mathematical performance.
    - no significant cross lagged pathways from mathematical anxiety to any of the measures of mathematical performance.

- There was no evidence of a reciprocal relationship between mathematical anxiety and mathematical performance.

7.8.3 Simultaneous Latent growth curve models:

- The initial status and rate of growth of Mathematical fluency did not predict either the initial status or rate of growth of mathematical anxiety over this study period.

- The initial status and rate of growth of Arithmetic performance did not predict either the initial status or the rate of growth of mathematical anxiety over this study period.

- The initial status of problem-solving performance did predict the rate of growth of mathematical anxiety over this study period but not the initial status. This negative path suggests that the higher initial scores in problem solving the slower the rate of change in mathematical anxiety over time. Therefore, children with higher scores in problem solving performance have slower increases in mathematical anxiety. Also, those with lower ability scores in problem solving performance exhibit greater increases in mathematical anxiety.

- The rate of growth of problem-solving performance did not predict the initial status or rate of growth of mathematical anxiety.

Chapter 8- The relationship between interest in mathematics, with mathematical anxiety and mathematical performance.

Chapter contents:

This chapter will investigate the relationships of interest in mathematics with mathematical anxiety and mathematical performance (fluency, arithmetic and word problem solving) separately. Then it will look to describe the role of interest in mathematics within the relationship between mathematical anxiety and mathematical performance. It will outline the relationship with reference to the Key Stage one (KS1), the younger children and Key Stage two (KS2), the older children at time point one and three. This chapter follows on from previous chapters looking at the relationship between mathematical anxiety and mathematical performance for the two cohorts (chapters five and six). The chapter is divided into the following subsections:

- Introduction
    - Interest
    - Interest and mathematical anxiety
    - Interest and mathematical performance
    - Mathematical interest and the relationship between mathematical anxiety and mathematical performance.
- Aims
- Hypotheses
- Method: Participants, Materials and Procedure.
- Results
    - Descriptive Statistics
    - Analyses.
    - Question A) What is the association between mathematical anxiety and interest in mathematics over time?
    - Question B) Is the relationship between mathematical anxiety and interest in mathematics significant above a child's general anxiety?
    - Question C) What is the association between interest in mathematics and mathematical performance?
    - Question D) Is the relationship between mathematical performance and interest in mathematics significant above their non-verbal intelligence?

    - Question E) Does interest in mathematics mediate the directional relationship between mathematical performance and mathematical anxiety?
- Discussion.
- Conclusion
- Chapter summary

8.1 Introduction

The focus of this chapter is to examine the role of the emotional factor interest in mathematics with mathematical anxiety and mathematical performance separately and with the relationship between mathematical anxiety and mathematical performance. This role is explored cross-sectionally with two age groups, younger children (KS1, ages six to eight) and older children (KS2, ages ten to twelve), during their SATs year. Mathematical anxiety, the feeling of apprehension when confronted by mathematical tasks (Dowker, 2016) is self-reported in primary aged children (Carey et al., 2017b; Harari et al., 2013; Henschel & Roick, 2017; Justica-Galiano et al., 2017; Vukovic et al., 2013). Mathematical performance the ability to complete mathematical tasks (fluency, arithmetic and word problem solving) is known to be affected by a number of factors, emotional (mathematical anxiety, trait and state anxiety) cognitive (non-verbal intelligence and working memory) and individual factors (age and gender). As previously discussed in chapters five and six, there are significant negative associations between mathematical anxiety and mathematical performance dependent on the age of the children, type of mathematical performance and the time of each study. Negative relationships were found between mathematical anxiety and mathematical performance taking account of their cognitive (non-verbal intelligence and working memory) and emotional attributes (trait and state anxiety) for the older children (KS2). These negative relationships were stronger at time point three, nearer to the SATs. For the younger children (KS1) there were no significant negative relationships between mathematical anxiety and mathematical performance at either time point one or three.

An important emotional factor involved within any learning situation is how interested individuals are in the subject they are learning (Harackiewicz, Smith & Prinisk, 2016). Interest within a subject is linked to positive attributes such as motivation, persistence, affect and learning (Ainley, Hidi, & Berndorff, 2002; Koller et al., 2001; Krapp, 2000; Renninger, 2000). Previous research has indicated that interest is particularly important in the subject of mathematics due to its perceived difficulty by individuals (Murphy & Alexander, 2000). Interest in mathematics was collected at time point one and time point three. As it was felt important within this thesis to establish whether interest in a subject affects the negative relationship between mathematical anxiety and mathematical performance.

8.1.1. Interest

Interest in a subject has been described as a positive construct with both state and trait like aspects (Carmicheal, Callingham & Watt, 2017). State like interest is defined as situational interest, where individuals interest is triggered in their learning by the tasks they are completing, sometimes new tasks (Hidi, Renninger & Krapp, 2004). Trait like interest is defined as individual interest, where an individuals' interest in a subject has developed over time (Hidi et al., 2004). An individual's move from situational to individual interest is supported by their emotional and cognitive involvement within a subject (Hidi & Renninger, 2006). The cognitive aspect is linked to how as interest within a subject develops, individuals look to acquire new knowledge and apply this knowledge (Krapp, 2007). For cognitive interest to develop in a subject, the activities need to be related to the subject providing new knowledge that inspires the understanding and application of this new knowledge (Carmichael et al. 2017). The emotional aspect is linked to how positive individuals feel about a subject, namely enjoyment and the feeling of excitement in completing tasks (Carmichael, et al., 2017). Therefore, the more individuals are enjoying and excited about their learning, the more they develop a sustained individual interest in that subject. For emotional interest to develop in a subject, the activities related to that subject need to be positive experiences for the learner increasing their emotional interest within the subject (Pintrich, 2000).

Control value theory assumes that the positive experiences within the subject will activate positive emotions and will lead to more interest in that subject (Pekrun, Frenzel, Goetz & Perry, 2007). Conversely negative experiences within the subject will activate negative emotions such as anxiety, which will reduce interest in the subject (Pekrun, Goetz, Titz & Perry, 2002). Another aspect of emotional interest is linked to the feedback that individuals receive of their performance in a subject. This feedback can be positive about their performance which in turn leads to greater interest and greater performance (Deci & Ryan, 1985; Ryan & Deci, 2000). Alternatively, feedback can be negative about their performance leading to distress and a decreased interest and performance in the subject (Dowker, 2019a).

Preference for a subject is where interest is described as content specific (Jones et al, 2012). This preference is demonstrated through self-reporting of accessing activities linked to the subject, academically and in the real world, including positive attributes such as liking and enjoying that subject (Hidi, Renninger & Krapp, 2004). Previous research has identified interest as a variable that can guide attention (Renninger & Hidi, 2011), one that facilitates learning in different content areas (Renninger & Hidi, 2002) and one that supports achievement in that subject (Hidi & Renninger, 2006; Schiefele, 1996). Also, those individuals with a higher interest in mathematics value it as an important subject within their education, they take more mathematics courses and achieve better grades than individuals with lower interest (Simpkins, Davis-Keen & Eccles, 2006; Wigfield, 1994; Wigfield & Eccles, 2002). This interest in academic subjects starts very early at the beginning of a child's school journey (Fisher, Dobbs-Oates, Doctoroff & Arnold, 2012; Lerkkanen et al., 2012).

Mathematical interest is an important consideration within mathematics curriculum and research into the achievements of children and young people. The UK National curriculum highlights the emotional aspect of interest in mathematics, in promoting the enjoyment and curiosity within learning mathematics:

“a sense of enjoyment and curiosity about the subject” (Department for Education, 2013b).

Whilst the PISA identifies interest as a stable construct that supports engagement in a subject and that interest in mathematics also supports learning through the “ability to select appropriate strategies and deepen understanding” (OECD, 2003).

Therefore, it is important to understand the role interest in mathematics has with mathematical anxiety, as is it that having a good interest in mathematics might mitigate the negative effects of mathematical anxiety.

8.1.2 Interest and Mathematical Anxiety.

The relationship between interest in mathematics and mathematical anxiety is not well documented. Ganley & McGraw, (2016), suggest that interest in mathematics predicts mathematical anxiety in children aged six to seven. Most research in this field is with older children (Pekrun, Goetz, Titz & Perry, 2002), adolescents (Luo, Wang & Luo, 2009) and adults (Asif & Khan, 2011). Studies with older school children have indicated that for those with more motivational interest in their subjects such as mathematics, learning is more positive, leading to less negative experiences and anxiety about the subject (Pekrun, Goetz, Titz & Perry, 2002). A cross- sectional study with adolescents aged from twelve to seventeen, reported that those adolescents with a high level of mathematical anxiety reported a low level of mathematical interest (Luo, Wang & Luo, 2009). Supporting these findings above is a cross-sectional study with undergraduate students, which reported a negative correlation between mathematical anxiety and mathematical interest. They found that students with high levels of mathematical anxiety reported low levels of interest in mathematics (Asif & Khan, 2011).

8.1.3 Interest and Mathematical Performance

The relationship between interest in mathematics and mathematical performance is well documented in line with control value theory. Studies have found there to be a positive relationship with a greater interest in mathematics leading to greater mathematical performance from pre-schoolers (Fisher et al., 2012) to adolescents (Koller et al., 2001). Findings suggest that it is the positive activating emotion of enjoyment of a subject in pre-schoolers, that leads to a positive relationship between mathematical skills and early mathematical interest (Fisher et al., 2012). Researchers have found that interest in mathematics is an important factor in the development of arithmetic skills in children (Gottfried, 1990). Equally this positive relationship between interest and mathematical performance has been found in older children (Ahmed et al., 2013; Frenzel, Goetz, Pekrun, & Watt, 2010). Also, previous research with adolescents has identified that those with a good level of interest in mathematics their mathematical performance level increases (Moore, Rudig & Ashcraft, 2015).

The relationship between interest in mathematics and mathematics performance is thought to be reciprocal with early interest promoting an increase in mathematical skills, through an increase in time, effort and sustained practice in mathematics (Ericsson, Krampe, & Tesch-Romer,1993; Koller, Baumert & Schnabel, 2001; Schiefele, 2001; Singh, Granville & Dika, 2002). Conversely, it is thought that early positive performance in mathematics leads to increased mathematical interest (Ma & Kishor,1997). Alternatively, this reciprocal relationship might have a negative influence as those individuals who start with poor mathematical performance might lead to decreased interest in mathematics and those who start with a low interest in mathematics might lead to poor mathematical performance. Fisher et al., (2012), looked at the relationship between mathematical interest and mathematical performance with children aged three to six years. Their study used two measures of mathematical interest, an observation of the children playing with educational mathematics materials and a teacher report of their interest in mathematics. They suggested that it is early interest in maths that predicts later good performance in mathematics (Fisher et al., 2012), Ganley and Lubienski, (2016), looked at the relationship between mathematical interest and mathematical performance with older children aged eight to fourteen. They used four questions to elicit the children's mathematical interest for example, I like maths. They suggested that it was mathematical performance that predicted later interest (Ganley & Lubienski, 2016). Thus, research to date provides conflicting results as to the direction of the relationship between interest in mathematics and mathematical performance, possibly as a consequence of the age of the children within the studies.

Equally, the relationship between interest in mathematics and mathematical performance is not thought to be static but dynamic. Studies have reported that young children aged from six to seven have high emotional interest in mathematics (Stevenson, Lee, Chen, Lummis, Stigler, Fan, & Ge, 1990). As children progress on their journey through education interest appears to decrease (Gottfried, Fleming & Gottfried, 2001; Jacobs, Lanza, Osgood, Eccles & Wigfield, 2002; Wigfield, Eccles, Schiefele, Roser, & Davis-Kean, 2006) especially as children reach adolescence (Moore, Rudig & Ashcraft, 2015). These research findings that the relationship between mathematical interest and mathematical performance is dynamic could be explained by increasing demands of the mathematical curriculum as children get older (Moore, Rudig & Ashcraft, 2015). As the mathematics curriculum increases in complexity with the introduction of more difficult content such as algebra (DFE, 201b).

Interest may be particularly important in mathematics as children get older as they need an increased interest to sustain their previous performance levels. Longitudinal studies have investigated the relationship between mathematical interest and mathematical performance in adolescents (Koller et al, 2001; Marsh, Trautwein, Ludtke, Koller & Baumert, 2005). Koller et al., (2001) suggest that a good subject interest is particularly important for a subject like mathematics as students consider mathematics to be a difficult subject. They concluded that motivational factors such as a child's interest in subjects is important for strengthening academic achievement. In their longitudinal research, German students in the high school years (students aged twelve to eighteen) were tested at the end of grade seven (children aged twelve to thirteen) and ten (adolescents aged fifteen to sixteen) and then in the middle of grade twelve (adolescents aged seventeen to eighteen). They found that mathematics interest in students aged twelve to thirteen had no direct effect on achievement later when they were aged fifteen to sixteen. However, interest in mathematics influenced the selection of further mathematical courses, whether students chose basic or advanced mathematics courses. Those students who chose advanced mathematics courses achieved better results at eighteen. They suggested that interest in mathematics is of more importance to students as they move through secondary education, as they make more independent choices around their learning. This previous research is supported by Marsh et al., (2005), who measured mathematical interest and achievement of students aged twelve to thirteen in Germany. They tested students at two time points during the same academic year. In their reciprocal effects model, they found that there was a significant relationship between mathematical interest and mathematical performance (mathematical grades and test scores). They found that it was the student's mathematical grades which significantly affected subsequent mathematical interest. Equally mathematical interest at time one affected mathematical interest at time two.

This dynamic effect between mathematical interest and mathematical performance has also been linked to the decrease in enrolment in mathematics courses during adolescence, when students have decreased mathematical interest (Wigfield, 1994, Wigfield & Eccles, 2002). Whereas increased mathematical interest results in students' completion of optional mathematical courses (Koller, Baumert & Schnebel, 2001).

Therefore, this positive relationship between mathematical interest and mathematical performance needs to be fostered in a child's early education and sustained in their later education. More important for this thesis is the link between mathematical interest and the relationship between mathematical anxiety and mathematical performance.

8.1.4. Mathematical interest and the relationship between mathematical anxiety and mathematical performance.

This link between mathematical interest and its contribution to the relationship between mathematical anxiety and mathematical performance is equally less well documented. It could be assumed that as there is a positive relationship between mathematical interest and mathematical performance and a negative relationship between mathematical interest and mathematical anxiety, there is a role for mathematical interest in the relationship between mathematical anxiety and mathematical performance. Asif & Khan, (2011) investigated the mathematics anxiety, mathematics interest and mathematical achievement of undergraduate students. They reported a significant negative correlation between mathematical anxiety and mathematics achievement, concluding that students with high mathematical anxiety had low mathematical achievement scores. They also reported a significant negative correlation between mathematical anxiety and mathematical interest concluding that students with high mathematical anxiety had lower mathematical interest. They also reported a significant positive correlation between mathematical achievement and mathematical interest, so students with a high level of interest in mathematics have higher levels of achievement. In their study they related mathematical anxiety, mathematical interest, and mathematical performance through correlations, but they did not relate all three together. This study therefore was able to discuss the association between mathematical interest and mathematical anxiety and mathematical performance separately for adults, this thesis aims to discuss these relationships in children.

This lack of well documented literature leaves a significant gap in knowledge regarding the role that interest in mathematics plays within the directional relationship between mathematical anxiety and mathematical performance. This thesis uses mediation analysis to better understand the role of interest in mathematics in children. As this meets the wider narrative of the thesis found in a previous chapter (chapter seven) that mathematical performance can predict mathematical anxiety, it is interesting to see whether interest would mediate this relationship at time point three (just before the SATs) where the relationship is stronger.

8.2 Aims

Thus, the aim within this chapter was to investigate the specific nature of the relationship between mathematical anxiety, interest in mathematics and mathematical performance. As this was to be explored longitudinally this aim was explored at time point one (year before the SATs) and time point three (just before the SATs).

In this chapter the following questions are examined to fully understand the pattern of the relationship between mathematical anxiety and interest in mathematics for the younger and older children.

> Question A) What is the association between mathematical anxiety and interest in mathematics over time?

Previous research has suggested that there is a negative correlation between mathematical anxiety and mathematical interest in adolescents (Asif & Khan, 2011).

> Question B) Is the relationship between mathematical anxiety and mathematical interest significant above a child's general anxiety?

> Question C) What is the association between interest in mathematics and mathematical performance?

Previous research has suggested that there is a positive association between mathematical interest and mathematical performance from pre-schoolers to primary aged children and adolescents (Ahmed, Van der Werf, Kuyper & Minnaert, 2013; Frenzel, Goetz, Pekrun, & Watt, 2010, Fisher et al., 2012; Gottfried, 1990; Moore, Rudig & Ashcraft, 2015).

> Question D) Is the relationship between mathematical performance and interest in mathematics significant above their non-verbal intelligence?

> Question E) Does interest in mathematics mediate the directional relationship between mathematical performance and mathematical anxiety?

8.3 Hypotheses.

The first hypothesis was that interest in mathematics would associate negatively with mathematical anxiety. From previous research, it was predicted that the students in these studies with more interest would find learning mathematics more positive, leading to less mathematical anxiety (Asif & Khan, 2011; Ganley & McGraw, 2016; Pekrun et al., 2002).

> H1-high levels of mathematical interest will be associated with lower levels of mathematical anxiety.

The second hypothesis was that the relationship between interest in mathematics and mathematical anxiety would still be present after controlling for any association with general anxiety (as measured by trait and state anxiety). As mathematical anxiety is thought to be a separate construct to general anxiety (trait and state) (Ashcraft, Krause, & Hopko, 2007; Hembree, 1990).

H2- High levels of mathematical interest will be associated with lower levels of mathematical anxiety after controlling for general anxiety (trait and state).

The third hypothesis predicted that interest in mathematics would associate positively with mathematical performance consistent with previous research (Ahmed et al., 2013; Frenzel, Goetz, Pekrun, & Watt, 2010, Fisher et al., 2012; Gottfried, 1990; Moore, Rudig & Ashcraft, 2015).

H3-high levels of mathematical interest will be associated with high levels of mathematical performance.

The fourth hypothesis predicted that the relationship between interest in mathematics and mathematical performance would still be present after controlling for any association with non-verbal intelligence. Previous research suggests that children with more interest will have higher levels of mathematical performance (Koller et al., 2001; Marsh et al., 2005).

H4-high levels of mathematical interest will be associated with higher levels of mathematical performance after controlling for non-verbal intelligence.

The fifth hypothesis suggests that interest in mathematics mediates the directional relationship between mathematical anxiety and mathematical performance. As interest in mathematics has been found to have a significant positive relationship on mathematical performance (Ahmed et al., 2013; Fisher et al., 2012; Frenzel, Goetz, Pekrun, & Watt, 2010; 2012; Moore, Rudig & Ashcraft, 2015) it was hypothesised that this would mediate the significant negative association between mathematical anxiety and mathematical performance (Carey, Devine, Hill & Szucs, 2017; Cargnelutti et al.,2017; Devine, Fawcett, Szucs & Dowker, 2012; Harari et al., 2013; Hembree, 1990; Ma, 1999; Ramirez et al, 2013; Ramirez et al., 2016; Sorvo et al., 2017; Wu et al., 2012; Zhang, Zhao & Kong, 2019).

H5-interest in mathematics will mediate the directional relationship between mathematical performance and mathematical anxiety.

8.4 Method

The methodology of this longitudinal study is described in detail in Chapter 3.

8.4.1 Participants

At time point one, the year before their SATs, there were sixty-seven year one children (M=75 months of age, SD= 3.7) then at time point three, just before their SATs, there were sixty-one year two children (M= 85 months of age, SD= 3.5). At time point one, the year before their SATs, there were seventy-three year five children (M=123 months of age, SD= 3.5) then at time point three, just before their SATs there were seventy-two year six children (M=133 months of age, SD= 3.5) (See chapter 3 for more details about the participants).

8.4.2. Materials

At time point one and three the children were assessed on all the emotional factors (interest in mathematics, trait, state, and mathematical anxiety), cognitive factors (non-verbal intelligence, working memory and reading) and Mathematical Performance (fluency, arithmetic and word problem solving) measures (see chapter three for more details).

8.4.3. Procedure

As described in chapter three (see testing timetable, table 3.4 chapter 3), testing took place over a number of sessions, with assessments being administered on a one-to-one basis with each child and the researcher in a small quiet space within the school. Apart from the mathematical fluency test which was administered in small group sessions with no more than six children at a time.

Testing was carried out four times over a twelve-month period from summer of school years one and five (April-July 2017), and Spring/summer term of school years two and six (March-May 2018).

All testing was carried out by the author and general praise and encouragements were the only feedback given.

8.5. Results

8.5.1. Descriptive Statistics.

The means and standard deviations of the measures for the younger cohort are provided in table 8.1 and the older cohort in table 8.2 at time point one and three.

Younger children	Study 1 Mean (SD) (N=67)	Study 3 Mean (SD) (N=61)
Emotional		
Mathematical Anxiety	37.3(11.7)	37.6 (13.3)
Trait Anxiety	32.5(6.7)	32.2(8.5)
State Anxiety	30.9(5.1)	31.4(6.4)
Interest in Mathematics	43.4(12.6)	43.5(12.2)
Cognitive		
Non-verbal Intelligence	18.2(.25)	22.8(5.7)
Mathematical Performance		
Mathematical Fluency	22.8(10.3)	34.1(17.2)
Arithmetic	3.9(3.9)	4.4(2.8)
Word Problem Solving	2.3(2.3)	1.8 (1.8)

Table 8.1: Means and Standard deviations for emotional, cognitive, and mathematical performance measures for the younger children for each study.

Older children	Study 1	Study 3
	Mean (SD)	Mean (SD)
	(N=73)	(N=72)
Emotional		
Mathematical Anxiety	39.3(11)	39.7 (11.7)
Trait Anxiety	31.1(6.9)	31.7(7.0)
State Anxiety	31.8(4.6)	32.4(4.7)
Interest in Mathematics	44.1(9.3)	42.5(12.3)
Cognitive		
Non-verbal Intelligence	28.8(4.3)	30.8(3.8)
Mathematical Performance		
Mathematical Fluency	107.7(39)	135.58(49.66)
Arithmetic	10(12)	12.5(1.94)
Word Problem Solving	7.4(2.1)	9.1 (3.11)

Table 8.2 Means and Standard deviations for emotional and mathematical performance measures for the older children for each study.

8.5.1.1 Assessing Normality: Looking for outliers in the data.

No data was excluded from all the participants as once the trimmed means were checked they were found to be similar to the mean for each variable. (Pallant, 2013).

8.5.2. Analyses.

Initial analyses were undertaken to ensure no violation of assumptions, including normality, linearity, and homoscedasticity. Therefore, the analyses chosen were parametric in nature including correlations and hierarchical regressions. Pearson product-moment correlations coefficients were reported in the correlational analyses. Throughout statistical significance was set at $p<.05$. Prior to conducting the series of hierarchical multiple regressions, the relevant assumptions of this statistical analysis were tested. Firstly, the sample sizes were considered acceptable given that there were five independent variables to be included in the analysis (Khamis & Kepler, 2010, Tabachnick & Fidell, 2014). The assumption of singularity was also met as the independent variables (non-verbal intelligence, trait, state, and mathematical anxiety) were not a combination of other independent variables. An examination of correlations (see correlation tables in chapter 8 appendix) revealed that no independent variables were highly correlated, as none of the predictors correlated at .80 or above. However, the assumption of multicollinearity was accepted as the collinearity statistics of Tolerance and VIF were all within acceptable limits, (Coakes, 2005; Hair, Black, Babin, Anderson &Tatham, 2006). Univariate outliers identified in initial data screening in the extreme range were kept, as the trimmed means were similar to the means in all variables (Pallant, 2013). Residual and scatter plots indicated the assumptions of normality, linearity and homoscedasticity were all satisfied (Hair et al., 2006; Pallant, 2013).

8.5.3. Question A) What is the association between mathematical anxiety and interest in mathematics over time?

In answering this question, the relationship between Interest in Mathematics and mathematical anxiety was investigated for both the younger and the older children at time point one and three.

Correlations coefficients for emotional factors with Mathematical Anxiety	Mathematical anxiety			
	Study 1 **Younger children** **(n=67)**	**Study 1** **Older children** **(n=73)**	**Study 3** **Younger children** **(n=61)**	**Study 3** **Older children** **(n=72)**
Interest in Mathematics	-.56**	-.67***	-.52**	-.59**
Trait Anxiety	.53**	.62***	.43**	.54**
State Anxiety	.42**	.36**	.36**	.46**

Table 8.3: Correlation coefficients for interest in mathematics, trait, and state anxiety with mathematical anxiety for studies one and three for the younger and older children ("*p < .05, **p < .01, ***p,.001").

8.5.3.1. Younger children

High levels of interest in mathematics, as analysed by Pearson product-moment correlations, were associated with lower levels of mathematical anxiety for the younger children at time point one, r= -.56, n= 67, p =<.001, and time point three, r= -.52, n= 61, p =.01 (see table 8.3).

8.5.3.2. Older children

High levels of interest in mathematics, as analysed by Pearson product-moment correlations, were associated with lower levels of mathematical anxiety for the older children at time point one, r= -.67, n= 73, p <.001 and time point three, r= -.59, n= 72, p =.01 (see table 8.3).

Hypothesis one is therefore met as there are significant negative associations between interest in mathematics and measures of mathematical anxiety for both cohorts at both times.

8.5.4. Question B) Is the relationship between mathematical anxiety and interest in mathematics significant above a child's general anxiety?

In answering this question, the relationship between interest in mathematics and mathematical anxiety was investigated for each cohort at time point one and three along with the other emotional variables (trait and state anxiety).

Two-step hierarchical multiple regression was conducted with mathematical anxiety as the dependent variable. Trait and state anxiety were entered at step one as previous research has indicated that mathematical anxiety is a separate construct, independent of general anxiety (Ashcraft et al., 2007; Hembree, 1990). Interest in mathematics was entered at step two. The means and SDs for each variable can be seen in Table 8.1.

8.5.4.1. Younger children

At time point one (year before SATs), the overall relationship was highly significant at step 2, (F (3,63) = 27.5, $p < .001$) with a good fit (multiple $R = .75$). Analysing the un-standardised coefficients showed that both interest in mathematics (B = -.42, t (63) =-5.3, p<.001), state anxiety (B = .78, t (63) =3.9, p<.001) and trait anxiety (B = .54, t (63) =3.6, p-.001) were all significant predictors of mathematical anxiety ($R^2 = 0.75$). The standardised coefficients showed that interest in mathematics (β = -.46) was a negative predictor, therefore higher scores in interest in mathematics indicated lower mathematical anxiety scores. Whereas state (β = .34) and trait anxiety (β = .31) were positive predictors of mathematical anxiety, therefore higher scores on state and trait anxiety questionnaires indicated higher mathematical anxiety scores (see table 8.4).

	β	t	*p*	R	R^2	Δ R^2
Step 1				**.61**	**.35**	**.37**
Trait Anxiety	.32	3.1	.003**			
State Anxiety	.46	4.5	p<.001***			
Step 2				**.75**	**.55**	**.19**
Interest in Mathematics	-.46	3.6	p<.001***			
Trait Anxiety	.31	3.6	p<.001***			
State Anxiety	.34	3.9	p<.001***			

Table 8.4: Summary of hierarchical regression analysis for variables predicting mathematical anxiety at time point one for the younger children (N =67; *p < .05, **p < .01, ***p< .001).

At time point three (just before SATs), the overall relationship was highly significant at step 2, (F (3,57) = 14.9, $p < .001$) with a good fit (multiple R = .66). Analysing the un-standardised coefficients showed that interest in mathematics (B = -.46, t (57) =-4.1, p<.001), state (B = .66, t (57) =3.2 p=.003) and trait (B = .37, t (57) =2.4 p=.022) were all significant predictors of mathematical anxiety (R^2 = 0.44) (see table 8.5). The standardised coefficients showed that interest in mathematics (β = -.42) was a negative predictor of mathematical anxiety scores, therefore higher scores on the interest in mathematics questionnaire indicated lower mathematical anxiety scores. Whereas state (β = .32) and trait (β = .24) were positive predictors of mathematical anxiety, therefore higher scores in the state and trait anxiety questionnaires indicated higher scores on the mathematical anxiety questionnaire.

	β	t	p	R	R^2	ΔR^2
Step 1				**.53**	**.28**	**.28**
Trait Anxiety	.48	2.7	p=.009**			
State Anxiety	.81	3.5	p=.001**			
Step 2				**.66**	**.44**	**.16**
Interest in mathematics	-.46	-4.2	p<.001***			
Trait Anxiety	.37	2.4	p=.022*			
State Anxiety	.66	3.1	p=.003**			

Table 8.5: Summary of hierarchical regression analysis for variables predicting mathematical anxiety at time point three for the younger children (N =61; *p < .05, **p < .01, ***p< .001).

Therefore, hypothesis two was met at both time points for the younger children as high levels of mathematical interest were associated with lower levels of mathematical anxiety above their general levels of anxiety.

8.5.4.2. Older children.

At time point one (year before SATs), the overall relationship was highly significant at step 2, (F (3,69) = 39, p < .001) with a good fit (multiple R = .79). Analysing the un-standardised coefficients showed that interest in mathematics (B = -.58, t (69) =-6.1, p<.001) state anxiety (B = .82, t (63) =4.1, p<.001) and trait anxiety (B = .34, t (63) =2.8, p-.006) were all significant predictors of mathematical anxiety (R^2 = 0.61). The standardised coefficients showed that interest in mathematics was a negative predictor of mathematical anxiety (β = -.50), therefore higher scores on the interest in mathematics questionnaire indicated higher mathematical anxiety scores. Whereas state (β = .35) and trait anxiety (β = .22) were positive predictors of mathematical anxiety, therefore higher scores on state and trait anxiety questionnaires indicated higher mathematical anxiety scores (see table 8.6).

	β	t	*p*	R	R^2	ΔR^2
Step 1				**.65**	**.42**	**.42**
Trait Anxiety	.22	2.3	p=.022*			
State Anxiety	.56	5.9	p<001***			
Step 2				**.70**	**.61**	**.20**
Interest in Mathematics	-.50	-6.1	p<.001***			
Trait Anxiety	.22	2.8	p=.006**			
State Anxiety	.35	4.1	p<.001***			

Table 8.6: Summary of hierarchical regression analysis for variables predicting mathematical anxiety at time point one for the older children (N =73; *p < .05, **p < .01, ***p< .001).

At time point three (just before SATs), the overall relationship was highly significant at step 2, (F (3,68) = 22.7, $p < .001$) with a good fit (multiple R = .71). Analysing the un-standardised coefficients showed that interest in mathematics (B = -.39, t (68) =-4.4 p<.001), and state anxiety (B = .70, t (68) 3.6, p=.001) were significant predictors of mathematical anxiety (R^2 = 0.50). The standardised coefficients showed that interest in mathematics (β = -.41) was a negative predictor of mathematical anxiety scores, therefore higher scores on the interest in mathematics questionnaire indicated lower mathematical anxiety scores. Whereas state anxiety (β = .34) was a positive predictor of mathematical anxiety, therefore higher scores on the state Anxiety questionnaire indicated higher scores on the mathematical anxiety questionnaire. Whilst trait anxiety (B =.16, t (68) =1.7, p=.10) was not a significant predictor of mathematical anxiety. (See table 8.7).

	β	t	*p*	R	R^2	Δ R^2
Step 1				**.60**	**.36**	**.36**
Trait Anxiety	.29	2.7	p=.008**			
State Anxiety	.42	4.0	p<.001***			
Step 2				**.71**	**.50**	**.14**
Interest in Mathematics	-.42	-4.4	p<.001***			
Trait Anxiety	.16	1.7	p=.10			
State Anxiety	.34	3.6	=.001**			

Table 8.7: Summary of hierarchical regression analysis for variables predicting mathematical anxiety at time point three for the older children (N =72; *p < .05, **p < .01, ***p< .001).

Therefore, hypothesis two was met at both time points for the older children as high levels of mathematical interest were associated with lower levels of mathematical anxiety beyond their general levels of anxiety.

8.5.5. Question C) What is the association between interest in mathematics and mathematical performance?

In answering the question, the relationship between interest in mathematics and mathematical performance was investigated for both the younger and the older children separately at time point one and three.

Correlations coefficients between mathematical performance and interest in mathematics	Interest in mathematics	
	Study 1 (n=67)	Study 3 (n=61)
Mathematical Fluency	.15	.29*
Arithmetic	.32**	.32*
Word Problem Solving	.20	.36**

Table 8.8: Correlation coefficients for interest in mathematics and all measures of mathematical performance for studies one and three for the younger children ("*p < .05, **p < .01").

Correlations coefficients between mathematical performance and interest in mathematics	Interest in mathematics	
	Study 1 (n=73)	Study 3 (n=72)
Mathematical Fluency	.28*	.44**
Arithmetic	.14	.26*
Word Problem Solving	.18	.33**

Table 8.9: Correlation coefficients for interest in mathematics and all measures of mathematical performance for studies one and three for the older children ("*p < .05, **p < .01").

8.5.5.1. Younger children

High levels of interest in mathematics, were associated with high levels of mathematical fluency at time point three, r= .29, n= 61, p =.024, but the correlation at time point one was not significant (see table 8.8).

High levels of interest in mathematics were associated with high levels of arithmetic performance at time point one, r=.32, n=67, p =.009 and time point three, r= .32, n=61, p=.013 (see table 8.8)

High levels of interest in mathematics were associated with high levels of word problem solving performance, at time point three, r= .36, n= 61, p =.004. but the correlation at time point one was not significant (see table 8.8).

8.5.5.2. Older children

High levels of interest in mathematics, were associated with high levels of mathematical fluency at time point one r=.28, n=73, p =.019 and at time point three, r= .44, n=72, p<.001 (see table 8.9).

High levels of interest in mathematics were associated with high levels of arithmetic performance at time point three, r= .26, n= 72, p =.027, but the correlation was not significant at time point one (see table 8.9)

High levels of interest in mathematics were associated with high levels of word problem solving performance, at time point three, r= .33, n= 72, p =.005, but the correlation at time point one was not significant (see table 8.9)

At time point three, hypothesis three is met as there are significant associations between interest in mathematics and measures of mathematical performance for both cohorts. At time point one hypothesis three is only met for arithmetic performance for the younger cohort and mathematical fluency for the older cohort.

8.5.6. Question D) Is the relationship between mathematical performance and interest in mathematics significant above their non-verbal intelligence?

In answering this question, the relationship between interest in mathematics and mathematical performance was investigated for each cohort at time point one and three, along with the cognitive factor of non-verbal intelligence.

Two-step hierarchical multiple regressions were conducted with mathematical performance as the dependent variable. Non-verbal intelligence was entered at step one of the hierarchical multiple regression, to adjust statistically for general intelligence. Non-verbal intelligence was entered at step one as previously within this thesis non-verbal intelligence had been the most significant positive predictor of mathematical performance (see chapter five and six), similarly in previous research non-verbal intelligence has been identified as a significant positive predictor of mathematical performance (Kyttala & Lehto, 2008) Interest in mathematics was entered at step two. The means and SDs for each variable can be seen in Table 8.1.

8.5.6.1 Younger children

When conducting the hierarchical regressions for each measure of mathematical performance at time point one, it was found that only non-verbal intelligence was a positive predictor. Interest in mathematics was not a significant positive predictor of any of the measures of mathematical performance. The findings were different at time point three, as they were dependent on the different measures of mathematical performance (Fluency, arithmetic and word problem solving) within the hierarchical regressions.

8.5.6.1.1. Mathematical Fluency

At time point three, the overall relationship was highly significant at step 2, (F (2,58) = 9.81, $p < .001$) with a good fit (multiple R = .51). Analysing the un-standardised coefficients showed that both nonverbal intelligence (B = 1.28, t (58) =3.63, p=.001) was the significant predictor of mathematical fluency (R^2 = 0.25), whilst interest in mathematics (B = .32, t (58) =1.98, p=.052) was not a significant predictor. The standardised coefficients showed that non-verbal intelligence (β = -.42) was a positive predictor of mathematical fluency scores, therefore higher scores in non-verbal intelligence indicated higher mathematical fluency scores (see table 8.10).

	β	t	*p*	R	R^2	Δ R^2
Step 1				**.45**	**.21**	**.19**
Non-verbal Intelligence	.45	3.87	p<.001***			
Step 2				**.50**	**.25**	**.23**
Non-verbal Intelligence	.42	3.63	p<.001***			
Interest in mathematics	.32	1.98	p=.052			

Table 8.10: Summary of Hierarchical Regression Analysis for Variables predicting Mathematical fluency at time point three for the younger children (N =61; *p < .05, **p < .01, ***p< .001).

8.5.6.1.2. Arithmetic Performance

At time point three, the overall relationship was highly significant at step 2, (F (2,58) = 16.22, p < .001) with a good fit (multiple R = .60). Analysing the un-standardised coefficients showed that both non-verbal intelligence (B = .25, t (58) =4.83, p=<001) and interest in mathematics (B = .06, t (58) =2.27, p=.027) were significant predictors (R^2 = 0.34). The standardised coefficients showed that non-verbal Intelligence (β = .51) was a positive predictor of arithmetic performance scores, therefore higher non-verbal intelligence scores indicated higher arithmetic performance scores. Also, the standardised coefficients showed that interest in mathematics (β = .24) was a positive predictor of arithmetic scores, therefore higher scores on the Interest in Mathematics indicated higher arithmetic performance scores (see table 8.11).

	β	t	*p*	R	R^2	Δ R^2
Step 1				**.55**	**.30**	**.29**
Non-verbal Intelligence	.45	3.87	p<.001***			
Step 2				**.60**	**.36**	**.34**
Non-verbal Intelligence	.51	4.83	p<.001***			
Interest in mathematics	.24	2.27	p=.027*			

Table 8.11: Summary of hierarchical regression analysis for variables predicting arithmetic performance at time point three for the younger children (N =61; *p < .05, **p < .01, ***p< .001).

8.5.6.1.3. Word problem solving performance.

At time point three, the overall relationship was highly significant at step 2, (F (2,58) = 13.94, p < .001) with a good fit (multiple R = .57). Analysing the un-standardised coefficients showed that both non-verbal intelligence (B = .14, t (58) =4.10, p=<001) and interest in mathematics (B = .04, t (58) =2.69, p=.009) were significant predictors (R^2 = 0.30). The standardised coefficients showed that non-verbal Intelligence (β = .45) was a positive predictor of word problem solving performance scores, therefore higher non-verbal intelligence scores indicated higher word problem solving scores. Also, the standardised coefficients showed that interest in mathematics (β = .29) was a positive predictor of word problem solving scores, therefore higher scores in interest in mathematics indicated higher word problem solving performance scores (see table 8.12).

	β	t	p	R	R^2	Δ R^2
Step 1				**.49**	**.24**	**.23**
Non-verbal Intelligence	.49	4.3	p<.001***			
Step 2				**.57**	**.33**	**.30**
Non-verbal Intelligence	.55	4.10	p<.001***			
Interest in mathematics	.29	2.69	p=.009**			

Table 8.12: Summary of hierarchical regression analysis for variables predicting word problem solving performance at time point three for the younger children (N =61; *p < .05, **p < .01, ***p< .001).

Therefore, hypothesis four was only met at time point three for the measures of arithmetic and word problem solving for the younger children. As high levels of mathematical interest were positively significant with higher levels of these measures of mathematical performance but not mathematical fluency.

8.5.6.2 Older children.

When conducting the hierarchical regressions for each measure of mathematical performance at time point one, it was found that only non-verbal intelligence was a positive predictor. Interest in mathematics was not a significant positive predictor of any of the measures of mathematical performance. The findings were different at time point three and were dependent on the different measures of mathematical performance (Fluency, arithmetic and word problem solving) within the hierarchical regressions.

8.5.6.2.1 Mathematical Fluency

At time point three, the overall relationship was highly significant at step 2, (F (2,69) = 10.821, p < .001) with a good fit (multiple R = .49). Analysing the un-standardised coefficients showed that both nonverbal intelligence (B = 2.02, t (69) =3.63, p=.047) and interest in mathematics (B = 1.66, t (69) =3.89, p<.001) were significant predictors with interest being the strongest (R^2 = 0.24). The standardised coefficients showed that non-verbal Intelligence (β = .22) was a positive predictor of mathematical fluency scores, therefore higher scores in non-verbal intelligence indicated higher mathematical fluency scores. The standardised coefficients showed that interest in mathematics (β = .41) was a positive predictor of mathematical fluency scores, therefore higher scores in interest in mathematics indicated higher mathematical fluency scores (see table 8.13).

	β	t	p	R	R^2	Δ R^2
Step 1				**.27**	**.07**	**.06**
Non-verbal Intelligence	.27	2.33	p=.023*			
Step 2				**.49**	**.24**	**.22**
Non-verbal Intelligence	.21	2.02	p=.047*			
Interest in mathematics	.41	3.89	p<.001***			

Table 8.13: Summary of hierarchical regression analysis for variables predicting mathematical fluency at time point three for the older children (N =69; *p < .05, **p < .01, ***p< .001).

8.5.6.2.2. Arithmetic performance.

At time point three, the overall relationship was highly significant at step 2, (F (2,69) = 8.45, p = .001) with a good fit (multiple R = .44). Analysing the un-standardised coefficients showed that nonverbal intelligence (B = .18, t (69) =3.33, p=.001) was the significant predictor of mathematical fluency, with interest in mathematics (B = .03, t (69) =1.96, p=.054) not being a significant predictor (R^2 = 0.20). The standardised coefficients showed that non-verbal intelligence (β = .36) was a positive predictor of arithmetic scores, therefore higher scores in non-verbal intelligence indicated higher arithmetic scores (see table 8.14).

	β	t	p	R	R^2	ΔR^2
Step 1				**.39**	**.15**	**.14**
Non-verbal Intelligence	.39	3.54	p=.001***			
Step 2				**.44**	**.20**	**.17**
Non-verbal Intelligence	.36	3.33	p=.001***			
Interest in mathematics	.21	1.96	p=.054			

Table 8.14: Summary of hierarchical regression analysis for variables predicting arithmetic performance at time point three for the older children (N =69; *p < .05, **p < .01, ***p< .001).

8.5.6.2.3. Word problem solving performance.

At time point three, the overall relationship was highly significant at step 2, (F (2,69) = 15.85, p < .001) with a good fit (multiple R = .56). Analysing the un-standardised coefficients showed that both non-verbal intelligence (B = .38, t (69) =4.56, p=<001) and interest in mathematics (B = .07, t (69) =2.67, p=.009) were significant predictors (R^2= 0.32). The standardised coefficients showed that non-verbal Intelligence (β = .46) was a positive predictor of word problem solving performance scores, therefore higher scores in non-verbal intelligence indicated higher word problem solving performance scores. The standardised coefficients showed that interest in mathematics (β = .27) was a positive predictor of word problem solving scores, therefore higher scores on the interest in mathematics questionnaire indicated higher word problem solving performance scores (see table 8.15).

	β	t	p	R	R^2	ΔR^2
Step 1				**.49**	**.24**	**.23**
Non-verbal Intelligence	.40	4.75	p<.001***			
Step 2				**.56**	**.32**	**.30**
Non-verbal Intelligence	.46	4.56	p<.001***			
Interest in mathematics	.27	2.87	p=.009**			

Table 8.15: Summary of hierarchical regression analysis for variables predicting word problem solving performance at time point three for the older children (N =69; *p < .05, **p < .01, ***p< .001).

Therefore, hypothesis four was only met at time point three for mathematical fluency and word problem solving performance for the older children. As high levels of mathematical interest were positively significant with higher levels of these measures of mathematical performance (fluency and word problem solving) but not for arithmetic performance.

8.5.7. Question E) Does interest in mathematics mediate the directional relationship between mathematical performance and mathematical anxiety?

Mediation analysis is a form of modelling which allows the introduction of a third variable that links a cause-and-effect relationship (Wu & Zumbo, 2008). This third variable adds to the understanding of a directional relationship between two variables. In a mediation analysis there is a direct effect (path c figure 8.1) and the indirect effect, from the independent variable to the mediator (path a figure 8.1) and from the mediator to the dependent variable (path b figure 8.1). Mediation analyses were conducted using R software (R Core team, 2020) to determine whether interest in mathematics was a mediator in the directional relationship between mathematical anxiety and mathematical performance of both the younger and older children. Earlier within this thesis (chapter seven) evidence has been provided that the directional relationship between mathematical anxiety and mathematical performance is one where poor mathematical performance leads to increased mathematical anxiety. Therefore, from this finding mediation models were created that contained mathematical performance as the predictor (see figure 8.1).

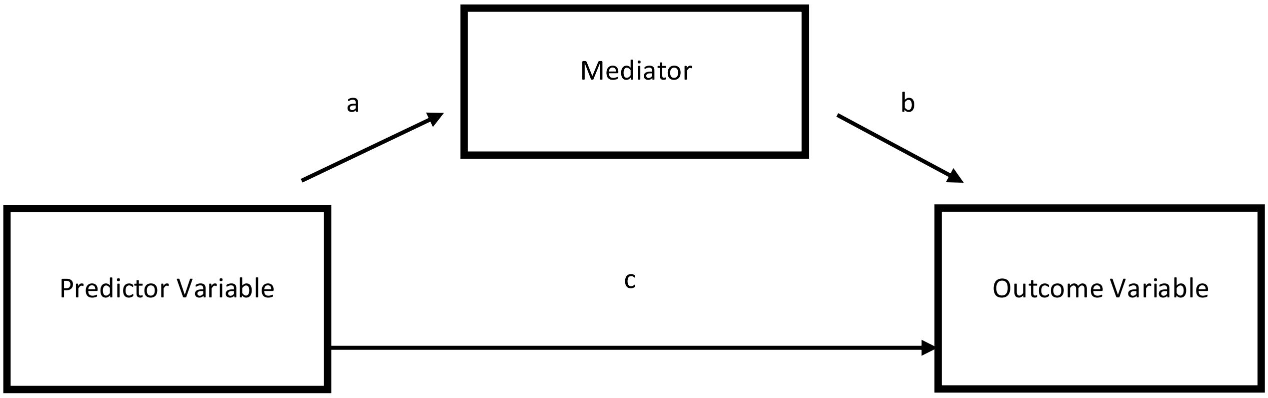

Figure 8.1: Diagram showing the mediation analysis, where **c** demonstrates the direct effect between predictor and outcome variable, and **a** and **b** show the indirect effect through a mediator variable.

Interest in mathematics was only found to a significant predictor of mathematical fluency (older children) and arithmetic performance (younger children) at time point one. However, there was a more consistent pattern of prediction at time point three, where interest in mathematics predicted two of the measures of mathematical performance (arithmetic and word problem solving) for the younger children and (fluency and word problem solving) for the older children therefore the mediation analyses were only conducted at time point three. As the significance levels for the other two measures were just below significance, they were also included within the mediation analyses (see tables 8.10 and 8.14).

The mediation models were created from each measure of mathematical performance (mathematical fluency, arithmetic and word problem solving), where the directional effect was from mathematical performance to mathematical anxiety, to determine whether there was a significant indirect effect.

8.5.7.1 Younger children.

8.5.7.1.1. Mathematical Fluency

At time point three, it was found that there was a significant indirect effect of mathematical fluency on mathematical anxiety through interest in mathematics (b= -0.10, p=.041). The independent variable mathematical fluency was a positive predictor of interest in mathematics (b=0.29, p<.001). The mediator interest in mathematics was a significant negative predictor of mathematical anxiety (b=- 0.44, p<.001). The total effect of mathematical fluency through interest in mathematics on mathematical anxiety was significant (b=-.031, p<.001) The direct effect was also negatively significant (b= 0.21, p<.001). This relationship is demonstrated in Figure 8.2. Therefore, the total effect of mathematical fluency through interest in mathematics on mathematical anxiety was found to be statistically significant.

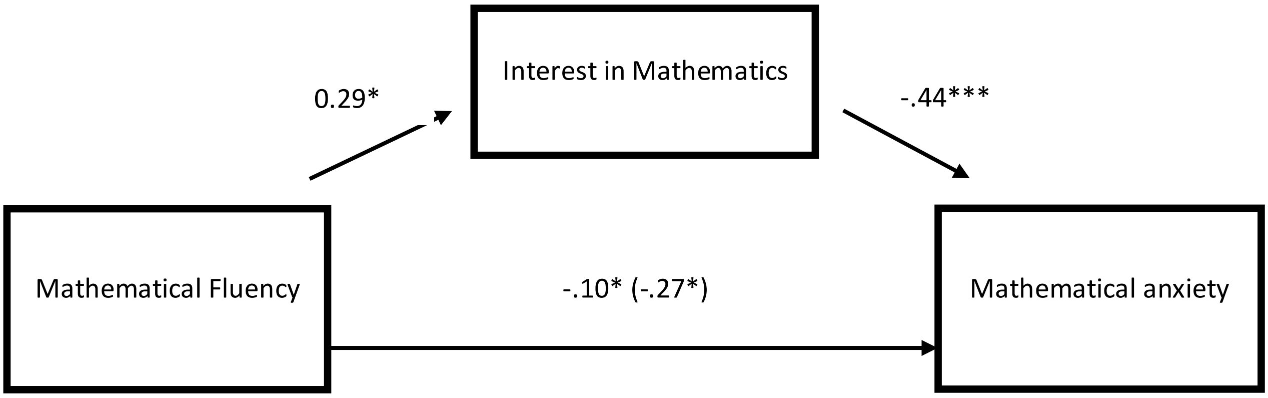

Figure 8.2: Model depicting the significant unstandardised indirect effect of mathematical fluency on mathematical anxiety via interest in mathematics. In brackets is the direct effect. *(Significance levels *p < .05, **p < .01, *** p<.001).*

8.5.7.1.2. Arithmetic performance

A significant indirect effect of arithmetic performance on mathematical anxiety through interest in mathematics was found (*b*= -0.69, p=.03). Arithmetic performance was a positive predictor of interest in mathematics (b=0.29, p<.001). Interest in mathematics was a significant negative predictor of mathematical anxiety (b=- 0.45, p=.009). The total effect of arithmetic performance through interest in mathematics on mathematical anxiety was significant (b=-1.81, p=.002). The direct effect was also negatively significant (b= -0.23, p=0.04). This relationship is demonstrated in Figure 8.3. Therefore, the total effect of arithmetic performance through interest in mathematics on mathematical anxiety was found to be statistically significant.

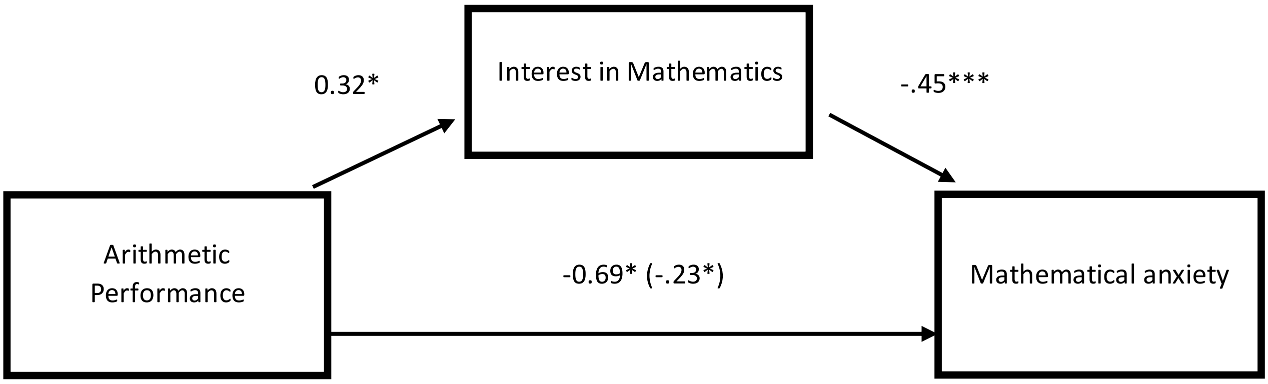

Figure 8.3: Model depicting the significant unstandardised indirect effect of arithmetic performance on mathematical anxiety via interest in mathematics. In brackets is the direct effect. *(Significance levels *p < .05, **p < .01, *** p<.001).*

8.5.7.1.3. Word Problem Solving Performance.

A significant indirect effect of word problem solving performance on mathematical anxiety through interest in mathematics was found at time point three (*b*= -1.18, p=.02). Word problem solving performance was a positive predictor of interest in mathematics (b=0.36, p=.003). Interest in mathematics was a significant negative predictor of mathematical anxiety (b=- 0.43, p<.001). The total effect of word problem solving performance through interest in mathematics on mathematical anxiety was significant (b=-3.05, p<.001). The direct effect was also negatively significant (b= -0.25, p=0.03). This relationship is demonstrated in Figure 8.4. Therefore, the total effect of word problem solving performance through interest in mathematics on mathematical anxiety was found to be statistically significant.

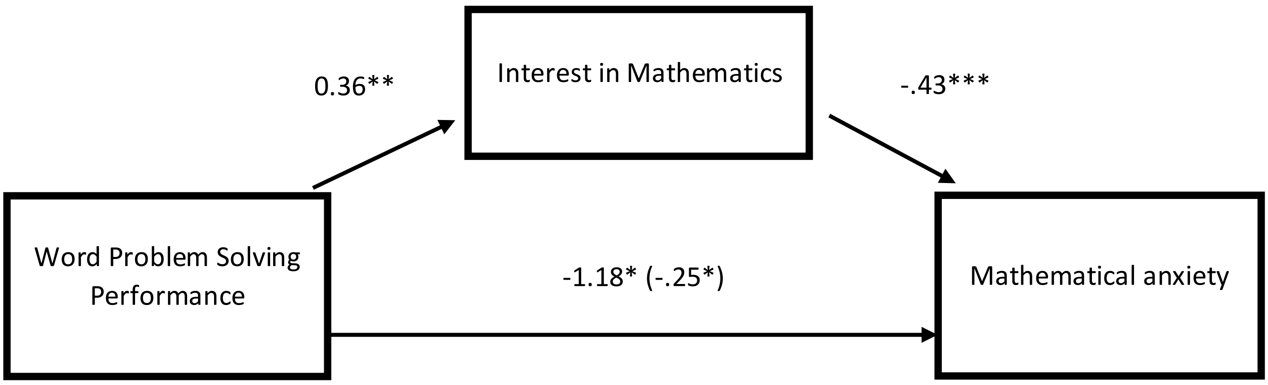

Figure 8.4: Model depicting the significant unstandardised indirect effect of word problem solving performance on mathematical anxiety via interest in mathematics. In brackets is the direct effect. *(Significance levels *p < .05, **p < .01, *** p<.001).*

8.5.7.2 Older children.

8.5.7.2.1. Mathematical Fluency

As with the younger children at time point three, there was a significant indirect effect of mathematical fluency on mathematical anxiety through interest in mathematics (*b*= -0.05, p=.002) for the older children. Mathematical fluency was a positive predictor of interest in mathematics (b=0.44, p<.001). Interest in mathematics was a significant negative predictor of mathematical anxiety (b=- 0.51, p<.001). The total effect of mathematical fluency through interest in mathematics on mathematical anxiety was significant (b=0-.10, p<.001) The direct effect was not significant (b= -0.04, p=.082). This relationship is demonstrated in Figure 8.5. Therefore, the total effect of mathematical fluency through interest in mathematics on mathematical anxiety was found to be statistically significant.

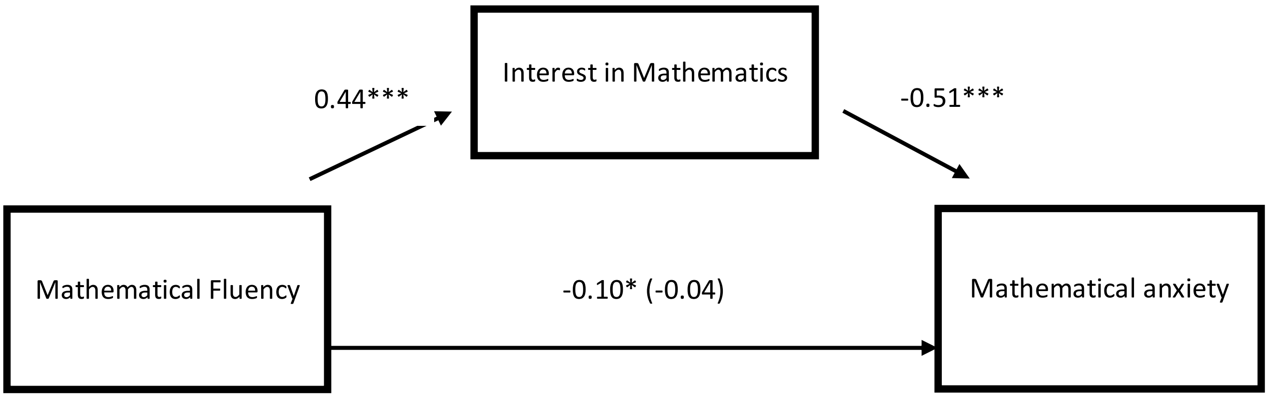

Figure 8.5: Model depicting the significant indirect effect of mathematical fluency on mathematical anxiety via interest in mathematics. In brackets is the direct effect. (Significance levels *p < .05, **p < .01, *** p<.001).

8.5.7.2.2. Arithmetic performance

A significant indirect effect of arithmetic performance on mathematical anxiety through interest in mathematics was found (*b*= -0.82, p=.03). Arithmetic performance was a positive predictor of interest in mathematics (b=0.26, p=.02). Interest in mathematics was a significant negative predictor of mathematical anxiety (b=- 0.52, p<.001). The total effect of arithmetic performance through interest in mathematics on mathematical anxiety was significant (b=-2.35, p<.001). The direct effect was also negatively significant (b= -0.25, p=0.008). This relationship is demonstrated in Figure 8.6. Therefore, the total effect of arithmetic performance through interest in mathematics on mathematical anxiety was found to be statistically significant.

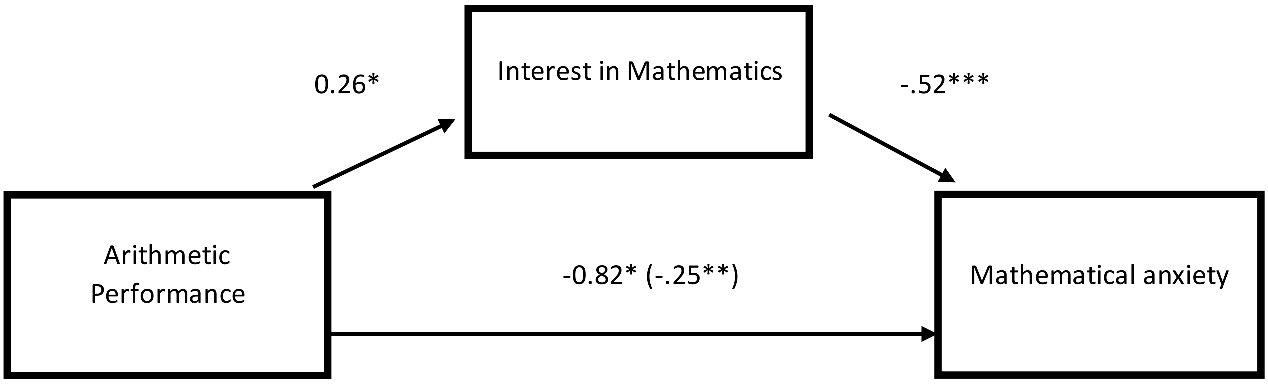

Figure 8.6: Model depicting the significant indirect effect of arithmetic performance on mathematical anxiety via interest in mathematics. In brackets is the direct effect. *(Significance levels *p < .05, **p < .01, *** p<.001).*

8.5.7.2.3. Word Problem Solving Performance.

A significant indirect effect of word problem solving performance on mathematical anxiety through interest in mathematics was found (*b*= -0.63, p=.01). Word problem solving performance was a positive predictor of interest in mathematics (b=0.36, p=.003). Interest in mathematics was a significant negative predictor of mathematical anxiety (b=- 0.50, p<.001). The total effect of word problem solving performance through interest in mathematics on mathematical anxiety was significant (b=-1.55, p<.001). The direct effect was also negatively significant (b= -0.25, p=0.01). This relationship is demonstrated in Figure 8.7. Therefore, the total effect of word problem solving performance through interest in mathematics on mathematical anxiety was found to be statistically significant.

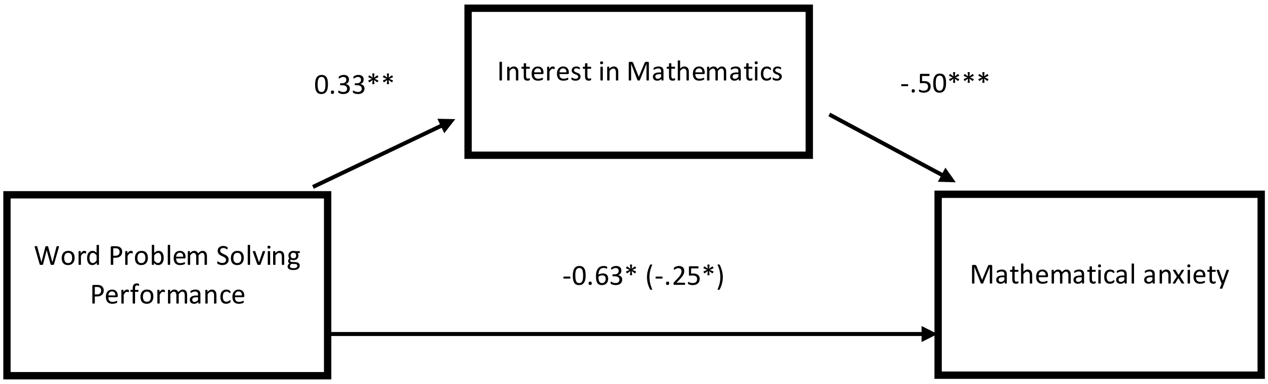

Figure 8.7: Model depicting the significant unstandardised indirect effect of word problem solving performance on mathematical anxiety via interest in mathematics. In brackets is the direct effect. *(Significance levels *p < .05, **p < .01, *** p<.001).*

8.6. Discussion

The main aims of this chapter were to investigate the research questions as to whether there were significant relationships between interest in mathematics with mathematical anxiety and mathematical performance at time points one (a year before SATs) and three (just before SATS). Then to investigate whether interest in mathematics might be a mediator between the directional relationship between mathematical anxiety and mathematical performance.

Correlational data revealed significant negative correlations between interest in mathematics and mathematical anxiety at time point one and three for both cohorts. This association was confirmed with hierarchical regressions finding significant negative relationships between interest in mathematics and mathematical anxiety at both time points and for both cohorts of children, through interest in mathematics being a significant negative predictor of a child's mathematical anxiety. This therefore indicates that children with high levels of interest in mathematics have lower levels of mathematical anxiety which agrees with the limited studies in this field, who found a relationship between interest in mathematics and mathematical anxiety (Asif & Khan, 2011; Luo, Wang, & Luo, 2009). These studies were carried out with adolescents and young adults, whereas this thesis was carried out with children aged six to eleven. This relationship between interest in mathematics and mathematical anxiety is therefore found in younger children which agrees with Ganley & McGraw, (2016) who found interest in mathematics predicted mathematical anxiety in children aged six to seven. This current finding highlights the need early on in a child's educational journey to foster a deep interest in mathematics.

Correlational data revealed an inconsistent pattern of significant positive correlations between interest in mathematics and mathematical performance, dependent on the age of the children (younger and older), type of mathematical performance (fluency, arithmetic and word problem solving) and the time point. At time point one, the only significant positive correlations were between interest in mathematics and arithmetic (younger children) and fluency (older children). At time point three there were significant positive correlations for all measures of mathematical performance for both cohorts. Hierarchical regressions explored the relationships between interest in mathematics and mathematical anxiety further. It was found that interest was not a significant predictor of mathematical performance at time one (year before SATS) for either cohort. At this time point the strongest predictor of mathematical performance was a child's non-verbal intelligence (see chapter 5 and 6 for a detailed explanation of this). Whereas a year later there are significant positive relationships between interest and mathematical performance, dependent on the type of mathematical performance. For the younger children this significant positive relationship is with arithmetic and word problem solving. Therefore, those children with higher interest in mathematics have higher performance in arithmetic and word problem solving. For the older children the pattern is different with significant positive relationships between interest in mathematics and mathematical fluency and word problem solving. Therefore, those children with higher interest in mathematics have higher performance in mathematical fluency and word problem solving. This is in accord with previous research which highlights the importance of having a strong interest in mathematics as this is associated with higher mathematical achievement (Ashcraft & Krause, 2007, Meece et al., 1990, Ramirez et al., 2013) with both adult and children participants.

Previous research found that interest in mathematics significantly decreased over time, as children got older and as the curriculum becomes harder (Fredricks & Eccles, 2002; Gottfried, Fleming & Gottfried, 2001). An alternative interpretation may be that for children to succeed as the curriculum gets harder, they need to sustain a high level of interest in the subject in order to achieve in that subject (Simpkins, Davis-Keen & Eccles, 2006; Wigfield, 1994; Wigfield & Eccles, 2002). Therefore, it is important to ensure that schools maintain children's interest in mathematics especially when the curriculum difficulty increases, and focus is placed on achievement in tests. Teaching mathematics in a way that combines elements of curiosity, engagement, and excitement is key in supporting children's interest within a subject (Boaler, 2016).

At time point three (just before SATs) the performance levels of all three mathematical measures were high and the children understood the importance of these high levels of performance. The children with low levels of mathematical performance had higher levels of mathematical anxiety. Mediation analysis added interest in mathematics as a third variable to determine whether it could explain more of the directional relationship between mathematical performance and mathematical anxiety.

For the younger cohort, at time point three (just before the SATs) there were significant partial mediation effects of interest in mathematics on the directional relationship between all measures of mathematical performance and mathematical anxiety. This finding agrees with previous research that suggests that early mathematical skills predict mathematical interest (Fisher, Dobbs-Oates, Doctoroff & Arnold, 2012) and the mediation analysis here adds another dimension in that mathematical interest partially mediates the relationship between mathematical performance and mathematical anxiety. Partial mediation is where the significance of the direct path is reduced and different from zero after the introduction of a mediator. This finding has importance within educational settings in the need to develop children's interest in mathematics early in their learning journey as a possible protective factor in the development of mathematical anxiety.

For the older children there were significant partial mediation effects of interest in mathematics on the directional relationship between all measures of mathematical performance and mathematical anxiety at time point three (just before SATs). This would indicate that for the older children more interest in mathematics was a factor in the directional relationship between mathematical performance and mathematical anxiety. This finding concurs with previous research that suggests a positive relationship between mathematical interest and mathematical performance in older children (Ahmed et al., 2013; Frenzel, Goetz, Pekrun, & Watt, 2010). The mediation analysis where mathematical interest partially mediates the relationship between mathematical performance and mathematical anxiety, adds to this literature. The findings from the mediation analyses emphasises the importance especially at time point three (just before the SATs) of how important it is to maintain the children's interest in mathematics, in order to support their motivation to learn, increase performance and lower mathematical anxiety.

8.7. Conclusion

Analyses revealed significant negative relationships between mathematical anxiety and interest in mathematics at both time points for both cohorts. Therefore, children with high mathematical anxiety had low levels of interest in mathematics and children with low mathematical anxiety had high levels of interest in mathematics. Indicating that promoting interest in mathematics decreases levels of mathematical anxiety in children.

Whereas the relationship between mathematical performance and interest in mathematics was only significant at time point three (just before SATs). This positive relationship was dependent on the type of performance for the different age groups. For the younger children the significant positive relationship between interest in mathematics was only with their arithmetic and word problem solving performance. For the older children the significant positive relationship between interest in mathematics was only significant with their mathematical fluency and word problem solving performance. Specifying that high levels of interest in mathematics increases mathematical performance specific to the type and age group of the child.

Mediation analyses which looked at whether interest in mathematics could be an explanation of the process or possible mechanism, by which mathematical performance influences mathematical anxiety revealed partial mediation for all types of mathematical performances for both cohorts. Therefore, promoting interest in mathematics in children, especially when the performance stakes are high is important in decreasing mathematical anxiety and increasing performance.

8.8. Chapter summary

Correlational analyses:

- Significant negative associations between mathematical anxiety and interest in mathematics at time point one and three for both cohorts.

- Significant positive associations between interest in mathematics and arithmetic for the younger cohort at time point one.

- Significant positive associations between interest in mathematics and mathematical fluency for the older cohort at time point one.

- Significant positive associations between interest in mathematics and all measures of mathematical performance at time point three for both cohorts.

Hierarchical Regression analyses:

- Significant negative relationship between mathematical anxiety and interest in mathematics at time points one and three for both cohorts.

- No significant relationships between interest in mathematics and all measures of mathematical performance for both cohorts at time point one. Non-verbal intelligence was the significant positive predictor of mathematical performance at time point one.

- Significant positive relationship between interest in mathematics and arithmetic and word problem solving performance at time point three for the younger children.

- Significant positive relationship between interest in mathematics and mathematical fluency and word problem solving performance at time point three for the older children.

Mediation Analyses:

- Significant indirect effect of all measures of mathematical performance on mathematical anxiety through interest in mathematics at time point three for the younger children.

- Significant indirect effect of all measures of mathematical performance on mathematical anxiety through interest in mathematics at time point three for the older children.

Chapter 9.- General Discussion and Conclusion.

Chapter contents:

The chapter is divided into the following subsections:

- Review of the aims of the thesis.
- Development of mathematical anxiety
- The association between mathematical anxiety and mathematical performance.
- The relationship between mathematical anxiety and mathematical performance.
- The directional relationship between mathematical anxiety and mathematical performance.
- The relationship between interest in mathematics with mathematical anxiety and mathematical performance.
- Limitations.
- Implications for psychological research.
- Educational Practice.
- Future research.
- Conclusions.

This final chapter draws together the aims, research findings, the wider theoretical implications within psychology and education, limitations, and future research of this thesis. The thesis explored the development of mathematical anxiety and its relationship with mathematical performance in primary aged children during their SATs year. Mathematical anxiety was tracked over time, through mean scores and individual trajectories taking account of age, gender, and school (chapter 4). The relationship between mathematical anxiety and mathematical performance was analysed during this key academic year for the younger (KS1) and older (KS2) children, cross sectionally at each time point (chapters 5 and 6). Then the relationship between mathematical anxiety and mathematical performance was explored longitudinally to determine whether evidence could be found for the direction of this relationship (Chapter7). Finally, the relationship of interest in mathematics on both mathematical anxiety and mathematical performance was investigated and in particular its effect on the relationship between mathematical anxiety and mathematical performance (Chapter 8).

9.1 Review of the aims of the thesis

The aims of this thesis were to investigate the development of mathematical anxiety over time and the relationship between mathematical anxiety and mathematical performance in primary aged children. A longitudinal design was used to track the development of mathematical anxiety and the directional nature of the relationship between mathematical anxiety and mathematical performance, in line with the call for more longitudinal research in this area (Dowker, 2019a). Additionally, the timing of this research was linked to high stakes testing within the UK, as the children who participated were in their SATs years (Year 2 and Year 6).

The first research question addressed as part of the thesis was whether there was a developmental effect of mathematical anxiety across the four time points. There has been a substantial body of research examining mathematical anxiety in children, with cross sectional studies investigating children aged four to six (Jamieson & Ross, 2011; Petronzi, Staples, Sheffield, & Hunt, 2019) through to children aged six to seven (Harari et al, 2013;) as well as older children (Devine et al, 2012; Dowker et al, 2012; Jameson, 2014; Sorvo et al. 2017; Thomas & Dowker, 2000; Wood, Pinheiro-Chagas, Julio-Costa, Micheli, Krinzinger, Kaufmann, Willmes, & Haase, 2012; Wu et al., 2012; Wu et al., 2014). Previous longitudinal studies provided conflicting evidence where Krinzinger et al, (2009), found a significant increase in mathematical anxiety with age for children aged six to nine but other researchers (Gunderson et al., 2018; Sorvo et al., 2019) suggested it was younger children who reported more mathematical anxiety. None of these previous studies linked their research to the timing of SATs, a time of high stakes preparation and testing in the lives of primary aged children. Therefore, it was argued that the SATs year was a particular year worthy of study, where added pressure would be placed on children to perform mathematically, thus impacting on their mathematical anxiety. Thus, it was predicted that children's mathematical anxiety would increase through the year the nearer they got to taking their SATs.

The second research question was whether there was an association between mathematical anxiety and mathematical performance over time. There have been several studies investigating the association between mathematical anxiety and mathematical performance in younger children (Cargnelutti et al., 2017; Harari et al., 2013; Vukovic et al., 2013; Sorvo et al., 2019) and older children (Carey et al., 2017b; Henschel & Roick, 2017; Justica- Galiano et al., 2017). As with the development of mathematical anxiety research, none of the previous research has been linked to the timing of SATs, a crucial time in the lives of primary aged children. It was argued that the pressure of the SATs year would impact both on children's mathematical anxiety and their mathematical performance (Connor, 2001; Connors et al., 2009; McDonald, 2001; Putwain et al., 2012; Tymms & Merrell, 2007; Ward & Quennerstedt, 2018). Therefore, it was predicted that high levels of mathematical anxiety would be significantly associated with lower levels of performance in both the younger (year two) and older (year six) children, especially at time point three (just before their SATs).

Secondary aims linked to this relationship between mathematical anxiety and mathematical performance were the influence of emotional (State and trait anxiety and interest in mathematics) and cognitive (non-verbal intelligence and working memory) factors. Thus, answering the third research question as to whether the relationship between mathematical anxiety and mathematical performance was significant above a child's general anxiety levels and general cognitive levels for both cohorts.

Figure 9.1 illustrates the possible relationships within the design from previous research between mathematical anxiety and mathematical performance alongside the relationships with the emotional (State anxiety, trait anxiety and interest in mathematics) and cognitive (Non-verbal intelligence, working memory and reading) factors.

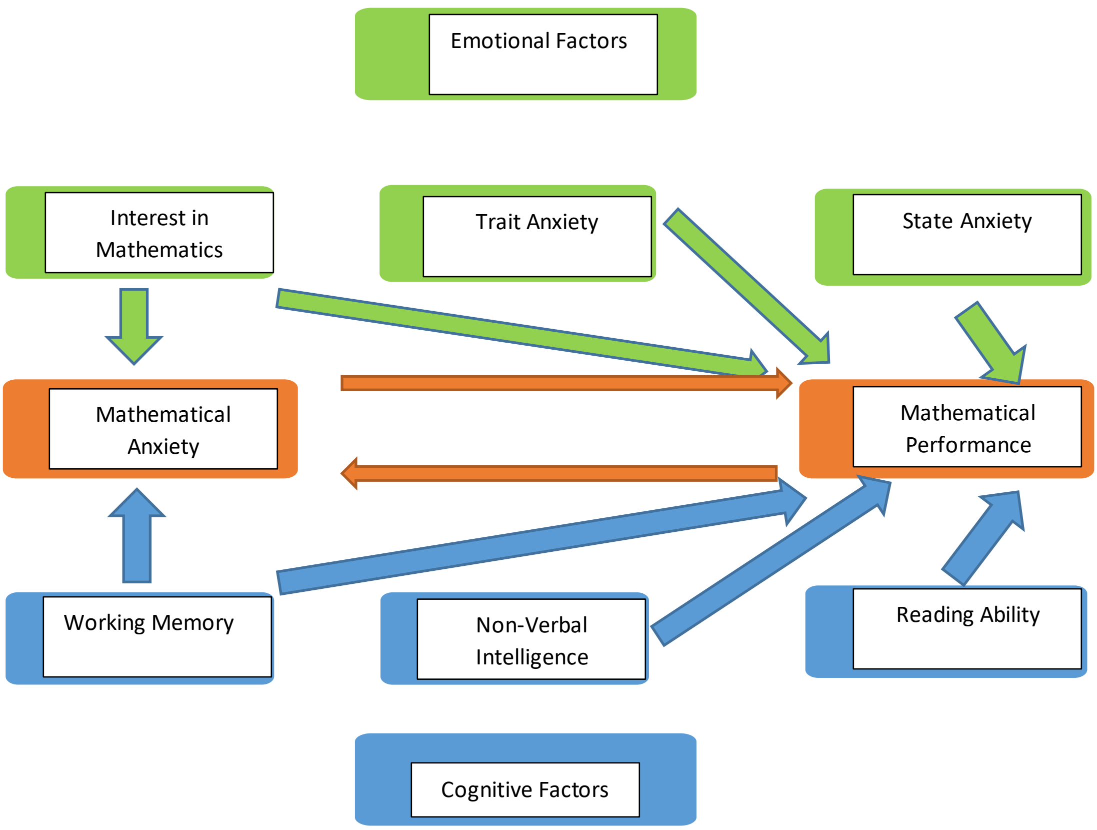

Figure 9.1: Model of the design of the thesis.

The longitudinal design of this thesis allowed the third research question to be extended to determine whether there is a directional relationship between mathematical anxiety and mathematical performance. Some researchers suggest that poor mathematical performance in children predicts later mathematical anxiety (Maloney, 2016; Tobias, 1986), whilst others suggest that high levels of mathematical anxiety predict later poor levels of mathematical performance (Carey, Hill, Devine, & Szucs, 2016; Hembree, 1990; Lyons & Beilock, 2012). Additionally, some researchers suggest that this relationship is in fact reciprocal, where prior mathematical anxiety predicts later mathematical performance and prior mathematical performance predicts later mathematical anxiety with children in primary education (Cargnelutti et al., 2017; Gunderson et al., 2018). The aim of the longitudinal analyses carried out within the thesis looked to add to this literature base on the directional nature of the relationship between mathematical anxiety and mathematical performance.

The fourth research question was around the emotional factor of interest in mathematics, firstly whether there was a significant association between interest in mathematics with mathematical anxiety and mathematical performance separately. Then whether there was a role for interest in mathematics in the relationship between mathematical anxiety and mathematical performance. Previous research suggests that there is a positive association between mathematical interest and mathematical performance from pre-schoolers (Fisher et al., 2012; Gottfried, 1990), primary aged children (Ganley & Lubienski, 2016) and older children (Ahmed, Van der Werf, Kuyper & Minnaert, 2013; Frenzel, Goetz, Pekrun, & Watt, 2010). In contrast to the research evidence investigating interest in mathematics and mathematical performance, there is little research evidence looking at the correlation between mathematical anxiety and mathematical interest (Asif & Khan, 2011). Therefore, this thesis looked to investigate whether there is a role for interest in mathematics within the relationship between mathematical anxiety and mathematical performance, by looking to see if it could be a mediator. Therefore, it was predicted that high levels of interest in mathematics, would lessen the effect of poor mathematical performance on mathematical anxiety in children.

9.2- Development of mathematical anxiety

Mathematical anxiety was explored during the period of national testing, a specific time point in a child's education, to see whether this period affected the development of mathematical anxiety. It was predicted that the added pressure to perform mathematically during this time would build the closer to the National tests and increase the children's mathematical anxiety. Contrary to predictions, mathematical anxiety was found not to develop over time, as there were no significant mean differences in the mathematical anxiety scores over time, no significant rate of growth in mathematical anxiety and the children's relative standings on mathematical anxiety changed little over time for adjacent time points.

In answering the first research question, analyses looked at the mean differences in the mathematical anxiety scores over time, the findings indicated that mathematical anxiety did not develop over time. Whilst other longitudinal research, Krinzinger et al., (2009), reported an increase in the mean level of mathematical anxiety in children aged six to nine, over four time points (eighteen months in total), this was not the case for this thesis. As mentioned previously, there were some similarities between this thesis and the Krinzinger et al., (2009) study. They both employed a similar longitudinal design with four time points and matched the age range for the younger children. There were some notable differences in the measure of mathematical anxiety, the inclusion of older children (aged ten and eleven), and the timing linked to the SATs year. The measure of mathematical anxiety was different in that this thesis used the Children's Anxiety in Math Scale (CAMS), (Jameson, 2013a, 2013b) chosen specifically for its three-dimensional structure ("General, mathematical performance and mathematical error anxiety"). Whilst Krinzinger et al., (2009) used a two-dimensional measure ("Negative affective reactions and worry") of mathematical anxiety (Math Anxiety Questionnaire, (MAQ): Thomas & Dowker, 2000). Therefore, adding to the need for researchers to be aware when choosing different measures of mathematical anxiety, that these measures target different aspects of mathematical anxiety which leads to differing findings (Sorvo et al., 2017). Including older children within the sample had been predicted to indicate that mathematical anxiety would develop over time in line with previous research that it increases with age (Dowker, 2016; Krinzinger et al, 2009). That mathematical anxiety did not increase for the children within the thesis adds little to the argument that mathematical anxiety increases more as children experience more complicated mathematics (Dowker, 2016) and have more exposure to failure in mathematics (Dowker, 2019a; Ma & Kishor, 1997). The timing of the studies, linked to the children's SATs year, a unique aspect of the thesis, led to the prediction that mathematical anxiety would develop and increase the nearer to the SATs. That mathematical anxiety did not develop over time for both the younger and older children at a group level providing evidence that these children appeared to cope with the added pressure of preparation for their SATs.

Although what was revealed through the latent growth curve modelling, was that mathematical anxiety remained statistically stable throughout the four time periods of study for both the older and younger cohorts. A finding which agrees with previous research, where mathematical anxiety remains stable over time (Krinzinger et al., 2009; Ma & Xu, 2004). This finding of statistical stability of the children's mathematical anxiety was confirmed using cross lagged panel modelling, which looked at the autoregressive effect of mathematical anxiety. The children's relative standings on mathematical anxiety stayed the same throughout the period. The largest significant coefficient within the cross lagged panel models was between mathematical anxiety measured at time two (the beginning of the SATS year) to time three (just before the SATS). This indicates that the children's mathematical anxiety and their relative standings on mathematical anxiety were the most statistically stable during this period. This effect in close proximity to National testing is an important finding as it indicates that those children who were high in mathematical anxiety during this period continued to report high mathematical anxiety and those who are low in mathematical anxiety continued to report low mathematical anxiety. This therefore provided evidence of stability in children's mathematical anxiety during the SATs year, it did not establish any significant mean change in mathematical anxiety during the SATs year. Therefore, in this thesis the fact that the timing was linked to the SATs year, an important year for teachers (Harlen, 2007: Tymms & Merrell, 2007) and children (Connor, 2001, 2003; Pollard, Triggs, Broadfoot, Mc Ness & Osborn, 2000) did not affect the development of these children's mathematical anxiety.

Attempting to understand the factors that might impact on the development of mathematical anxiety as there was significant individual variance in initial starting points and rates of growth, which suggested that individual or environmental elements might be the reason for this variance. Time invariant factors, individual (age and gender) and environmental (school) were added to conditional latent growth curve models. These conditional latent growth curve models revealed that individual (age and gender) and environmental (school) were not good predictors of the development of mathematical anxiety over this period. As mentioned previously, there was significant variability in the individual initial mathematical anxiety and individual trajectories of mathematical anxiety. There were significant inter- individual differences in the children's intial scores of mathematical anxiety at time one in both younger and older children. This individual difference in initial mathematical anxiety supports research that mathematical anxiety is a construct found in primary aged children (Devine et al, 2012; Dowker et al, 2012; Harari et al., 2013; Jameson, 2014; Jameson & Ross, 2011; Petronzi et al., 2019; Sorvo et al. 2017; Thomas & Dowker, 2000; Wood, Pinheiro-Chagas, Julio-Costa, Micheli, Krinzinger, Kaufmann, Willmes, & Haase, 2012; Wu et al., 2012; Wu et al., 2014), with significantly varying levels. Important to this thesis is that the both the younger and older children were reporting mathematical anxiety a year before their SATS. Therefore adding to the discussion around the early testing of mathematical anxiety within schools and the need for teachers to be trained in the detection of mathematical anxiety.

There were also significant inter- individual differences in the children's growth of mathematical anxiety in both younger and older children. This fluctuation in individual's mathematical anxiety reflects how individual children reported their mathematical anxiety at each time of testing and is in accord with previous research documenting considerable individual variation in mathematical anxiety (Sorvo et al., 2019). Therefore, children's individual trajectories of the development of mathematical anxiety reveals significant variation. This therefore adds to the discussion around whether there are key times within a child's educational journey that increases or decreases their mathematical anxiety trajectory, especially identifying the need to understand the individual and environmental factors that might impact on each individual child.

Of significance here is that although there was no incremental increase in mathematical anxiety, it was established that mathematical anxiety stayed statistically stable over the period. These findings indicated that children with high mathematical anxiety continued to have high mathematical anxiety and those with low mathematical anxiety continued to have low mathematical anxiety. Therefore, this establishes evidence that accessing a child's mathematical anxiety early in their educational journey is important. That then suggests that support needs to be given to children with high mathematical anxiety as early as possible (see educational implications for more detail).

9.3 The association between mathematical anxiety and mathematical performance.

In answering the second research question significant negative correlations indicating an association between mathematical anxiety and mathematical performance were found which were dependent on the age of the children, type of mathematical performance and the time point. Mathematical fluency significantly negatively correlated with mathematical anxiety at time point one (before the SATs year) and three (just before the SATs) for both the younger and older children. Whilst for the older children it also significantly negatively correlated at time point four (after the SATs). Overall, these findings agree with previous literature of significant negative correlations between mathematical anxiety and mathematical fluency (Cargnelutti et al., 2017; Harari et al., 2013; Sorvo et al., 2019). Arithmetic performance significantly correlated with mathematical anxiety at all four time points for the older children and time points two and three (during the SATs year) for the younger children. Findings that are supported by previous research where significant negative correlations have been reported between mathematical anxiety and arithmetic (Cargnelutti et al., 2017; Justica-Galiano et al., 2017; Sorvo et al., 2019; Vukovic et al., 2013; Wu et al., 2012). Word problem solving performance negatively correlated with mathematical anxiety at time points two, three and four for the older children and time points one and three for the younger children. Findings supported by previous cross-sectional research (Justica-Galiano et al., 2017; Vukovic et al., 2013), found significant negative correlations between mathematical anxiety and word problem solving performance. Thus, the current work builds on previous research and extends the work on the association between mathematical anxiety and mathematical performance. It highlights the need to determine the type of performance when researching the association between mathematical anxiety and mathematical performance.

Importantly to this thesis was the effect of timing (SATs year) on the relationship between mathematical anxiety and mathematical performance. The finding that the strongest negative correlation for all types of performance was at time point three (just before the SATs) for the younger children and during the whole of the SATs year for the older children, indicates that the children were experiencing higher cognitive demands (Connors, 2003; Dowker, 2019a). This adds support to the increasing pressure of the SATs on mathematical performance (Connor, 2001; Connors et al., 2009; McDonald, 2001; Putwain et al., 2012; Tymms & Merrell, 2007; Ward & Quennerstedt, 2018) as predicted. That the younger children had significant negative correlations just before the SATs, despite attempts being made to reduce the pressure on the younger children (STA, 2020a) reveals that timing is a key element. That there was still a negative correlation between mathematical anxiety and mathematical performance at time point four (after the SATs) for the older children indicates the lingering effect of added pressure on children.

Therefore, these correlational findings support the contribution of this thesis in better understanding the effect of timing on the association between mathematical anxiety and mathematical performance.

9.4 The relationship between mathematical anxiety and mathematical performance.

The third research question looked to determine the strength of the relationship between mathematical anxiety and mathematical performance above a child's general anxiety levels and general cognitive levels for both cohorts. The relationship between mathematical anxiety and mathematical performance was found to be dependent on the age of the children, type of mathematical performance and the time point.

At time point three (just before SATs), there were significant negative relationships between mathematical anxiety and mathematical performance (Fluency and word problem solving) only for the older children. That mathematical fluency, was a significant negative predictor of mathematical anxiety at time point three, may have been influenced by the fact that it was the only timed test. As other researchers have identified that timed tests are associated with an increased anxiety leading to poorer performance in adults (Ashcraft & Moore, 2009; Kellogg, Hopko & Ashcraft, 1999). What is of importance here is that at time point three (just before SATs) the hypothesis that high levels of mathematical anxiety will be significantly associated with lower levels of mathematical performance was met. Therefore, this provides evidence that the time before the SATs, where there is increased pressure for children to perform and make less mistakes in a limited time, is affecting the relationship between mathematical anxiety and mathematical performance. That this is only for the older children suggests that they were under more pressure than the younger children. Additionally, there was a significant negative relationship between mathematical anxiety and problem solving, which could be explained by the complexity of the word problems. This explanation is supported by the fact that this significant negative relationship between mathematical anxiety and mathematical performance was only found in the older children and not the younger children. Explained in part by the fact that more of the older children completed all problems within the task, with the later word problems requiring more complex understanding of the rules of mathematics and a completion of more steps in order to solve the mathematical problem (Zhang et al., 2019). It is unlikely to be linked to the way in which the tasks were administered timed or not timed, as with the previous significant relationship between mathematical anxiety and mathematical fluency. As the problem-solving tasks in this thesis were not timed, children could take as much time as they needed to solve the word problems. It is more likely to be explained by cognitive load theory (Sweller, 1988), where factors that make mathematical tasks more complicated add to its cognitive load. The word problems, where children need to interpret the language of the sentences to access the mathematical properties and required operations, will exert a higher cognitive load. Although it is likely that it was the timing of the testing which gave rise to the significant negative relationships as it was just before the SATS, with the older children being more aware that they were under pressure to succeed in their mathematical performance (Connors, 2003; Dowker, 2019a).

At time point one (year before SATs), there are no significant relationships between mathematical anxiety and mathematical performance (Fluency, arithmetic and word problem solving) for either the younger or older children. The strongest positive predictor of both the younger and older children's mathematical performance at this time point was non-verbal intelligence (see figure 9.2). Indicating that children with high levels of non-verbal intelligence had higher levels of mathematical performance. This finding agrees with previous research which indicated that measures of general intelligence are predictors of mathematics achievement (Deary, Strand, Smith, & Fernandes, 2007, Fuchs et al., 2010; Geary, 2011; Hale, Fiorello, Kavanaugh, Hoepprer & Gathercole, 2001; Kyttala & Lehto, 2008). This provides some support to thinking that developing children's non-verbal intelligence through enhancing their logical, abstract thinking and reasoning skills might help to counter the effects of mathematical anxiety and improve their mathematical performance. One study has looked at the benefits of non-verbal reasoning training on problem solving (Repeated patterns, sequential order and classifications, matrices and block design) with 4-year-olds (Bergman Nutley, Soderqvist, Bryde, Thorell, Humprehys & Klingberg, 2011). Therefore, this finding that non-verbal intelligence is a strong predictor of mathematical performance and its possible benefits as a key element in teaching and learning would provide an appropriate field for further study.

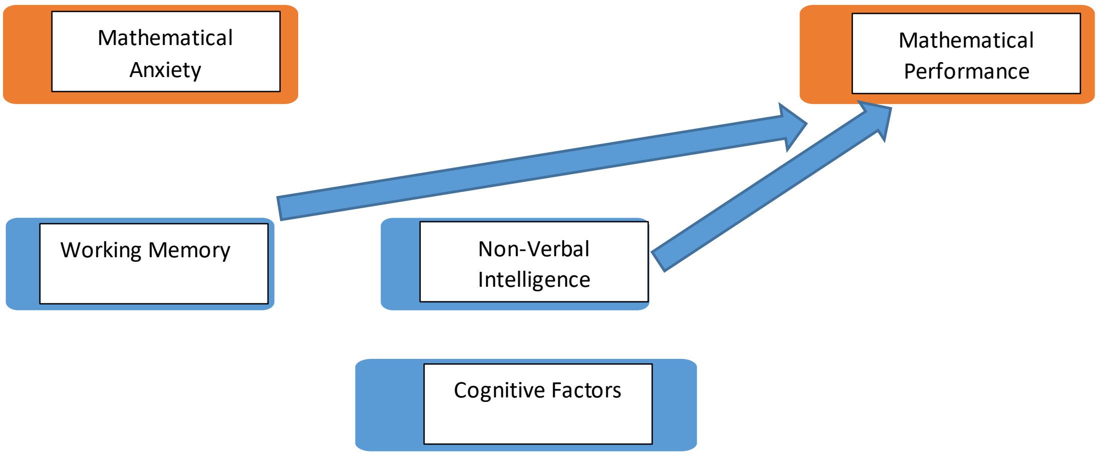

Figure 9.2: Illustration of the cognitive factors (non-verbal intelligence positive predictors at time point one affecting mathematical performance for both the younger and older children.

Additionally, working memory was found to be a positive predictor of their mathematical performance at time point one (year before SATS), but only for word problem solving performance for the younger children and mathematical fluency for the older children. Therefore, the younger children with a better working memory at time point one were better problem solvers. This could be explained as younger children need a greater working memory capacity to cope with the cognitive load and the mathematical needs of the problem (Andersson, 2010; Cowan & Powell, 2014, Fuchs et al., 2010). As these children did not have access to concrete apparatus during testing, known to alleviate the demands on working memory, a good working memory was needed at time point one. As working memory was no longer a significant predictor of word problem- solving performance at time point three, this could indicate that the children were now more familiar with word problems, coping better with the language of them and beginning to rely more on automatic recall of arithmetical facts. Therefore, older children with high working memory scores performed better at tasks which required quick recall of arithmetic facts. As the older children used automatic retrieval of facts more effectively with much higher scores than the younger children, they would need a good working memory in order to activate this information from their long-term memory (Barrouillet et al., 2004, Cowan, 1999, Engle et al., 1999, Unsworth & Engle, 2007). Therefore, this finding that working memory is a strong predictor of mathematical performance in the younger children at time point one, would indicate the possible benefits of working memory training as an appropriate field for further study. As to date school-based working memory training (Holmes & Gathercole, 2014; Söderqvist & Bergman Nutley, 2015) have investigated the benefits in older children (year 5 and 6). Both of these studies (Holmes & Gathercole, 2014; Söderqvist & Bergman Nutley, 2015) found significant improvement in mathematical performance after working memory training, when they followed up participants at a later date.

9.5 The directional relationship between mathematical anxiety and mathematical performance.

The third research question was extended to determine whether there is evidence of a directional relationship between mathematical anxiety and mathematical performance. Models have been proposed to reflect the directional nature of the relationship between mathematical anxiety and mathematical performance (see figure 9.3).

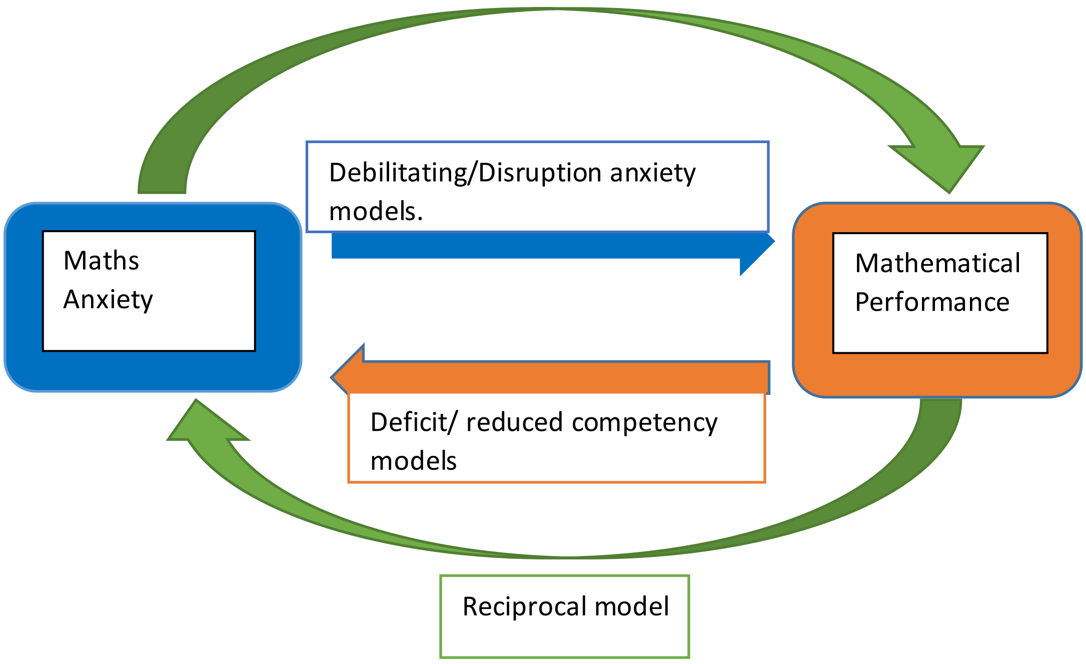

Figure 9.4: Summarises the models of the causal links between mathematical anxiety and mathematical performance.

Models, where mathematical anxiety is represented as the means by which individuals experience mathematical performance deficits (Luo et al., 2014), include the disruption (Ramirez et al., 2018a) and debilitating anxiety (Carey et al., 2016; Lyons & Beilock, 2012) models. Both models suggest that an individual's mathematical anxiety occupies their working memory at the point that they are completing the mathematical tasks. Therefore, prior high levels of mathematical anxiety led to reduced performance. Longitudinal analyses within this thesis looked at the relationship between mathematical anxiety and mathematical performance they revealed no significant unidirectional pathways between mathematical anxiety and any of the measures of mathematical performance. Therefore, no support from these findings can be added to the disruption (Ramirez et al., 2018a) or debilitating anxiety (Carey et al., 2016; Lyons & Beilock, 2012) models.

Alternatively, models where mathematical performance is represented as the means by which individuals experience mathematical anxiety, include the deficit (Tobias, 1986) and reduced competency (Maloney, 2016) models. The deficit model (Tobias, 1986) assumes that it is the memory of prior poor mathematical performance that leads to increased mathematical anxiety. Whereas the reduced competency model (Maloney, 2016), suggests that it is an individual's poor numerical and spatial ability which accounts for their poor mathematical performance which ultimately leads to increased mathematical anxiety. In the longitudinal analyses within this thesis, two significant unidirectional pathways from measures of mathematical performance to mathematical anxiety were found. The first significant pathway was within the cross lagged panel model between mathematical anxiety and mathematical fluency. This pathway was the one from mathematical fluency at time three (Just before the SATs) and time four (just after the SATs). This significant negative relationship indicates that children who are struggling with their mathematical fluency at time point three are then higher in mathematical anxiety at time point four. Time point three was of importance within this research, as it was the time closest to the children completing their SATs, therefore the time point where it was assumed that the children would be under most pressure to perform. This significant pathway is consistent with one study conducted longitudinally with children from second grade to fifth grade, where prior lower mathematical fluency performance was linked to later high mathematical anxiety (Sorvo et al., 2019). This finding within the thesis is a possible indication that time point three (just before the SATs) was a significant time, where children were under pressure to perform within a specified time limit, that then affected their mathematical anxiety when reported at the next time point (after the SATs).

The second significant pathway was within the cross lagged panel model between mathematical anxiety and problem-solving performance. This pathway was the one from problem solving performance at time point one (a year before the SATS) and mathematical anxiety at time point two (the beginning of the SATS year). This negative relationship indicated that children, who were struggling with their problem solving at time point one, were subsequently higher in mathematical anxiety at time point two. This significant pathway is consistent with one study using similar cross lagged panel modelling (Gunderson et al., 2018). Their results indicated, that the first and second grade children in their study, whose mathematical performance was low reported higher mathematical anxiety six months later. This finding within the thesis is an indication that poor mathematical performance is a means of increasing mathematical anxiety especially in problem solving ability, the more complex mathematical task.

These longitudinal findings provide evidence of a significant negative relationship between mathematical anxiety and mathematical performance. The dominating direction of this relationship within the thesis, was from prior mathematical performance to later mathematical anxiety (Carey et al., 2016; Tobias, 1986). This significant finding therefore offers limited support to the Deficit model (Carey et al., 2016; Tobias, 1986) and supports researchers in future to investigate further this directional relationship. As the deficit model proposes that the memories children have of their poor performance to succeed at previous mathematical tasks leads to increased mathematical anxiety in the future. It will be important to ensure that children are supported to develop an understanding that mistakes and poor performance are not always negative but can be viewed positively (Boaler, 2013; Boaler, 2014a; Steuer, Rosentritt-Brunn, &

Dresel, 2013). That is that understanding where mistakes and errors are made, can be used to improve mathematical performance (Boaler, 2014b).

As discussed previously the evidence for this directional relationship from poor mathematical performance leading to later higher levels of mathematical anxiety was influenced by the type of mathematical performance and the time points. For mathematical fluency where the significant pathway was between time three and time four, the reasons for this may have been the time limit imposed on completion of the test and the timing of the test. As asking children to perform under a time limit, is a known factor thought to lead to increased mathematical anxiety (Boaler, 2014b; Engle, 2002). This significant pathway was from time point three (just before SATs) to time point four (after the SATs) which indicates a legacy effect from time point three where the children were under pressure to perform. This finding adds support to the proposal that it is memories of performance that leads to increased mathematical anxiety. That after the SATs there is a lingering effect of poor performance on mathematical anxiety.

For word problem solving where the significant pathway was between time point one and time point two, a possible explanation for this may have been the word problems themselves. As the word problems had been devised to assess the mathematical skills of all children at the time of their SATs a year later. Therefore, all the children would have found these word problems unfamiliar and quite challenging at time point one. Supporting this interpretation is that fact that previous research has indicated that the significant negative relationship with mathematical anxiety is more pronounced when children are required to complete more demanding mathematical tasks (Wu et al., 2012).

A further model, the reciprocal model (Carey et al., 2016; Hembree, 1990; Ramirez, Shaw & Maloney, 2018a) suggests that the relationship between mathematical anxiety and mathematical performance is cyclical. That prior mathematical anxiety has a negative effect on mathematical performance which then leads to increased mathematical anxiety. The longitudinal findings in this thesis do not support a reciprocal model, as the only significant pathways were from prior mathematical performance to later mathematical anxiety at specific time points. This differs from other researchers who found significant reciprocal pathways (Gunderson et al., 2018) and latent profile reciprocal relations (Carey et al., 2017b).

Another environmental factor that is specific to children within the UK, is the fact that children within the UK experience no less than five statutory high stakes tests within their primary educational journey. These tests could be creating an environment for the children where the emphasis is placed on good performance, as the children will know from a very early age their ability level. Therefore, if they are constantly classed as poor performers and, in some cases, identified as “failures” (Bradbury, Braun & Quick, 2019) this would provide a “risk factor” (Rubinsten et al, 2018) leading to increased anxiety. In this thesis this was found in the directional relationship of poor mathematical performance leading to increased mathematical anxiety.

Implications of this directional relationship will be discussed in the sections on implications, educational practice, and future research.

9.6 The relationship between interest in mathematics with mathematical anxiety and mathematical performance.

In answering the fourth research question, the role of interest in mathematics with mathematical anxiety and mathematical performance and their relationship was investigated. Interest in mathematics was found to have a significant negative relationship with mathematical anxiety at both time points (one and three) for both the younger and older children. Therefore, the children studied in this thesis with high levels of interest in mathematics have lower levels of mathematical anxiety. This finding agrees with the limited studies in this field, which found a relationship between a higher motivation for mathematics (e.g., interest) and a lower mathematical anxiety in adolescents and young adults (Asif & Khan, 2011; Luo, Wang, & Luo, 2009) and in children aged six to seven (Ganley & McGraw, 2016). This line of research is of importance as it widens the limited studies with young children to include older primary aged children. Furthermore, this preliminary evidence could suggest that developing a strong interest in mathematics could act as a support factor (Rubinsten, Marciano, Eidlin Levy, & Daches Cohen, 2018) in that those children with high levels of interest in mathematics have lower levels of mathematical anxiety.

The relationship between interest in mathematics and mathematical performance was dependent on the time point of testing and the type of mathematical performance. At time point one (year before SATs), there were no significant relationship between interest in mathematics and mathematical performance for either cohort. Rather, the strongest predictor of mathematical performance is a child’s non-verbal intelligence. Therefore, the importance of a strong interest in mathematics on its relationship with mathematical performance is linked to the timing of the data collection. At time point three (just before SATs), there are significant positive relationships between interest and mathematical performance. These significant relationships are dependent on the type of mathematical performance and cohort of children. For the younger children this significant positive relationship is with arithmetic and word problem solving. Therefore, those children with higher interest in mathematics have higher performance in arithmetic and word problem solving. For the older children the pattern is different with significant positive relationships between interest in mathematics and mathematical fluency and word problem solving. Therefore, those children with higher interest in mathematics have higher performance in mathematical fluency and word problem solving. This agrees with previous research which highlights the importance of having a strong interest in mathematics as this is associated with higher mathematical achievement (Ahmed et al., 2013; Ashcraft & Krause, 2007; Frenzel, Goetz, Pekrun, & Watt, 2010; Meece et al., 1990, Ramirez et al., 2013) with both adult and children. What this thesis adds to this research field is the importance of environmental factors on the relationship, how close to National testing (SATs) data collection is carried out.

Interest in mathematics was found to have a partial mediation role in the relationship between mathematical performance and mathematical anxiety. At time point three (just before SATs) for both cohorts (younger and older), interest in mathematics partially mediated the directional relationship between mathematical performance (fluency, arithmetic and word problem solving) and mathematical anxiety. The findings from the mediation analyses emphasise the importance especially at time point three (just before the SATs) of maintaining the children's interest in mathematics. This finding again outlines the possibility of a strong interest in mathematics acting as a support factor (Rubinsten et al., 2018) in the directional relationship between mathematical performance and mathematical anxiety. Fostering children's interest in mathematics appears to be important within primary schools, so ways to engage children actively (Boaler, 2009) and deepen their interest in mathematics as a subject to improve mathematical performance (Simpkins, Davis-Keen & Eccles, 2006; Wigfield, 1994; Wigfield & Eccles, 2002) are crucial for parents, teachers, and educationalists.

9.7 Limitations:

There are several limitations worth noting, including the length of the longitudinal study, timing of testing, retest effects, ceiling effects and statistical analyses. One major limitation of longitudinal research is the length of longitudinal studies. As there is a need to balance the requirement for a sufficient length of time for a relationship to develop, alongside the practical implications of undertaking longitudinal research. A strength of this thesis was that the length of the longitudinal study was specifically linked to the SATs year. Measurement was taken at four time points across an eighteen-month period. These were time point one, (year before SATs), time point two (beginning of SATs year), time point three (just before the SATs) and time point four (after the SATs). This length of study is like other longitudinal studies, where the longitudinal relationship between mathematical anxiety and mathematical performance was explored (Gunderson et al., 2018; Krinzinger et al., 2009). This timing was of key importance to the thesis, enabling the relationship between mathematical anxiety and mathematical performance to be tracked during the children's SATs year.

This major focus of the thesis, of how the SATs year affected children's mathematical anxiety and mathematical performance, leads to another limitation. The fact that mathematical anxiety was not measured at the point at which the children completed their SATs, that is their mathematical anxiety was not measured on the day they took their mathematics SATs papers. This would not have been appropriate due to the possibility of adding to the pressure at this crucial point in time. It was also likely that schools would not have granted access to the children at this sensitive time. To accommodate these limitations, their mathematical anxiety was measured as close to their SATs as possible. Equally, ensuring that the tasks of mathematical performance, especially the arithmetic and word problem solving, were similar in structure to those that the children would encounter in their SATS. These two accommodations allowed the findings to be considered within the context of the effect of the SATs year.

Another limitation when modelling longitudinal data is the case of retest effects. This occurs when participants are repeatedly measured with the same instrument, i.e., the mathematical anxiety questionnaire used was the same for all four studies. Equally the measures of mathematical performance used were the same. Retest effects manifest as either the children remember materials from one study to the next and react negatively or positively to the repeated questioning. In some cases, the children may even begin to lose interest with the research and then do not try their best. In this thesis what was found was that mathematical anxiety had high test –retest reliability. Equally Mathematical performance (fluency, arithmetic and word problem solving) all had high test- retest reliability.

Equally with retesting in longitudinal research there is always a possibility of ceiling effects within performance measures. To accommodate the possible ceiling effect, more complicated arithmetic and word problems were added to the set of questions after time point one. This increased the number of problems the children needed to complete from twelve to fifteen. These added questions ensured that ceiling effects were not encountered throughout the thesis.

Another limitation to note is the recognition that statistical approaches such as cross lagged panel modelling requires some caution to be taken as the models produced are not true causal models (Selig & Todd, 2012), they do however provide a useful model to explore the relations between variables over time and therefore provide support to an argument. Therefore, in this thesis they have been used to add further information to the statistical stability and development of mathematical anxiety, along with the directional relationship between mathematical anxiety and mathematical performance.

9.8 Implications for psychological research:

There are several findings within this thesis which have implications for psychological research. As mathematical anxiety was reported by children as young as six within this thesis which concurs with previous research (Jameson & Ross, 2011; Petronzi, Staples, Sheffield, & Hunt, 2019). This finding adds to the call for more psychological research with younger children (Petronzi, et al., 2019). As it is important to understand the development of mathematical anxiety from this early age.

Although mathematical anxiety did not develop at a group level throughout the time period, as the means score did not increase. There were significant individual differences in the development of mathematical anxiety, as significant variance was found for the children's starting point and rate of growth of mathematical anxiety. Future research where the individual trajectories of mathematical anxiety were examined would be valuable to get a clearer understanding of the development of mathematical anxiety.

An important finding was that there was a significant negative relationship between mathematical anxiety and types of mathematical performance (fluency and word problem solving) in the older children at time point three (just before SATs). This significant finding so close to the SATs illustrates the need for more research in ways to support children at this crucial point in time. Interventions at this point to alleviate mathematical anxiety would be valuable. Researchers have had some positive results in alleviating mathematical anxiety with the use of expressive writing (Park, Ramirez & Beilock, 2014). In this research university students were encouraged to write about their feelings before undertaking mathematical tests and it was found that their mathematical anxiety decreased. A recent study (Mesghina & Engle Richland, 2020) with children aged 10 to 12 years of age, found opposite results to the study with adults as they reported that the children's anxiety increased when they participated in expressive writing before a mathematics lesson. Therefore, further research into the use of expressive writing with children would be valuable especially when linked to high stakes testing.

As non-verbal intelligence was found to be a strong positive predictor of mathematical performance in children. It is important to research how supporting children in developing their non-verbal intelligence through enhancing their logical, abstract thinking and reasoning skills will impact on their mathematical performance and consequently their mathematical anxiety.

A key finding in the thesis was that of a directional relationship between mathematical performance (fluency and word problem solving) and mathematical anxiety. The finding that prior poor mathematical performance predicts later mathematical anxiety, is an important one for psychological research. As it adds further support to the deficit/ reduced competency models (Maloney, 2016; Tobias, 1986), which propose that memories of previous poor mathematical performance predict later mathematical anxiety.

9.9 Educational practice.

As this research was carried out in schools with primary aged children there are several possible implications which could lead on from this research for educational practice, especially in terms of whether these implications are linked to a support or risk factor for mathematical anxiety and mathematical performance (Rubinsten et al., 2018).

The first educational implication leads from the finding that mathematical anxiety as an emotional construct stayed stable over the study period, notably that children with high levels of mathematical anxiety continued to have high levels of mathematical anxiety. This fact would suggest that early testing of mathematical anxiety within schools needs to be put in place to identify these children as early as possible, to provide support for them. It would also suggest that professionals who teach and support children in mathematics need to have a clear understanding of mathematical anxiety, training at initial teacher training and ongoing professional development (Mammarella, Caviola & Dowker, 2019). Therefore, early knowledge of a child's mathematical anxiety would be a support factor, as professionals would be able to intervene early.

Another educational implication is linked to the fact that there was considerable individual differences in mathematical anxiety, namely in their initial starting level and rate of growth of mathematical anxiety. Thus, early identification of mathematical anxiety, informally where the teacher picks up on how children react within mathematics lessons to formally where a questionnaire is administered, would provide a means to help to identify children at need of support. This also adds to the understanding that interventions are better tailored to meet the individual needs of children (Dowker, 2009).

A further educational implication leads on from the finding within this thesis that the directional nature of the relationship between mathematical anxiety and mathematical performance is one where prior poor mathematical performance leads to increased mathematical anxiety. Thus, early poor mathematical performance is a risk factor in the development of mathematical anxiety (Rubinsten et al., 2018) Therefore this suggests that mathematical performance interventions should be put in place early in a child's education to tackle poor mathematical performance. These interventions could focus on improving children's mathematical knowledge, especially ensuring that children have secure mathematical foundations. In order for these interventions to be effective they need to be based around the assessment of the individual child's strengths and difficulties in mathematics early in their educational journey (Dowker, 2009). There are several existing interventions which are focussed on poor mathematical performance. The Education Endowment Foundation (EEF) (2021) provides evaluations of several mathematical interventions of high-quality targeted support for children experiencing difficulties in mathematics in KS1 and KS2 (e.g., 1stclass@number, onebillion, maths counts and catch-up numeracy) and some promising new interventions (mathematical reasoning, tutor trust-affordable tutoring). These high-quality support interventions are targeted to be delivered by teaching assistants in either small groups or on a one-to one basis. The EEF, (2021) measure the impact of this support in terms of progress in mathematical performance, as number of months progress, typically resulting in 2 -3 months progress in their mathematical performance. EEF (2018) suggest that for targeted interventions to support children they need to happen early in a child's educational journey, therefore poor performance needs to be picked up early especially so that children are not exposed to failure (Dowker, 2019a; Ma & Kishor, 1997) as this reduces the risk of the children developing negative attitudes to mathematics (Ma & Kishor, 1997) and mathematical anxiety (Hembree, 1990; Supekar et al., 2015).

Linked to the previous implication is that specifically there is a need to ensure that children have good mathematical problem-solving skills early in their educational journey, as within this thesis, those children with poor performance in problem solving at time one (year before SATs) had higher levels of mathematical anxiety at time two (beginning of the SATs year). The EEF (2018) recommends that pupils should be taught strategies for solving problems. Woodward et al., (2012) recommends children aged nine to fourteen should be taught to use visual representations (tables, diagrams), worked examples, monitoring and reflecting on how they solve problems (Kramarski & Mavarech, 2003) whilst being exposed to a multitude of problem-solving strategies. Kramarski & Mavarech, (2003) suggest that children's mathematical reasoning could be enhanced with both cooperative learning (children working together to solve mathematical problems through joint discussion), (Slavin, 1996) and metacognitive skills (children being taught to ask a series of metacognitive questions about the problem to be solved), (Ellis, Denton& Bond, 2014; Polya, 1945; Rittle-Johnson, Loehr, & Durkin, 2017) training.

The final implication is linked to the fact that within this thesis, it was found that have a high level of interest in mathematics acted as a mediator in the relationship between mathematical performance and mathematical anxiety. This then identifies that a good interest in mathematics is a support factor (Rubinsten et al., 2018) in the relationship between mathematical performance and mathematical anxiety. The EEF, (2018) suggests that interventions should motivate pupils to learn mathematics e.g., with primary aged children with the use of games (Peters, 1998; Sonnenschein, Metzger, Dowling, Gay & Simons, 2016), the use of games was found to be most effective when children were supported by an adult. Traditionally these games have been board games but with the increasing access to computer-based software in schools and at homes, their use as a motivational intervention are being explored as a means of increasing mathematical performance (Bakker, van den Heuvel-Panhuize & Robitzsch, 2015; Foster, Anthony, Clements & Samara, 2016; Singer, 2015). Simms, McKeaveney, Sloan, & Gilmore, (2019) in a recent systematic review identified eleven studies that used computer-based software as interventions to engage children (aged eight to eleven) in their mathematical learning, although findings were mixed as to the benefit. Therefore, it is important to ensure that schools maintain children's interest in mathematics especially when the curriculum difficulty increases, and focus is placed on achievement in tests. Teaching mathematics in a fun, engaging and stimulating way is key in supporting children's interest within a subject (Boaler, 2016). This finding has importance within educational settings in the need to develop children's interest in mathematics early in their learning journey as a possible protective factor in the development of mathematical anxiety.

9.10 Future research

In this thesis there was a focus on how emotional and cognitive factors interplayed within the relationship between mathematical anxiety and mathematical performance over a critical period (SATs) in the children's primary education. Future work would need to expand the knowledge of this interplay to extend our understanding of the relationship between mathematical anxiety and mathematical performance, to include other environmental influences (cross cultural, educational, parental and teacher attitudes), especially in terms of factors that could be considered as risk factors or support factors (Rubinsten et al., 2018).

Future research could look to determine cross cultural differences in the development of mathematical anxiety between children from different countries, some studies have been carried out cross culturally but mainly with older children (Ho et al., 2000). Therefore, there is a further need for comparison research with primary aged children (Wood et al., 2012). Equally the relationship between mathematical anxiety and mathematical performance in children, in the UK where high-stakes testing begins early, could be compared with countries with high stakes testing at an early age (USA, grade 3 aged eight to nine years) and countries where high stakes testing is at a much later age (e.g., Finland, end of high school, aged eighteen). As this thesis only had children from the UK, where they have been exposed to early high stakes testing, in fact children in the UK encounter five types of National high stakes testing from a very early age (Foundation stage profile, phonics screening, KS1 SATs, Multiplication check and KS2 SATS) in their primary educational journey. Comparison research would offer more information on the impact of high stakes testing pressure.

Another area for future research could be the differences in the development of mathematical anxiety linked to a child's school starting age. In the UK children start school within the year that they turn five, which means that some children are in fact only four when they start. Around the world the school starting age varies with some countries starting children at age 5 (e.g., Australia, New Zealand, and Ireland), some at age 6 (e.g., USA, Singapore, Portugal, and Italy) whereas others delay children starting school until age 7 (e.g., Finland, Hungary, and Poland) (UNESCO, 2020). As mathematical anxiety has been found in very young children (Jameson & Ross, 2011; Petronzi, Staples, Sheffield, & Hunt, 2019) is their school starting age a factor in this development, for example are children meeting formal mathematical concepts too early for their cognitive development (Katz, 2010). In this thesis it was found that poor mathematical performance predicted later mathematical anxiety, therefore children meeting mathematical concepts too early, concepts that they struggle to understand could be a risk factor (Rubinsten et al, 2018) in their development of mathematical anxiety and subsequent mathematical performance.

An important area for future research is to include the mathematical anxiety and mathematical performances of adults within a child's environment, namely their parents and teachers. Rubinsten et al., (2018) suggest that parents and teachers influence could be classed as either a risk factor or a support factor. Parenting influence would have a positive impact if parents were secure in their own mathematical knowledge, low in mathematical anxiety and therefore confident to support their child's mathematical learning (Rubinsten et al., 2018). Whereas if parents are not secure in their mathematical knowledge and have high levels of mathematical anxiety themselves then the impact on their children will be negative (Daches Cohen & Rubinsten, 2017; Roberts & Vukovic, 2011). Interesting within this area is the gender difference in parents, a recent longitudinal study found that maths anxiety in mothers and not fathers predicted the mathematical performance of eight- to nine-year-old children (Szczygiel, 2020b), which could be attributed to children at this age being supported in their education more by their mothers (Dotti Sani and Treas, 2016). Equally the influence of teachers can influence the development of mathematical anxiety in children (Beilock et al, 2010; Herts et al., 2019), their mathematical performance (Szczygiel, 2020b) and negative attitudes to mathematics (Gunderson et al., 2012). Therefore, including the mathematical anxiety and mathematical performance of the adults within a child environment will add to our understanding of the impact either positively or negatively of these external influences on the development of children's mathematical anxiety and their mathematical performance.

Another important aspect for future research which could be either a risk or support factor (Rubinsten et al., 2018), would be to include teaching style (Hembree, 1990; Herts et al., 2019; Newstead, 1998; Park, Gunderson, Tsukayama, Levine, & Beilock, 2016) used by the teachers in mathematics lessons. Previous research has identified teaching style as a factor that could be contributing to the children's mathematical anxiety and mathematical performance (Baroody and Hume, 1991: Jackson and Leffingwell, 1999). Specifically, the use of traditional teaching methods as opposed to investigative methods is thought to contribute to mathematical anxiety (Curtain-Phillips, 1999). Therefore, adding teaching style as a factor within future research will add to the discussion around how educational differences might impact on the mathematical anxiety and mathematical performance of children.

Finally, future research could begin to investigate in more detail the positive relationship that interest in mathematics has in the relationship between mathematical performance and mathematical anxiety. In this thesis it was found that interest in mathematics was a partial mediator in the relationship between mathematical performance and mathematical anxiety, therefore this could indicate that children having a strong interest in mathematics acts as a support factor (Rubinsten et al., 2018) in the relationship between mathematical anxiety and mathematical performance.

9.11 Conclusion:

The SATs year is a developmental period in a child's life with increased emotional and cognitive pressure, the build up to high stakes testing is a period of high intensity focussed on performance and error for the children. Therefore, setting this research within this period provides a unique contribution to the understanding of the development of mathematical anxiety and its relationship with mathematical performance. Mathematical anxiety did not develop over time during the SATs year for these two cohorts of children. Although, children who already had high mathematical anxiety at the beginning continued to have high mathematical anxiety through their SATs year. The relationship between mathematical anxiety and mathematical performance was different for the two cohorts, dependent on the time of testing. For the younger children mathematical anxiety was not a significant predictor of their mathematical performance at time point one (year before SATs) or time point three (just before the SATs). In contrast, for the older children mathematical anxiety was a significant predictor of their mathematical performance (mathematical fluency and word-problem solving) at time point three. This provides a reflection of the different experiences for both cohorts within the SATS year. The directional relationship between mathematical anxiety and mathematical performance (mathematical fluency and word problem solving, with prior mathematical performance (mathematical fluency and word-problem solving) predicting later mathematical anxiety, lends support to the Deficit Model (Tobias, 1986).

Interest in mathematics as an emotional support factor was found to partially mediate the relationship between mathematical anxiety and mathematical performance. This positive influence of interest in mathematics, previously less well documented, provides evidence of the need for further study in this area.

This thesis has expanded the understanding of mathematical anxiety in primary aged children. Its original contribution to knowledge is the specific course of mathematical anxiety during the SATs years and the relationship during that year of mathematical anxiety and mathematical performance. Along with the possible support factor (Rubinsten et al., 2018) of the value of a strong interest in mathematics.

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Appendices

Chapter 1- Appendix

A1.1 Children's Anxiety in Math Scale (CAMS)

Question Score

1

Chapter 3 -Appendix

3.1 Socio-economic Status Statistics:

To establish the socio-economic status of the children participating, two statistics from the English Indices of Deprivation 2015 were used (Department for Communities and Local Government, 2015). Both statistics allow for an indication of the socio-economic status to be established. The first statistic the index of multiple deprivation (IMD) was based on the lower super output areas (LSOAs) which was accessed through the postcode of the school. LSOAS are small geographical areas which are used for reporting small area statistics in England (Ministry of Housing communities and Local Government, 2019). As most primary aged children live close to the school that they attend it can be assumed that the children would live either in the same or adjacent areas to the school. The overall IMD of the Nottingham 018D area indicates that this area shows a higher-than-average deprivation being in the 2nd percentile (where 1 is the most deprived 10%) with a rank of 3,784 out of 32,844. This would equate to children from this school having a very low socio-economic status. The overall IMD of the Ashfield 001A area indicates that this area shows an average deprivation being in the 6th percentile (where 1 is the most deprived 10%) with a rank of 17.397 out of 32,844. This would equate to children from this school having a low socio-economic status.

The second statistic is the Income deprivation affecting children Index (IDAC), which again is based on the lower super output area in which each school resides. This index measured the proportion of all children aged 0-15 living in income deprived families. This measure is calculated by looking at those children living in families where their parents are either out of work or in jobs with low earnings. The IDACI of the Nottingham 018D area indicates that this area shows a higher-than-average deprivation being in the 2nd percentile (where 1 is the most deprived 10%) with a rank of 3,569 out of 32,844. The IDACI of the Ashfield 001A area indicates that this area shows an average deprivation being in the 5th percentile (where 1 is the most deprived 10%) with a rank of 14,827 out of 32,844.

Appendix 3.2: SAT style arithmetic questions for Study 1.

Questions	Operation
1. 9 + 6 =	Addition
2. 14 - 5 =	Subtraction
3. 50 + ☐ = 70	Missing number addition
4. 66 - ☐ = 61	Missing number subtraction
5. 8 X 5 =	Multiplication
6. 8 ÷ 2 =	Division
7. 897 + 100 =	Addition
8. 36 + 204 =	Addition
9. 378 – 9 =	Subtraction
10. ☐ = 945 + 136	Addition
11. 314 x 36 =	Multiplication
12. 648 ÷ 27=	Division

Appendix A3.3: SAT style Word Problem Solving questions for Study 1.

	Questions	Mathematical Complexity- number of steps.	Readability FRE	Readability FKGL
1	There are **9** shells in the red bucket. There are **3** more shells in the blue bucket. How many shells are there in the blue bucket?	1 step addition.	100	1
2	There are **20** balloons. **8** balloons fly away. How many are left?	1 step subtraction	83	3
3	There are **4** boxes with **5** pencils in each box. How many children will get a pencil?	1 step multiplication	89	3
4	There are **35** children. They get into teams of **5**. How many teams are there altogether?	1 step division	75	4
5	The gardener plants **4** rows of carrots. There are **3** carrots in each row. A rabbit eats **2** of the carrots. How many carrots are left?	2 step – multiplication then subtraction.	90	2
6	Apples cost **20p** each. Pears cost **30p** each. How much would it cost to buy **3** apples and **1** pear?	2 step- multiplication, addition.	99	1

7	A sweet shop orders **12** boxes of lollipops. Each box contains **6** bags of lollipops. Each bag contains **25** lollipops. How many lollipops does the shop order in total?	2 step-multiplication, multiplication.	65	6
8	A corner shop opens for **15** hours every weekday, **12** hours on Saturdays and **9** hours on Sunday. How many hours is it open each week?	3 step-multiplication then addition, addition	70	7
9	A bag of **5** apples cost **£2.00.** A bag of **3** pears cost **£1.50**. How much more does one pear cost than one apple?	3 step- division, division, subtraction	79	4
10	**6** pens cost **£1.80**. **3** pens and a rubber cost **£1.09**. What is the cost of **1** rubber?	3 step-division, multiplication, and subtraction.	69	5
11	Diana makes a muesli with **425g** of oat flakes, **220g** of nuts and **255g** of dried fruit. The mixture provides fifteen portions. How much muesli is in each portion?	3 step-addition, addition, then division	69	6
12	A first-class stamp cost 65p and a second-class stamp costs 56p. How much does it cost to send 12 letters first class and 14 letters second class? How much did it cost altogether?	3 step-multiplication, multiplication, and addition	83.8	4

Appendix 3.4: SAT style arithmetic questions for Studies 2, 3 and 4.

Questions	Operation
1. 9 + 6 =	Addition
2. 14 - 5 =	Subtraction
3. 50 + ☐ = 70	Missing number addition
4. 66 - ☐ = 61	Missing number subtraction
5. 8 X 5 =	Multiplication
6. 8 ÷ 2 =	Division
7. 897 + 100 =	Three-digit Addition
8. 36 + 204 =	Two and three Addition
9. 378 – 9 =	Subtraction
10. ☐ = 945 + 136	Three digit Addition
11. 314 x 36 =	Three and two digit Multiplication
12. 648 ÷ 27=	Three and two digit Division
13. 1,067 + 2,399	Four digit Addition
14. 237,459 – 63,631	Six and five digit subtraction
15. 200 – 15 x 6 =	Multiplication and Subtraction. (BODMAS rule question)

Appendix 3.5: SAT style word problem solving questions for studies 2, 3 and 4.

	Questions	Mathematical Complexity- number of steps.	Readability FRE	Readability FKGL
1	There are **9** shells in the red bucket. There are **3** more shells in the blue bucket. How many shells are there in the blue bucket?	1 step addition.	100	1
2	There are **20** balloons. **8** balloons fly away. How many are left?	1 step subtraction	83	3
3	There are **4** boxes with **5** pencils in each box. How many children will get a pencil?	1 step multiplication	89	3
4	There are **35** children. They get into teams of **5**. How many teams are there altogether?	1 step division	75	4
5	The gardener plants **4** rows of carrots. There are **3** carrots in each row. A rabbit eats **2** of the carrots. How many carrots are left?	2 step – multiplication then subtraction.	90	2
6	Apples cost **20p** each. Pears cost **30p** each. How much would it cost to buy **3** apples and **1** pear?	2 step- multiplication, addition.	99	1

7	A sweet shop orders **12** boxes of lollipops. Each box contains **6** bags of lollipops. Each bag contains **25** lollipops. How many lollipops does the shop order in total?	2 step- multiplication, multiplication.	65	6
8	A corner shop opens for **15** hours every weekday, **12** hours on Saturdays and **9** hours on Sunday. How many hours is it open each week?	3 step- multiplication then addition, addition	70	7
9	A bag of **5** apples cost **£2.00.** A bag of **3** pears cost **£1.50**. How much more does one pear cost than one apple?	3 step- division, division, subtraction	79	4
10	**6** pens cost **£1.80**. **3** pens and a rubber cost **£1.09**. What is the cost of **1** rubber?	3 step-division, multiplication, and subtraction.	69	5
11	Diana makes a muesli with **425g** of oat flakes, **220g** of nuts and **255g** of dried fruit. The mixture provides fifteen portions. How much muesli is in each portion?	3 step, -addition, addition, then division	69	6
12	A first-class stamp cost 65p and a second-class stamp costs 56p. How much does it cost to send 12 letters first class and 14 letters second class? How much did it cost altogether?	3 step- multiplication, multiplication, and addition	83.8	4
13	Three schools raise money for charity. St Joseph's raises **£250.** Hillside raises **£305.** Chegwell raises **£673.**	3 step- addition, addition, subtraction.	38.4	9.2

	Altogether, how much more than **£1,000** did the 3 schools raise?			
14	A teacher is taking a class of 26 children to France for the weekend. The flights cost £173 and the accommodation costs £ 156. How much money must she collect from the children altogether?	3 step- multiplication, multiplication, and addition	59.7	7.6
15	An aeroplane has 39 first class seats and 120 economy seats. It costs £655 for a first-class seat and £336 for an economy seat. How much money does the airline take altogether if the flight is full?	3 step- multiplication, multiplication, and addition	64.8	7.3

Appendix 3.6- Completed questions by each cohort at each time point

Table A3.1 below illustrates the range of questions completed for each type of mathematical problem, year group and school at timepoint 2 (beginning of SATs year), timepoint 3 (just before SATs) and timepoint 4 (after the SATs).

Type of mathematical problem	Year group	School A range of completed questions.	School B range of completed questions.
Arithmetic	Year 2	0-10	0-10
	Year 6	5-15	2-15
Word Problem Solving	Year 2	0-6	0-6
	Year 6	1-14	1-15

Table A3.1: Range of problems completed by type of problem, year group and school during SATs year.

As can be seen the KS1 (Year 2) children completed correctly up to 10 arithmetic questions and 6 word-problem solving questions. Within the KS2 (Year 6) children there were some children who only correctly completed the questions at the beginning of the set, with a lower range of 2 in the arithmetic questions and 1 in the word problem solving questions. This is consistent with research that has demonstrated that there is a seven-year variation in the individual mathematical performance scores of children in school year six in their National Standardised tests (SATS) (Brown, Askew, Rhodes, Denvir, Ranson & William, 2003).

Chapter 4- Appendix.

4.1 Emotional Measures over time.

4.1.1 Trait Anxiety

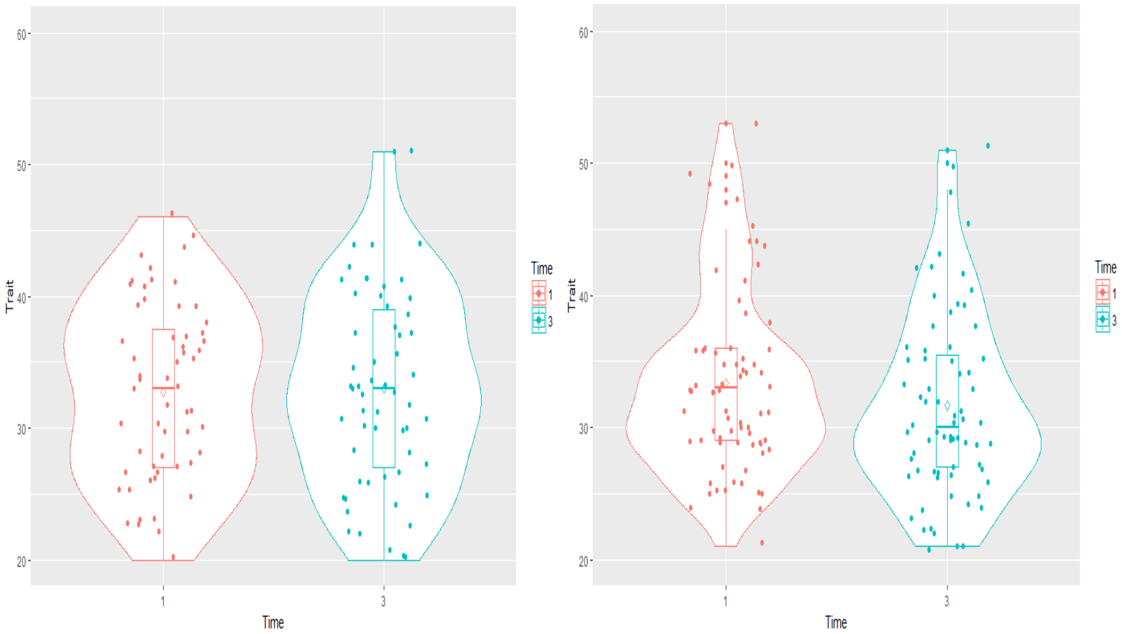
The means and standard deviations for each cohort at each testing time are outlined in table A4.1.

Year group	Time Period	N	Mean	Standard Deviation
Year 1 and 2	Time 1	59	32.7	6.8
	Time 3	59	32.5	8.5
Year 5 and 6	Time 1	71	33.3	7.0
	Time 3	71	31.6	7.0

Table A4.1: Descriptive statistics for Trait Anxiety scores for Time 1 and time 3.

A one-way repeated measures ANOVA was conducted to compare the scores on the Trait Anxiety at time 1 (conducted when children were in year 1) and time 3 (conducted when the children were in year 2 just before the SATs). The means and standard deviations are presented in table A4.1. There was no significant effect for time, Wilks' Lambda=1.0, F (1,58) =.05 p=.826, multivariate partial eta squared =.053.

A one-way repeated measures ANOVA was conducted to compare the scores on the Trait Anxiety at time 1 (conducted when children were in year 5) and time 3 (conducted when the children were in year 6 just before the SATs). The means and standard deviations are presented in table A4.1. There was no significant effect for time, Wilks' Lambda=.95, F (1,70) =3.9, p=.053, multivariate partial eta squared =.053. Therefore, the children's Trait Anxiety stays relatively stable over the 12-month period.



Year 1 and 2 **Trait Anxiety** **Year 5 and 6**

Figure A4.1: Violin Plots of the distribution of Trait Anxiety scores over the four time points for Year 1 and 2 and Year 5 and 6 over the two time points.

The means and standard deviations for the two cohorts are outlined in table A4.1. There is no significant difference over time for both cohorts, this pattern can clearly be seen in figure A4.1. Therefore, the children's Trait Anxiety stays relatively stable over the 12-month period.

4.1.2. Interest in Mathematics

The means and standard deviations for each cohort at each testing time are outlined in table A4.2.

Year group	Time Period	N	Mean	Standard Deviation
Year 1 and 2	Time 1	59	44.1	12
	Time 3	59	44	12
Year 5 and 6	Time 1	71	44.1	9.3
	Time 3	71	42.4	12.4

Table A4.2: Descriptive statistics for Interest in Mathematics scores for time 1 and time 3.

A one-way repeated measures ANOVA was conducted to compare the scores on the Interest in Mathematics at time 1 (conducted when children were in year 1) and time 3 (conducted when the children were in year 2 just before the SATs). The means and standard deviations are presented in table A4.2. There was no significant effect for time, Wilks' Lambda=.1.0, F (1,58) =.004 p=.95, multivariate partial eta squared =.000.

A one-way repeated measures ANOVA was conducted to compare the scores on the Interest in Mathematics at time 1 (conducted when children were in year 5) and time 3 (conducted when the children were in year 6 just before the SATs). The means and standard deviations are presented in table A4.2. There was no significant effect for time, Wilks' Lambda=97, F (1,70) =1.9, p=.170, multivariate partial eta squared =.027. Therefore, the children's Interest in Mathematics stays relatively stable over the 12-month period.

Year 1 and 2 Interest in Mathematics Year 5 and 6

Figure A4.2: Violin Plots of the distribution of Interest scores over the four time points for Year 1 and 2 and Year 5 and 6 over the two time points.

There is no significant difference over time for both cohorts, this pattern can clearly be seen in figure A4.2. Therefore, the children's Interest in Mathematics stays relatively stable over the 12-month period.

4.1.3 State Anxiety

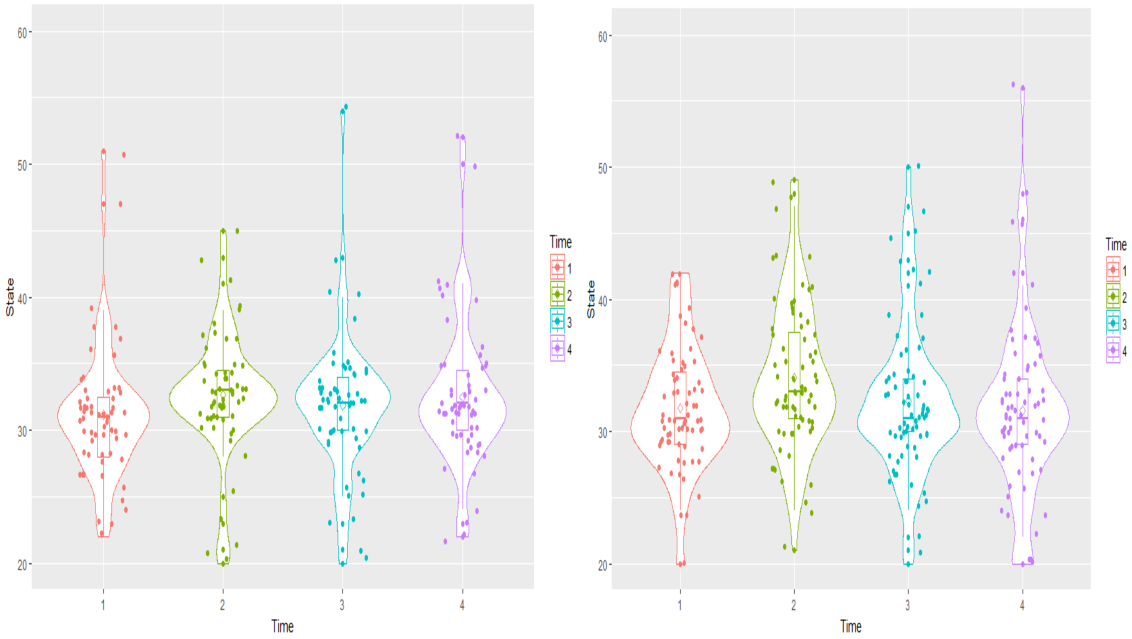
The means and standard deviations for each cohort at each testing time are outlined in table A4.3.

Year group	Time Period	N	Mean	Standard Deviation
Year 1 and 2	Time 1	59	31.2	5.0
	Time 2	59	32.7	4.6
	Time 3	59	31.4	6.4
	Time 4	59	32.5	5.4
Year 5 and 6	Time 1	71	31.8	4.6
	Time 2	71	34.1	5.5
	Time 3	71	32.3	5.8
	Time 4	71	31.6	6.5

Table A4.3: Descriptive statistics for State Anxiety scores for Time 1, 2 ,3 and 4.

A one-way repeated measures ANOVA was conducted to compare the scores on the State Anxiety at time 1 (conducted when children were in year 1) and time 2, 3 and 4 (conducted when the children were in year 2 beginning of the SATs year, just before the SATs and end of the SATs year). The means and standard deviations are presented in table A4.3. There was no significant effect for time, Wilks' Lambda=.89, F (3,56) =2.24, p=.094, multivariate partial eta squared =.107.

A one-way repeated measures ANOVA was conducted to compare the scores on the Interest in Mathematics at time 1 (conducted when children were in year 5) and time 2, 3 and 4 (conducted when the children were in year 6 at the beginning of the SATs year, just before the SATs and at the end of the SATs year). The means and standard deviations are presented in table A4.3. There was a significant effect for time, Wilks' Lambda=.76, F (3,68) =1.19, p<.001, multivariate partial eta squared =.241.



Year 1 and 2 **State Anxiety** **Year 5 and 6**

Figure A4.3: Violin Plots of the distribution of State Anxiety scores over the four time points for Year 1 and 2 and Year 5 and 6 over the four time points.

There is no significant difference over time for the younger cohort. Therefore, the younger cohorts, State Anxiety stays relatively stable over the 18-month period, this pattern can clearly be seen in figure A4.3.

The older cohort show a significant difference over time and their state anxiety scores change over the 18-month period. The significant difference is between time 1 and time 2, where the state anxiety scores increase significantly. Then there is a significant difference between time 2 and time 4 where the state anxiety scores decrease.

4.2 Cognitive measures

4.2.1 Non-verbal Intelligence

The means and standard deviations for each cohort at each testing time are outlined in table A4.4. As expected for non-verbal intelligence, the older children have higher scores than the younger children.

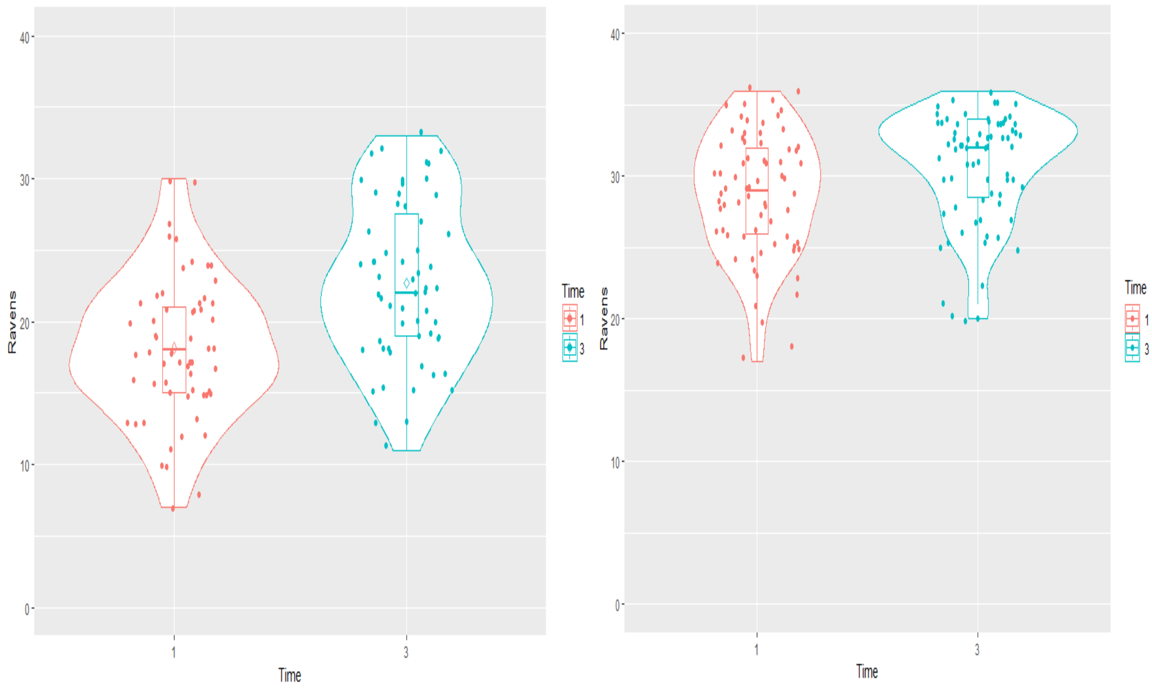
Year group	Time Period	N	Mean	Standard Deviation
Year 1 and 2	Time 1	59	18.2	5.0
	Time 3	59	22.7	5.6
Year 5 and 6	Time 1	71	28.7	4.3
	Time 3	71	30.7	3.9

Table A4.4: Descriptive statistics for Non-verbal Intelligence scores for Time 1 and time 3.

A one-way repeated measures ANOVA was conducted to compare the scores on the non-verbal intelligence at time 1 (conducted when children were in year 1) and time 3 (conducted when the children were in year 2 just before the SATs). The means and standard deviations are presented in table A4.4. There was a significant effect for time, Wilks' Lambda=.30, F (1,58) =137.2 p<.001, multivariate partial eta squared =.71.

A one-way repeated measures ANOVA was conducted to compare the scores on the non-verbal intelligence (Ravens) at time 1 (conducted when children were in year 5) and time 3 (conducted when the children were in year 6 just before the SATs). The means and standard deviations are presented in table A4.4. There was a significant effect for time, Wilks' Lambda=.74, F (1,70) =25.04, p<.001, multivariate partial eta squared =.26.

There is a significant difference over time for both cohorts, indicating that the children's non-verbal intelligence improves significantly over the 12^{th} Month period.



Year 1 and 2 **Non-Verbal intelligence** **Year 5 and 6**

Figure A4.4: Violin Plots of the distribution of Non-verbal Intelligence scores over the four time points for Year 1 and 2 and Year 5 and 6 over the two time points.

There is a significant difference over time for both cohorts, this pattern can be clearly seen in figure A4.4. Therefore, for both cohorts the children's non-verbal intelligence improves significantly over the 12^{th} Month period.

4.2.2 Reading ability

The means and standard deviations for each cohort at each testing time are outlined in table A4.5. As expected, the older children have higher scores than the younger children.

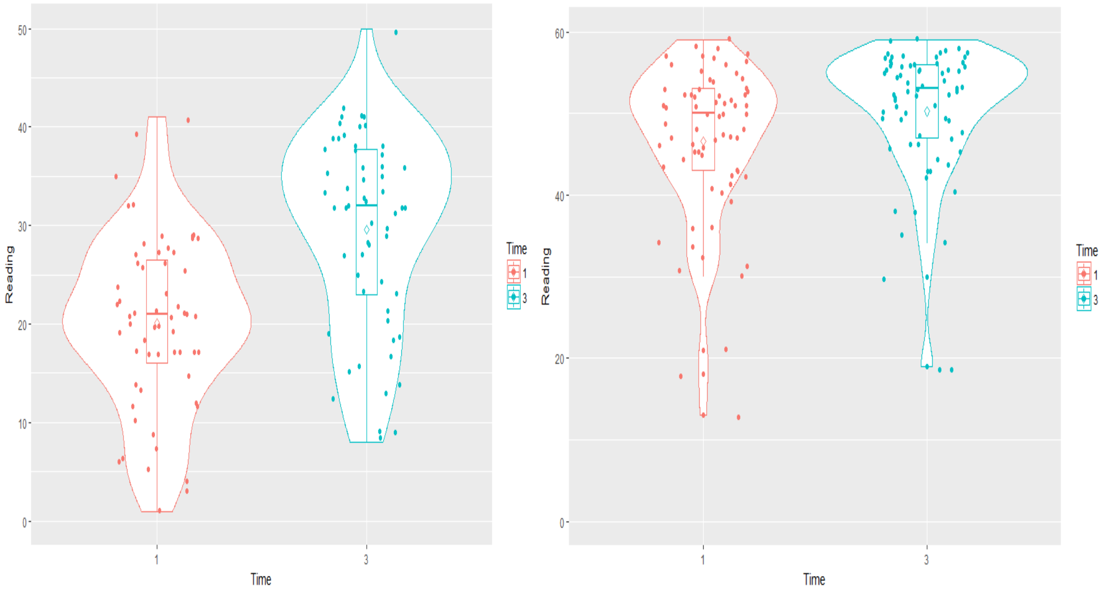
Year group	Time Period	N	Mean	Standard Deviation
Year 1 and 2	Time 1	59	20.1	8.8
	Time 3	59	30	10.2
Year 5 and 6	Time 1	71	46.6	9.5
	Time 3	71	50.2	8.3

Table A4.5: Descriptive statistics for Reading ability scores for Time 1 and time 3.

A one-way repeated measures ANOVA was conducted to compare the scores on word reading ability at time 1 (conducted when children were in year 1) and time 3 (conducted when the children were in year 2 just before the SATs). The means and standard deviations are presented in table A4.5. There was a significant effect for time, Wilks' Lambda=.18, F (1,58) =268.9 p<.001, multivariate partial eta squared =.82.

A one-way repeated measures ANOVA was conducted to compare the scores on the word reading ability at time 1 (conducted when children were in year 5) and time 3 (conducted when the children were in year 6 just before the SATs). The means and standard deviations are presented in table A4.5. There was a significant effect for time, Wilks' Lambda=.55, F (1,70) =57.1, p<.001, multivariate partial eta squared =.45.

There is a significant difference over time indicating that for both cohorts the children's word reading ability improves significantly over the 12th Month period.



Year 1 and 2 Reading Year 5 and 6

Figure A4.5: Violin Plots of the distribution of Reading scores over the four time points for Year 1 and 2 and Year 5 and 6 over the two time points.

There is a significant difference over time for both cohorts, this pattern can be clearly seen in figure A4.5. Therefore, for both cohorts the children's reading ability improves significantly over the 12th Month period.

4.2.3 **Working Memory**

The means and standard deviations for each cohort at each testing time are outlined in table A4.6. As expected, the older children have higher scores than the younger children.

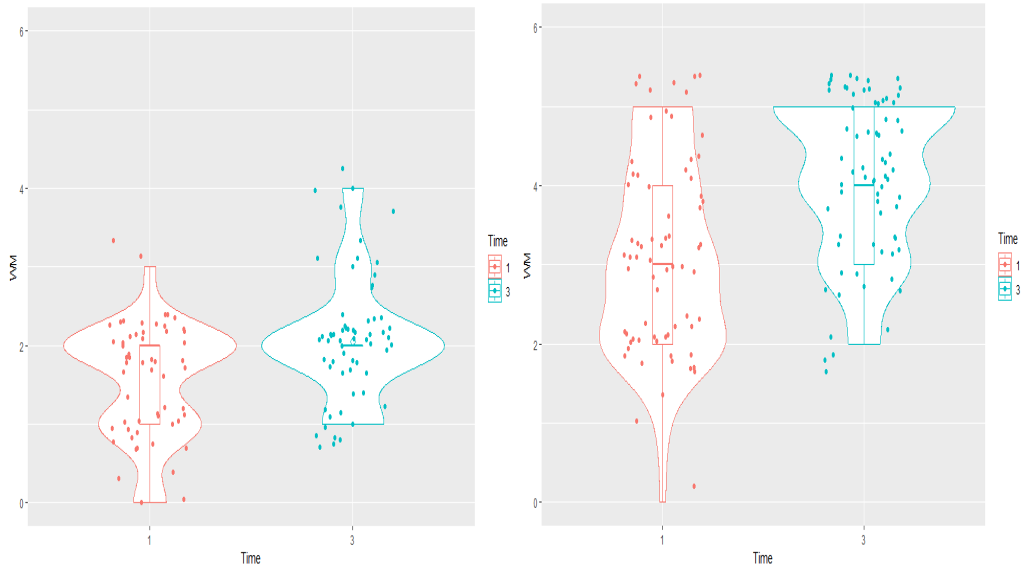
Year group	Time Period	N	Mean	Standard Deviation
Year 1 and 2	Time 1	59	1.5	.73
	Time 3	59	2.1	.78
Year 5 and 6	Time 1	71	3.1	1.2
	Time 3	71	4.1	1.0

Table A4.6: Descriptive statistics for Working Memory (Operation span) scores for time 1 and time 3.

A one-way repeated measures ANOVA was conducted to compare the scores on reading ability at time 1 (conducted when children were in year 1) and time 3 (conducted when the children were in year 2 just before the SATs). The means and standard deviations are presented in table A4.6. There was a significant effect for time, Wilks' Lambda=.75, F (1,58) =19.1 p<.001, multivariate partial eta squared =.25.

A one-way repeated measures ANOVA was conducted to compare the scores on the reading ability at time 1 (conducted when children were in year 5) and time 3 (conducted when the children were in year 6 just before the SATs). The means and standard deviations are presented in table A4.6. There was a significant effect for time, Wilks' Lambda=.64, F (1,70) =40.3, p<.001, multivariate partial eta squared =.37.

There is a significant difference over time for both cohorts indicating that the children's working memory improved significantly over the 12 Month period.



Year 1 and 2 Working Memory Year 5 and 6

Figure A4.6: Violin Plots of the distribution of Working Memory scores over the four time points for Year 1 and 2 and Year 5 and 6 over the two time points.

There is a significant difference over time for both cohorts, this pattern can be clearly seen in figure A4.6. Therefore, for both cohorts the children's working memory improves significantly over the 12 Month period.

As expected over the 12-month period the cognitive skills of the children improve as they increased with age. Older children are more cognitive able than the younger children. Also, each child because of age and education increases their cognitive skills to a greater or lesser extent.

Chapter 5 -Appendix

5.1: Study 1: Correlations

5.1.1 Correlations with Mathematical Fluency.

	Mathematical Fluency	Ravens	Reading	Working Memory	Interest In Mathematics	Trait Anxiety	State Anxiety	Mathematical Anxiety
Mathematical Fluency	1							
Ravens	.61*	1						
Reading	.50**	.37**	1					
Working Memory	.20	.13	.13	1				
Interest in Mathematics	.15	.26*	.19	.36**	1			
Trait Anxiety	.06	-.04	-.13	-.06	-.07	1		
State Anxiety	-.26*	-.24	-.48**	-.30*	-.25*	.22	1	
Mathematical Anxiety	-.28*	-.31*	-.38**	-.13	-.56*	.56**	.53**	1

Table A5.1: Correlation Matrix of cognitive and emotional variables with Mathematical Fluency for year 1 children ("*p < .05, **p < .01").

5.1.2 Correlations with Arithmetic.

	Arithmetic	Ravens	Reading	Working Memory	Interest In Mathematics	Trait anxiety	State Anxiety	Mathematical Anxiety
Arithmetic	1							
Ravens	.59**	1						
Reading	.24**	.37**	1					
Working Memory	.24*	.13	.13	1				
Interest in Mathematics	.32*	.26*	.19	.36**	1			
Trait Anxiety	.09	-.04	-.13	-.06	-.07	1		
State Anxiety	-.09	-.24	-.48**	-.30*	-.25*	.22	1	
Mathematical Anxiety	-.16	-.31*	-.38**	-.13	-.56**	.42**	.53**	1

Table A5.2: Correlation Matrix of cognitive and emotional variables with Arithmetic for year 1 children ("*p < .05, **p < .01").

5.1.3 Correlations with word problem solving.

	Word Problem Solving	Ravens	Reading	Working Memory	Interest In Mathematics	Trait Anxiety	State Anxiety	Mathematical Anxiety
Word Problem Solving	1							
Ravens	.47**	1						
Reading	.13	.37**	1					
Working Memory	.27*	.13	.13	1				
Interest in Mathematics	.20	.27*	.19	.36**	1			
Trait Anxiety	.06	-.04	-.13	-.06	-.07	1		
State Anxiety	-.04	-.24	-.48**	-.30*	-.25*	.22	1	
Mathematical Anxiety	-.05	-.31*	-.38**	-.13	-.57**	.42**	.53**	1

Table A5.3: Correlation Matrix of cognitive and emotional variables with Word Problem Solving for year 1 children (“*$p < .05$, **$p < .01$”).

5.2 Study 2 Correlations

5.2.1 **Correlations with arithmetic performance.**

Measure	Arithmetic correct scores	Mathematical Anxiety	State Anxiety
Arithmetic correct scores	**1**		
Mathematical Anxiety	**-.3***	**1**	
State Anxiety	**-.38****	**.38****	**1**

Table A5.4: Correlation matrix for Arithmetic correct scores, Mathematical Anxiety and State Anxiety for year 2 children ("*$p < .05$, **$p < .01$").

5.2.2 **Correlations with word problem solving performance**

Measure	Problem Solving correct scores	Mathematical Anxiety	State Anxiety
Problem Solving correct scores	**1**		
Mathematical Anxiety	**-.4****	**1**	
State Anxiety	**-.29***	**.38****	**1**

Table A5.5: Correlation matrix for Problem Solving correct scores, Mathematical Anxiety and State Anxiety for year 2 children ("*$p < .05$, **$p < .01$").

5.3 Study 3 Correlations.

5.3.1 Correlations with mathematical fluency.

	Mathematical Fluency	Ravens	Reading	Working Memory	Interest In Mathematics	Trait Anxiety	State Anxiety	Mathematical Fluency
Mathematical Fluency	1							
Ravens	.45**	1						
Reading	.58**	.32*	1					
Working Memory (WM)	.26*	.30*	.07	1				
Interest in Mathematics	.29*	.15	.19	.25	1			
Trait Anxiety	-.12	-.17	-.01	.25	-.18	1		
State Anxiety	-.27*	-.24	-.13	-.16	-.20	-.13	1	
Mathematical Anxiety	.40**	-.38**	-.14	-.06	.52**	.36**	.43**	1

Table A5.6: Correlation Matrix of cognitive and emotional variables with Mathematical Fluency (ARIC) for year 2 children ("**p* < .05, ***p* < .01").

5.3.2 Correlations with arithmetic performance.

	Arithmetic	Ravens	Reading	Working Memory	Interest In Mathematics	Trait Anxiety	State Anxiety	Mathematical Anxiety
Arithmetic	1							
Ravens	.55**	1						
Reading	.56**	.32*	1					
Working Memory	.25*	.30*	.24	1				
Interest in Mathematics	.32*	.15	.19	.25	1			
Trait Anxiety	-.14	-.17	-.01	.25	-.18	1		
State Anxiety	-.27*	-.24	-.13	-.16	-.20	.13	1	
Mathematical Anxiety	-.38**	-.38**	-.14	-.06	-.52**	.36**	.43**	1

Table A5.7: Correlation Matrix of cognitive and emotional variables with Arithmetic for year 2 children ("*p < .05, **p < .01").

5.3.3 Correlations with word problem solving

	Problem Solving	Ravens	Reading	Working Memory	Interest In Mathematics	Trait Anxiety	State Anxiety	Mathematical Anxiety
Problem Solving	1							
Ravens	.49**	1						
Reading	.52**	.32*	1					
Working Memory	.28*	.30*	.07	1				
Interest in Mathematics	.36**	.15	.15	.25	1			
Trait Anxiety	-.03	-.17	.92	.25	-.18	1		
State Anxiety	-.42**	-.25	.30	-.16	-.20	.13	1	
Mathematical Anxiety	-.40**	.38**	.30	-.06	-.52**	.36**	.43**	1

Table A5.8: Correlation Matrix of cognitive and emotional variables with Problem Solving for year 2 children (“*$p < .05$, **$p < .01$”).

Of note here, correlations between working memory and mathematical performance were found to be positively significant for the younger children at time points one and three when performing arithmetic and word problem solving but only for mathematical fluency at time point three. Using this measure of working memory may have influenced the correlations between working memory and mathematical performance as within the operation span the children are asked to solve simple arithmetical problems, therefore as working memory increased so did the mathematical performance of the children

5.4 Study 4 Correlations.

5.4.1 Correlations with mathematical fluency

Measures	Mathematical Fluency	Mathematical Anxiety	State Anxiety
Mathematical Fluency	**1**		
Mathematical Anxiety	**-.3**	**1**	
State Anxiety	**-.3**	**.48****	**1**

Table A5.9: Correlation matrix for Mathematical fluency correct scores, Mathematical Anxiety and State Anxiety for year 2 children ("*p < .05, **p < .01").

5.4.2 Correlations with arithmetic performance.

Measures	Arithmetic correct scores	Mathematical Anxiety	State Anxiety
Arithmetic correct scores	**1**		
Mathematical Anxiety	**-.14**	**1**	
State Anxiety	**-.26***	**.49****	**1**

Table A5.10: Correlation matrix for Arithmetic correct scores, Mathematical Anxiety and State Anxiety for year 2 children ("*p < .05, **p < .01").

5.4.3 **Correlations with word problem solving.**

Measure	Problem Solving correct scores	Mathematical Anxiety	State Anxiety
Problem Solving correct scores	**1**		
Mathematical Anxiety	**-.21**	**1**	
State Anxiety	**-.19**	**.49****	**1**

Table A5.11: Correlation matrix for Problem Solving correct scores, Mathematical Anxiety and State Anxiety for year 2 children. (**correlation is significant at the .01 level (2-tailed).

Chapter 6 – Appendix

6.1: Study 1 Correlations.

6.1.1. Correlations with Mathematical Fluency.

	Mathematical Fluency	Ravens	Reading	Working Memory	Interest	Trait	State	Mathematical Anxiety
Mathematical Fluency	1							
Ravens	.35**	1						
Reading	.58**	.40**	1					
Working Memory	.37**	.31**	.17	1				
Interest in Mathematics	.28*	.23	.23	.21	1			
Trait Anxiety	-.24*	-.01	-.23	-.14	-.12	1		
State Anxiety	-.31**	-.11	-.16	-.003	-.43**	.25*	1	
Mathematical Anxiety	-.24*	-.12	-.20	-.03	-.67**	.36**	.61**	1

Table A6.1: Correlation Matrix of cognitive and emotional variables with Mathematical Fluency for year five children (N =73; *p < .05, **p < .01, ***p< .001).

6.1.2. Correlations with Arithmetic.

	Arithmetic	Ravens	Reading	Working Memory	Interest	Trait	State	Mathematical Anxiety
Arithmetic	1							
Ravens	.42**	1						
Reading	.50**	.40**	1					
Working Memory	.26*	.31**	.17	1				
Interest in Mathematics	.14	.05	.23	.21	1			
Trait Anxiety	-.36**	.93	-.28	-.14	-.12	1		
State Anxiety	-.28*	.34	-.16	-.003	-.43**	.21*	1	
Mathematical Anxiety	-.3*	.33	-.20	-.02	-.67**	.36**	.61**	1

Table A6.2: Correlation Matrix of cognitive and emotional variables with Arithmetic for year five children (N =73; *p < .05, **p < .01, ***p< .001).

6.1.3. Correlations with word problem solving.

	Problem Solving	Ravens	Reading	Working Memory	Interest	Trait	State	Mathematical Anxiety
Problem Solving	1							
Ravens	.52**	1						
Reading	.53**	.40**	1					
Working Memory	.31**	.31**	.17	1				
Interest in Mathematics	.18	.23	.23	.21	1			
Trait Anxiety	-.24*	-.01	-.23	-.14	-.12	1		
State Anxiety	-.29*	-.11	-.16	-.003	-.43**	.25*	1	
Mathematical Anxiety	-.22	-.12	-.20	-.03	-.67**	.36**	.61**	1

Table A6.3 Correlation Matrix of cognitive and emotional variables with Problem Solving for year five children (N =73; *p < .05, **p < .01, ***p< .001).

6.2. Study 2 Correlations

6.2.1. Correlations with arithmetic performance.

Measure	Arithmetic correct scores	Mathematical Anxiety	State Anxiety
Arithmetic correct scores	**1**		
Mathematical Anxiety	**-.4****	**1**	
State Anxiety	**-.13**	**.45****	**1**

Table A6.4: Correlation matrix for Arithmetic correct scores, Mathematical Anxiety and State Anxiety for year 6 children (n=72, *$p < .05$, **$p < .01$).

6.2.2. Correlations with word problem solving performance

Measure	Problem Solving correct scores	Mathematical Anxiety	State Anxiety
Problem Solving correct scores	**1**		
Mathematical Anxiety	**-.3***	**1**	
State Anxiety	**-.23**	**.45****	**1**

Table A6.5: Correlation matrix for Problem Solving correct scores, Mathematical Anxiety and State Anxiety for year 6 children (N=72, *$p < .05$, **$p < .01$).

6.3. Study 3 Correlations

6.3.1. Correlations with mathematical fluency.

	Mathematical Fluency	Ravens	Reading	Working Memory	Interest	Trait	State	Mathematical Anxiety
Mathematical Fluency	1							
Ravens	.27*	1						
Reading	.44**	.46**	1					
Working Memory	.15	.35**	.15	1				
Interest in Mathematics	.44**	.13	.06	.008	1			
Trait Anxiety	-.24	-.19	-.12	-.07	.39**	1		
State Anxiety	-.33**	-.25*	-.03	-.28*	-.32**	.41**	1	
Mathematical Anxiety	-.40**	-.33**	-.20	-.25*	-.59**	.46**	.54**	1

Table A6.6: Correlation Matrix of cognitive and emotional variables with Mathematical Fluency for year six children (N=72, *$p < .05$, **$p < .01$).

6.3.2. Correlations with arithmetic performance.

	Arithmetic	Ravens	Reading	Working Memory	Interest	Trait	State	Mathematical Anxiety
Arithmetic	1							
Ravens	.39**	1						
Reading	.51**	.43**	1					
Working Memory	.26**	.35**	.14	1				
Interest in Mathematics	.26*	.13	.07	.008	1			
Trait Anxiety	-.24*	-.19	-.12	-.07	-.39**	1		
State Anxiety	-.35**	-.25*	-.03	-.28*	-.32**	.41**	1	
Mathematical Anxiety	-.39**	-.33**	.20	-.25*	-.59**	.46**	-.54**	1

Table A6.7: Correlation Matrix of cognitive and emotional variables with Arithmetic for year six children (N=72, *$p < .05$, **$p < .01$).

6.3.3. Correlations with word problem solving

	Problem Solving	Ravens	Reading	Working Memory	Interest	Trait	State	Mathematical Anxiety
Problem Solving	1							
Ravens	.49**	1						
Reading	.64**	.43**	1					
Working Memory	.26*	.35**	.15	1				
Interest in Mathematics	.33*	.13	.06	.008	1			
Trait Anxiety	-.17	-.20	-.12	-.07	-.39**	1		
State Anxiety	-.28*	-.25*	-.03	-.28*	-.32**	.41**	1	
Mathematical Anxiety	-.41**	-.33**	-.20	-.25*	-.59**	.46**	.54**	1

Table A6.8: Correlation Matrix of cognitive and emotional variables with Problem Solving for year six children (N=72, $*p < .05$, $**p < .01$).

Of note here, correlations between working memory and mathematical anxiety were only found to be negatively significant in study three (just before the SATs) only for the older children, when they were performing arithmetic and word problem solving. Thus, for the older children when performing arithmetic and word problem solving those with a high working memory would have low mathematical anxiety and those with low working memory would have high mathematical anxiety. Therefore, adding to the literature that having a good working memory supports reduced mathematical anxiety. Caution should be taken with these results as using the operation span measure of working memory where children are asked to solve simple arithmetic problems may have influenced the correlation.

Equally, correlations between working memory and mathematical performance (see appendix for chapter 6) were found to be positively significant for the older children at time points one and three when performing arithmetic and word problem solving but only for mathematical fluency at time point one. Using this measure of working memory may have influenced the correlations between working memory and mathematical performance as within the operation span the children are asked to solve simple arithmetical problems, therefore as working memory increased so did the mathematical performance of the children.

6.4. Study 4 Correlations

6.4.1. Correlations with mathematical fluency

Measure	Mathematical Fluency	Mathematical Anxiety	State Anxiety
Mathematical Fluency	**1**		
Mathematical Anxiety	**-.44****	**1**	
State Anxiety	**-.40****	**.50****	**1**

Table A6.9: Correlation matrix for Mathematical Fluency correct scores (ARIC), Mathematical Anxiety and State Anxiety for year six children (N =71; *p < .05, **p < .01, ***p< .001).

6.4.2. Correlations with arithmetic performance.

Measure	Arithmetic correct scores	Mathematical Anxiety	State Anxiety
Arithmetic correct scores	**1**		
Mathematical Anxiety	**-.40****	**1**	
State Anxiety	**-.39****	**.50****	**1**

Table A6.10: Correlation matrix for Arithmetic correct scores, Mathematical Anxiety and State Anxiety for year six children (N =72; *p < .05, **p < .01, ***p< .001).

6.4.3. Correlations with word problem solving.

Measure	Problem Solving correct scores	Mathematical Anxiety	State Anxiety
Problem Solving correct scores	**1**		
Mathematical Anxiety	**-.42****	**1**	
State Anxiety	**-.41****	**.50****	**1**

Table A6.11: Correlation matrix for Problem Solving correct scores, Mathematical Anxiety and State Anxiety for year six children (N =72; *p < .05, **p < .01, ***p< .001).

Chapter 7- Appendix

7.1 Mathematical Fluency (TOBANS) over time.

The test for Mathematical Fluency consists of 5 one-minute individual tests of addition, addition with carry, subtraction, subtraction with carry and multiplication. The children complete as many problems as they can and then the scores for each individual test are added together to give a composite score.

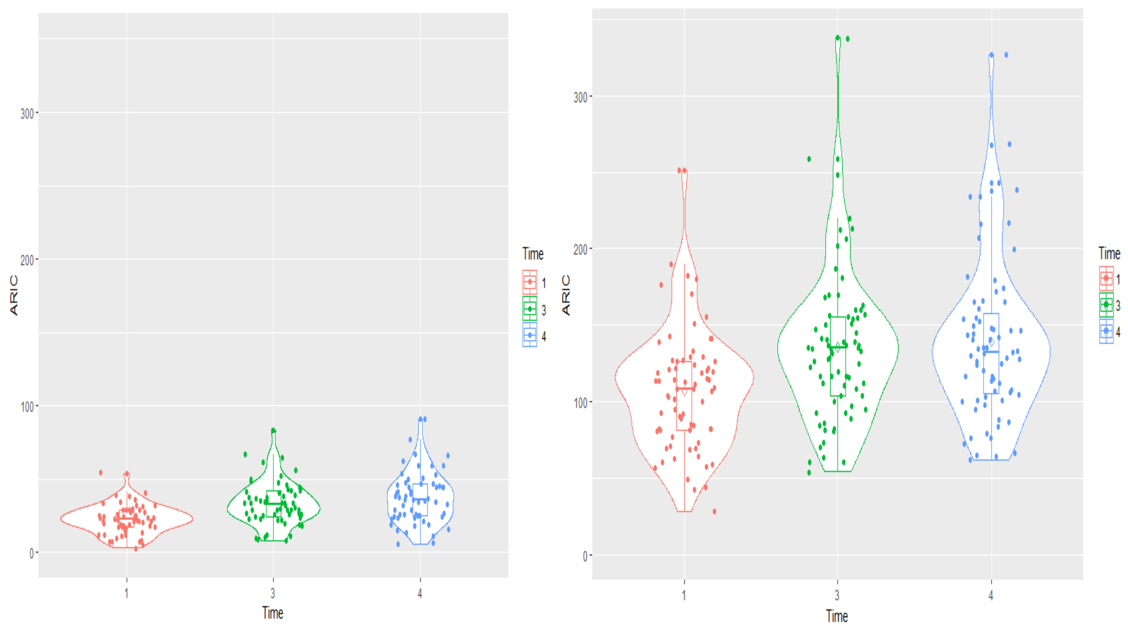
The means and standard deviations for mathematical fluency scores for each cohort at each testing time are outlined in table A7.1.

Year group	*Time Period*	*N*	*Mean*	*Standard Deviation*
Year 1 and 2	*Time 1*	*59*	*22.5*	*9.8*
	Time 3	*59*	*33.6*	*14.9*
	Time 4	*59*	*37.1*	*17.2*
Year 5 and 6	*Time 1*	*71*	*107*	*39*
	Time 3	*71*	*136*	*50*
	Time 4	*71*	*139*	*52*

Table A7.1: Descriptive statistics for Mathematical Fluency scores for Time 1, 3 and 4.

A one-way repeated measures ANOVA was conducted to compare the scores on the Mathematical Fluency task (ARIC) at time 1 (conducted when children were in year 1) and time 3 and 4 (conducted when the children were in year 2, just before the SATs and end of the SATs year). The means and standard deviations are presented in table 4.8. There was a significant effect for time, Wilks' Lambda=.4, $F(2,57) = 32.1$ $p<.001$, multivariate partial eta squared =.53. The pairwise comparisons demonstrated significant increases in mathematical fluency scores from time 1 to time 3 and 4 indicating that the children became more proficient at mathematical fluency over the 18-month period. There was a significant increase in the scores from time 3 to 4, so the children became steadily more proficient.

A one-way repeated measures ANOVA was conducted to compare the scores on the Mathematical Fluency task (ARIC) at time 1 (conducted when children were in year 5) and time 3 and 4 (conducted when the children were in year 6 just before the SATs and at the end of the SATs year). The means and standard deviations are presented in table 4.8. There was a significant effect for time, Wilks' Lambda=.30, $F(2,69) = 79.8$, $p < .001$, multivariate partial eta squared =.70. The pairwise comparisons demonstrated significant increases in arithmetic scores from time 1 to time 3 and 4 indicating that the children became more proficient at arithmetic over the 18-month period. There was no significant increase in the scores from time 2 to 3, so the children's proficiency stabilised in year 6.



Year 1 and 2   Mathematical Fluency   Year 5 and 6

Figure A7.1: Violin Plots of the distribution of Mathematical Fluency scores over the four time points for Year 1 and 2 and Year 5 and 6 over the four time points.

There is a significant difference over time for both cohorts, this pattern can clearly be seen in figure A7.1. Therefore, the children's mathematical fluency improves over the 18^{th} Month period.

7.2 Arithmetic performance over time.

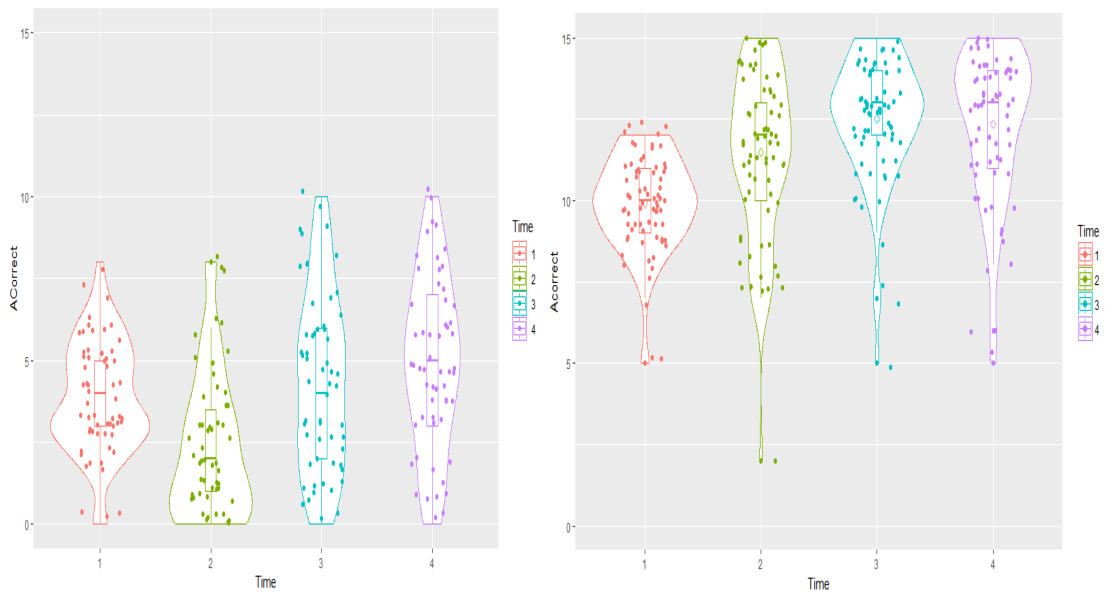
The means and standard deviations for number of correct arithmetic questions for each cohort at each testing time are outlined in table A7.2.

Year group	*Time Period*	*N*	*Mean*	*Standard Deviation*
Year 1 and 2	*Time 1*	*59*	*3.8*	*1.7*
	Time 2	*59*	*2.3*	*2.2*
	Time 3	*59*	*4.3*	*2.7*
	Time 4	*59*	*4.9*	*2.6*
Year 5 and 6	*Time 1*	*71*	*10*	*1.5*
	Time 2	*71*	*11.5*	*2.6*
	Time 3	*71*	*12.5*	*1.9*
	Time 4	*71*	*12.3*	*2.3*

Table A7.2: Descriptive statistics for Arithmetic Task correct scores for Time 1, 2 3 and 4.

A one-way repeated measures ANOVA was conducted to compare the scores on the Arithmetic task at time 1 (conducted when children were in year 1) and time 2, 3 and (conducted when the children were in year 2 beginning of the SATs year, just before the SATs and end of the SATs year). The means and standard deviations are presented in table 4.9. There was a significant effect for time, Wilks' Lambda=.33, F (3,56) =38.1 p<.001, multivariate partial eta squared =.67. The pairwise comparisons demonstrate a significant decrease in arithmetic scores from time 1 to time 2. This can be explained as the younger children were encouraged verbally by the researcher in order to access the questions at time 1 as the questions were age appropriate for year 2. The pairwise comparisons demonstrated significant increases in arithmetic scores from time 2 to time 3 and time 3 to time 4, at these time points the children were in year 2 and able to access the questions independently.

A one- way repeated measures ANOVA was conducted to compare the scores on the Arithmetic task at time 1 (conducted when children were in year 5) and time 2, 3 and 4 (conducted when the children were in year 6 at the beginning of the SATs year, just before the SATs and at the end of the SATs year). The means and standard deviations are presented in table 4.9. There was a significant effect for time, Wilks' Lambda=.31, F (3,68) =50.8, p,.001, multivariate partial eta squared =.69. The pairwise comparisons demonstrated significant increases in arithmetic scores from time 1 to time 2, 3 and 4 indicating that the children became more proficient at arithmetic over the 18-month period. There were also significant increases in the scores from time 2 to 3 and 4, so the children became steadily more proficient.



Year 1 and 2 ***Arithmetic*** ***Year 5 and 6***

Figure A7.2: Violin Plots of the distribution of Arithmetic scores over the four time points for Year 1 and 2 and Year 5 and 6 over the four time points.

There is a significant difference over time for cohorts, this pattern can clearly be seen in figure A7.2. Therefore, the children's mathematical performance in arithmetic improves over the 18th Month period.

7.3 Word Problem Solving performance over time.

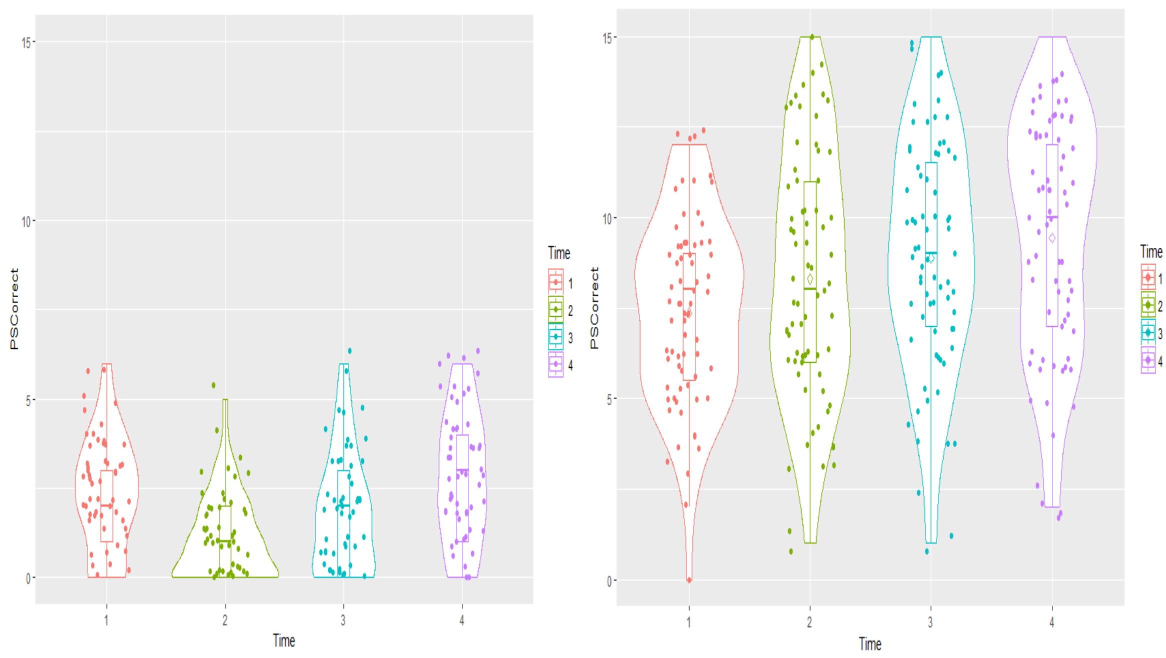
The means and standard deviations for number of correct word problem solving questions (PSCorrect) for each cohort at each testing time are outlined in table A7.3.

Year group	*Time Period*	*N*	*Mean*	*Standard Deviation*
Year 1 and 2	*Time 1*	*59*	*2.4*	*1.6*
	Time 2	*59*	*1.1*	*1.2*
	Time 3	*59*	*1.8*	*1.7*
	Time 4	*59*	*2.8*	*1.8*
Year 5 and 6	*Time 1*	*3.3*	*7.4*	*2.6*
	Time 2	*71*	*8.3*	*3.4*
	Time 3	*71*	*8.9*	*3.2*
	Time 4	*71*	*9.4*	*3.3*

Table A7.3: Descriptive statistics for Word Problem Solving Task correct scores for Time 1, 2 3 and 4.

A one-way repeated measures ANOVA was conducted to compare the scores on the Word problem solving task at time 1 (conducted when children were in year 1) and time 2, 3 and (conducted when the children were in year 2 beginning of the SATs year, just before the SATs and end of the SATs year). The means and standard deviations are presented in table 4.10. There was a significant effect for time, Wilks' Lambda=.35, F (3,56) =34.2 p<.001, multivariate partial eta squared =.65. The pairwise comparisons demonstrate a significant decrease in word problem solving scores from time 1 to time 2. This can be explained as the younger children were encouraged verbally by the researcher in order to access the questions at time 1 as the questions were age appropriate for year 2. The pairwise comparisons demonstrated significant increases in arithmetic scores from time 2 to time 3 and 4 and from time 3 to time 4, at these time points the children were in year 2 and able to access the questions independently.

A one-way repeated measures ANOVA was conducted to compare the scores on the Word problem solving task at time 1 (conducted when children were in year 5) and time 2, 3 and 4 (conducted when the children were in year 6 at the beginning of the SATs year, just before the SATs and at the end of the SATs year). The means and standard deviations are presented in table 4.10. There was a significant effect for time, Wilks' Lambda=.58, $F(3,68)=16.2$, $p<.001$, multivariate partial eta squared =.42. The pairwise comparisons demonstrated significant increases in arithmetic scores from time 1 to time 2, 3 and 4 indicating that the children became more proficient at arithmetic over the 18-month period. There were also significant increases in the scores from time 2 and 4.



Year 1 and 2 ***Problem Solving (PSCorrect)*** ***Year 5 and 6***

Figure A7.3: Violin Plots of the distribution of Problem Solving (PScorrect) scores over the four time points for Year 1 and 2 and Year 5 and 6 over the four time points. (NB: Same scale used).

There is a significant difference over time for both cohorts, this pattern can clearly be seen in figure A7.3. Therefore, the children's mathematical performance in word problem solving improves over the 18-Month period.

As expected over the 18-month period the mathematical performance of the children improves. Older children are more proficient in mathematical ability than the younger children. Also, each child because of age and education increases their mathematical performance to a greater or lesser extent.