An exploration of the mechanisms underpinning the relationship between mathematics anxiety and performance: The relevance of event-related potentials, intrusive thoughts and eye-movement.

Thomas Edward Hunt

A thesis submitted in partial fulfilment of the requirement of Staffordshire University for the degree of Doctor of Philosophy

April 2011

Acknowledgements

Firstly, I would like to thank my supervisors Professor David Clark-Carter and Professor David Sheffield for their support and guidance during the development of my thesis. Also, I would like to extend my thanks to Dr Sheila Ford for her constructive feedback. In addition, I would like to express my gratitude for all the technical help provided by Dr Tracy Warbrick and Paul Gallimore during the early stages of my thesis. I owe a big thank you to my parents, Nigel and Joanne Hunt, and all of my family and friends for their support. Finally, my thanks go to my wife, Lucy, and children, Isobel and Benjamin, for their love, understanding, support, and patience.

Contents

Abstract

Previous research findings suggest that maths anxiety may mask an individual's true maths ability. The overarching aim of the studies presented in the current thesis was to empirically study possible mechanisms underpinning the typically observed negative relationship between maths anxiety and maths performance. One of the main theoretical explanations for the relationship between maths anxiety and performance has focused on the influence of maths anxiety on working memory. In particular, processing efficiency theory (Eysenck & Calvo, 1992) accounts of anxiety effects refer to the role of worry in draining working memory resources, and other accounts also refer to potential problems with a deficient inhibition mechanism associated with intrusive thoughts. However, previous research has failed to adequately investigate a processing efficiency account of maths anxiety effects. Using self-report measures of maths anxiety and performance on two-digit addition verification tasks, the studies presented in this thesis attempt to address this, also taking into account the recent update to processing efficiency theory: attentional control theory (Eysenck, Santos, Derakshan & Calvo, 2007).

Initially, in order to address the question of whether there are neuropsychological correlates of maths anxiety, perhaps associated with increased activation within the frontal cortex, an experiment employing an electroencephalogram methodology was used to measure event-related potentials (ERPs) in response to mental arithmetic. Results showed no evidence for an effect of maths anxiety on ERPs. Despite this, the typical negative relationship between maths anxiety and performance was observed. The subsequent studies therefore attempted to investigate the mechanisms behind this.

The next experimental study used a modified version of the Cognitive Intrusions Questionnaire (Freeston et al., 1993) to assess self-reported in-task intrusive thoughts. Maths anxiety was found to be related to specific task-related intrusive thoughts. In turn, some cognitive intrusions were related to performance. However, there was no evidence to suggest a joint relationship between maths anxiety and cognitive intrusions in explaining maths performance, providing little support for some of the existing explanations of maths anxiety effects.

The third experimental study used a novel eye-tracking methodology to investigate the role of eye-movements in explaining the maths anxiety-to-performance relationship. However, maths anxiety was not found to moderate the relationship between eye-movement, e.g. fixations, dwell-time, and saccades, and performance, despite eye-movements being a strong predictor of performance.

Across studies, and particularly on maths problems involving a carry operation, maths anxiety was found to be related to longer response times to correctly answered maths problems, with some inconsistency in error rates. Such maths anxiety-to-performance relationships are consistent with key assumptions of a processing efficiency and attentional control account of anxiety effects on performance. The exact mechanisms underpinning this relationship, however, remain unclear.

In addition, the thesis reports on and presents a newly developed scale for measuring maths anxiety. The need for a new scale arose out of acknowledgement of validity issues with existing scales and the new Mathematics Anxiety Scale – U.K. has been shown to be both a reliable and valid tool for measuring maths anxiety in a British, and potentially European, undergraduate population.

List of Tables

List of Figures

CHAPTER ONE

1. Mathematics anxiety: A review of the literature

1.1 Introduction

The current thesis is concerned with the study of mathematics anxiety, in particular its relationship with maths performance and the mechanisms that underpin that relationship. This chapter is designed to present a broad overview of the maths anxiety literature and will set the scene for the thesis. To begin, definitions of maths anxiety will be considered, along with a summary of existing scales for measuring it. The review will then turn to a consideration of maths as a specific form of anxiety and how research has demonstrated a relationship between maths performance and physiological reactivity. This will lead to a review of literature suggesting that, whilst maths anxiety shares some similarities with other forms of anxiety, it may be considered as a separate construct. Other associated factors will then be discussed, including possible gender differences in maths anxiety. The influence of maths anxiety in an everyday context will also be considered, along with the suggestion that maths anxiety is related to students' choice of courses that they attend, possibly influencing career choice. Then, the review will discuss the relationship between maths anxiety and attitudes towards maths, and will subsequently present an overview of how maths self-efficacy may be an important variable to consider in the context of maths anxiety. Finally, the review will end by summarising empirical findings that have demonstrated a relationship between maths anxiety and performance. This will provide the background to the subsequent chapter in which key theoretical explanations for this relationship, and their relevance to the investigations presented in this thesis, are discussed.

1.2 Definitions and measurement

Most people will understand what is generally meant by the term maths anxiety, with the most obvious description being that of "anxiety towards maths". An early definition of maths anxiety was that it is "the presence of a syndrome of emotional reactions to arithmetic and mathematics" (Dreger & Aiken, 1957, p. 344). However, there is much empirical research that has used or resulted in a range of more complex definitions and some of these will be considered here. Tobias and Weissbrod (1980) define maths anxiety as "The panic, helplessness, paralysis, and mental disorganization that arises among some people when they are required to solve a mathematical problem" (p.403). This definition appears to describe many of the reactions that may be experienced as part of a general anxious response, but this is with specific reference to mathematics. The most commonly used definition of mathematics anxiety is that given by Richardson and Suinn (1972, p.551) who define it as "feelings of tension and anxiety that interfere with the manipulation of numbers and the solving of mathematical problems in a wide variety of ordinary life and academic situations". These definitions provide a useful starting point for the studies reported in this thesis.

Disagreement over what constitutes maths anxiety has led to the development of a range of instruments purporting to measure maths anxiety, including, for example, the Mathematics Anxiety Rating Scale (MARS, Richardson & Suinn, 1972), the Mathematics Anxiety Questionnaire (MAQ, Wigfield & Meece, 1988), the Anxiety Towards Mathematics Scale (ATMS, Sandman, 1979), and several shortened versions of the MARS (Plake & Parker, 1982; Alexander & Martray, 1989; Suinn & Winston, 2003; Hopko, Mahadevan, Bare & Hunt, 2003). Whilst further discussion of these will take place in Chapter Five, in order to gain a better understanding of what researchers consider maths anxiety to be it is worth referring to the results of factor analysis studies of maths anxiety. For example, Rounds and Hendel (1980) identified two factors of maths anxiety: maths test anxiety and numerical anxiety, representing evaluation of maths ability and performing direct calculation, respectively. Plake and Parker (1982) later identified two factors which they labelled learning maths anxiety and maths evaluation anxiety, representing anxiety towards learning maths and anxiety towards being evaluated, respectively. Also, Alexander and Martray (1989) and Resnick, Viehe and Segal (1982) have identified factors relating to learning maths, doing maths and having maths ability evaluated. In addition, Resnick et al. identified what they termed social responsibility anxiety that represented involvement with maths in social contexts as opposed to educational settings. Later research by Bessant (1995) identified several factors but, on closer examination, these appear to fall into the general dimensions of previously identified factors. Overall, it appears that the main factor or dimension of maths anxiety represents evaluation or testing of maths ability, with several studies observing that this factor represents the majority of variance in maths anxiety (e.g. Alexander & Martray, 1989; Suinn & Winston, 2003). Thus, test anxiety appears to be a major component of maths anxiety, although this is specific to evaluation of maths ability, as discussed later. Other factors also appear to contribute to the construct of maths anxiety, including the learning of maths, actual calculation, and maths in social contexts and there will be more discussion of this later, in Chapter Five.

Using the newly developed Mathematics Anxiety Scale – U.K (MAS-U.K) Hunt, Clark-Carter and Sheffield (in press) demonstrated that, in undergraduates, maths anxiety is an issue that needs to be addressed in U.K undergraduates. Further details of this study are provided in Chapter Five. Figures proposed by studies across the USA further show just how big a problem maths anxiety is. For example, Jackson and Leffingwell (1999) found that only 7% of Americans have had a positive maths experience. Furthermore, in a study of over 9000 students, Jones (2001) found that 25.9% had a moderate to high need of help with maths anxiety. Whilst these findings were based only on North American populations, such figures clearly justify the need for the empirical study of maths anxiety.

1.3 Maths anxiety and physiological reactivity

Hopko, McNeil, Zvolensky, and Eifert (2001) note that although certain performance-based anxiety disorders, such as maths anxiety, are not categorised within the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV, American Psychiatric Association, 1994), they can still be seen as representing a significant clinical problem according to their high prevalence and frequent co-occurrence with other disorders, for example a significant and positive relationship between maths anxiety and general anxiety (Hembree, 1990). According to Hopko et al. one defining feature of performance-based anxieties is the physiological hyperarousal often seen within performance-based contexts.

Mental arithmetic tasks represent one specific performance-based context and are regularly used as a method of inducing heightened physiological arousal in studies designed to investigate the effects of stress. For example, Carroll, Turner and Prasad (1986) measured the heart rate of 18 males performing three mental arithmetic tasks, previously classified by the researchers as easy, difficult or impossible. They found that heart rate changes were sensitive to the level of task difficulty; greater heart rate was observed in the difficult condition compared to the easy and impossible conditions. This demonstrates the utility of heart rate monitoring as a method of differentiating between difficulty levels of mental arithmetic tasks.

Research has also demonstrated the effects of mental arithmetic on salivary secretory immunoglobulin A (sIgA); an immunoglobulin associated with immune defense (Lamm, 1998) and a mediator of the relationship between psychosocial stress and respiratory illness (Carroll, Ring & Winzer, in Fink, 2000). Ring, Drayson, Walkey, Dale and Carroll (2002) gave 24 undergraduate students a mental arithmetic task in which they were required to add two sequentially presented single-digit numbers, while retaining the latter of the two numbers in memory for subsequent addition to the next number presented. Meanwhile the experimenter continually monitored student performance and added pressure by instructing participants to move on to the next two numbers if they failed to respond. Results showed that salivary sIgA rate and concentration were significantly greater when performing mental arithmetic compared to resting and recovery states. Therefore, this suggests that stress induced by mental arithmetic may be related to immunoglobulin release and potentially immune defence.

Such studies have provided evidence to suggest that tasks involving maths may result in increased physiological reactivity. It is plausible that maths anxiety may also be related to such increased physiological reactivity. In an unpublished doctoral dissertation, Faust (1992) demonstrated how physiological arousal and mathematics anxiety are related. In a group of highly maths anxious university students Faust found that heart rate increased in proportion to maths task difficulty (in Ashcraft, 2002). However, such physiological reactivity was not observed on an increasingly difficult verbal task (Ashcraft, 1995), thus demonstrating the specificity of maths anxiety.

In a related study of undergraduate students, Dew, Galassi and Galassi (1983) found a significant positive correlation between skin conductance level and maths anxiety during performance of arithmetic computations. They also observed a significant positive correlation between heart rate and maths anxiety during the task, providing some evidence of the relationship between heightened physiological arousal and anxiety towards maths. Despite the limited number of studies that have measured both physiological arousal and self-reported maths anxiety, there is then some evidence for the actual existence of maths anxiety as a construct.

1.4 Maths anxiety as a unique construct

According to Ashcraft, Kirk and Hopko (1998), although moderately correlated with other forms of anxiety, maths anxiety should be viewed as a separate construct. As may be expected, maths anxiety has been found to correlate positively and significantly with statistics anxiety (Bierenbaum & Eylath, 1994). However, as with other forms of anxiety, such as general trait anxiety, Bierenbaum and Eylath found that approximately 70% of the variance in maths anxiety was unexplained by statistics anxiety.

In a study of 50 college students studying mathematics, Sewell, Farley and Sewell (1983) found a weak ($r = .11$) and non-significant correlation between trait anxiety and achievement across three course-related maths tests. They did, however, find quite a strong and significant negative correlation between state anxiety and maths achievement. Although, it is not clear what the causal mechanisms underlying the high state anxiety levels were, for example whether test anxiety or maths anxiety contributed to the anxiety reported.

Hunsley (1987) proposed a cognitive theory for maths anxiety. He took measures of participants' appraisals, negative internal dialogue and performance attributions and used regression analysis to determine the amount of variance across these variables accounted for by maths anxiety and test anxiety separately. Maths anxiety and test anxiety were found to be significantly positively correlated. However, after controlling for trait anxiety, maths anxiety accounted for an additional 11% of variance in expected grades prior to the exam. Maths anxiety and test anxiety together accounted for 25% of the variance in negative internal dialogue (negative thoughts during the exam), with maths anxiety accounting for the greater proportion of this variance. In relation to predicting performance attributions, the main difference observed between maths anxiety and test anxiety was that maths anxiety accounted for a significant amount of the variance in attributions related to blaming maths backgrounds for impaired exam performance, whereas test anxiety did not. Therefore, it is important that distinctions were made (in terms of variance accounted for) between maths anxiety and test anxiety. As Hunsley notes, "some of the cognitive processes involved in math anxiety differ qualitatively from those found in test anxiety" (p.392). Thus, it is important that maths anxiety is not assumed to simply be a part of test anxiety. Several studies have reported a strong correlation between maths anxiety and general test anxiety (e.g. Betz, 1978; Benson, 1989; Bandalos, Yates & Thorndike-Christ, 1995). In addition, test anxiety has been shown to correlate positively with maths anxiety measured using a range of instruments. For example, Kazelskis et al. (2000) studied a sample of 321 university students and report a correlation (r) of .45 between test anxiety (as measured using Test Anxiety Inventory, Spielberger, 1977) and maths anxiety (as measured using the RMARS, Alexander & Martray, 1989). Further correlations of .57 and .51 were found between test anxiety and maths anxiety measured using the Mathematics Anxiety Questionnaire (Wigfield & Meece, 1988) and The Mathematics Anxiety Scale (Fennema & Sherman, 1976), respectively. Zettle and Raines (2000) looked at the relationship between maths anxiety and trait and test anxiety in a sample of 192 college students, with results showing significant positive correlations between the three types of anxiety. In particular, strong correlations were observed between maths anxiety and trait ($r = .49$) and test ($r = .66$) anxiety. Also, Dew et al. (1983) tested the relationship between both trait test anxiety and state test anxiety and maths anxiety. They found significant positive correlations, of similar magnitude, between trait test anxiety and maths anxiety (r = .52) and between state test anxiety and maths anxiety (r = .56). Hopko, Hunt and Armento (2005) also found a strong positive correlation between maths anxiety and test anxiety. Similar findings were reported by Hembree (1990), in which maths anxiety and test anxiety were found to have a correlation (r) of .52. Maths anxiety was found to be correlated with general anxiety (r = .35), trait anxiety (r = .38), and state anxiety (r = .42).

Several other studies have investigated the parallels between maths anxiety and general test anxiety. Sarason (1987) suggests that maths anxiety may be increased, as with test anxiety, by worrying about performance and through emotional reactions to stress. Using the Mathematics Anxiety Rating Scale (Richardson & Suinn, 1972) and the Suinn Test Anxiety Behavior Scale (Suinn, 1969), Hendel (1980) measured self-reported maths anxiety and test anxiety in 69 women at a US university and found a strong positive correlation (r = .65) between the two variables. Also, Haynes, Mullins and Stein (2004) found a significant and moderate positive correlation between test anxiety and maths anxiety, even when other variables, such as perceived maths ability, were controlled for. The correlations noted in the above studies clearly indicate a moderate to large (according to Cohen’s 1988 criteria) relationship that maths anxiety has with general anxiety and test anxiety and suggest some degree of overlap between the constructs. It is important to note any measurement invariance reported in such studies, but such correlations indicate that, whilst related, maths anxiety may be a separate construct, with much variance still unaccounted for when examining the correlations.

Other forms of anxiety have been shown to be related to maths anxiety. For example, Todman and Lawrenson (1992) found a significant and moderate positive correlation (r = .39) between maths anxiety and computer anxiety among a sample of undergraduate students. As with the general size of the correlations found between maths anxiety and trait or test anxiety, this suggests that whilst maths anxiety and computer anxiety may be related, there still remains a substantial amount of variance unaccounted for in one variable by the other. In addition to this, Todman and Lawrenson report that even though females scored more highly than males on the maths anxiety measure, the same difference in level of computer anxiety was not reproduced, emphasizing the relative independence of the two measures.

These findings, taken together, provide two main points to consider in the context of the current thesis. Firstly, maths anxiety appears to be positively correlated with other forms of anxiety to an extent that highlights the validity of maths anxiety as a construct, including moderate to strong correlations with forms of anxiety such as trait anxiety, state anxiety, test anxiety, computer anxiety, and statistics anxiety. Secondly, despite the above, the reported correlations indicate that much variance across measures remains unaccounted for, highlighting maths anxiety as a distinctly separate construct.

1.5 Gender differences

There appears to be some inconsistency in findings related to gender differences in maths anxiety with some research demonstrating that women report greater maths anxiety than men (e.g. Lussier, 1996; Zettle & Raines, 2000) but some studies finding no difference in the level of maths anxiety reported by men and women (e.g. Dambrot,Watkins-Malek, Silling, Marshall & Garver, 1985; Zettle & Houghton, 1998).

Dambrot et al. (1985) reported no significant difference in maths anxiety between male and female US University students, even though the sample size was large (N = 941). Similarly, while Zettle and Houghton (1998) found that female US university students reported slightly higher maths anxiety than men (d = 0.09[1]) the difference was found to be non-significant. Further to this, in a study of 166 US university students, Haynes et al. (2004) found no significant difference (d = 0.05[1]) in maths anxiety between males and females as measured using the Math Anxiety Scale (Fennema & Sherman, 1976; Betz, 1978).

However, several studies have found that females score higher than males on maths anxiety scales (Dew et al., 1983; LeFevre, Kulak & Heymans, 1992; Levitt & Hutton, 1983). Also, Zettle and Raines (2000) found that female students reported significantly greater levels of test and maths anxiety than males did. Hembree's (1990) meta-analysis of gender differences in self-reported maths anxiety found effect sizes (d) of 0.19 and 0.31 for pre-college and college students, respectively, suggesting that before college (University) females experience more maths anxiety than males do, but this difference increases at college age. A more recent study by Baloglu and Kocak (2006) on a large (N = 759) sample of undergraduate students also found that women reported a significantly higher level of maths anxiety than men on the Revised Mathematics Anxiety Rating Scale (RMARS, Alexander & Martray, 1989) (d = 0.22), particularly on the maths test anxiety sub-scale.

Overall, females appear to report slightly higher levels of maths anxiety than males. It is not clear why there is some inconsistency in findings relating to gender differences, particularly as there are no obvious methodological differences across studies. However, whilst two of the studies that reported non-significant gender differences in maths anxiety (Zettle & Houghton, 1998; Haynes et al., 2004) also reported very small effect sizes, calculation of the effect size from data reported by Dambrot et al. (1985) revealed that females experienced higher maths anxiety than men

[1] Based on a pooled standard deviation for males and females

(d = 0.24) of the magnitude reported by others (e.g. Hembree, 1990; Baloglu & Kocak, 2006).

There are other demographic variables to consider in relation to maths anxiety, for example culture (Engelhard, 1990), ethnicity (Acherman-Chor, Aladro & Dutta Gupta, 2003), and age (Balgolu & Kocak, 2006), but the studies reported in the current thesis are not concerned with cross-cultural variations in maths anxiety, nor are they concerned with differences in maths anxiety across ethnic groups. Similarly, as the population under study is that of undergraduates, participants are taken from a fairly homogeneous age group, so age is not a key factor under investigation. However, considering the various findings that females report higher levels of maths anxiety, gender is deemed to be an important variable that is necessary to consider within the context of the current thesis. For exploratory purposes, then, gender is included in all analyses reported within this thesis.

1.6 Maths anxiety effects in everyday settings

The studies reported in the current thesis are based on investigations within the academic setting of University. In fact, the majority of published empirical investigations of maths anxiety have been based on samples taken from academic settings. Studies that have investigated maths anxiety in situations outside of an academic context are limited. However, of the small number of studies that have been published it is evident that maths anxiety can have detrimental effects in “real world” contexts too. For example, research into consumer behaviour has shown that maths anxiety not only affects the processing of price information but also differentially influences processing at different price levels (Suri & Monroe, 1998).

In a qualitative study of 33 journalists at a large newspaper, Curtin and Maier (2001) used focus groups to investigate participants' attitude, anxiety, and confidence around maths and in particular participants' experiences of maths in the context of journalism. Using axial coding the authors identified a clear dichotomy between "maths phobics" and "non maths phobics". Curtin and Maier report several themes associated with participants in these two categories. For example, they report that maths phobic individuals liken their reaction to maths to a physical disability that actually creates a feeling of being incapacitated. They also report other specific sources of anxiety towards maths, including feelings of reliance on an informal group of work colleagues deemed to be maths experts, as well as a lack of clarity over which colleague(s) has the final, formal, responsibility for numbers. In addition, Curtin and Maier identified other themes related to maths anxiety, including the view that numbers are either "right or wrong" and worry about making mistakes.

It is important to be aware of the possible variations in context when investigating maths anxiety, as demonstrated by those studies that have reported factors on maths anxiety scales that relate to contexts not necessarily academic based, such as "social responsibility anxiety" (Resnick et al., 1982) and "everyday numerical anxiety" (Bessant, 1995). As will be seen in Chapter Five, such a factor will be described from the newly developed Mathematics Anxiety Scale U.K. (Hunt et al., in press) and will also be considered in later analyses within chapters six and seven.

1.7 Course/career choice

As noted earlier, the current thesis is concerned primarily with the study of maths anxiety in an undergraduate population. Bearing in mind University study is not compulsory it is important to consider the possible relationship between maths anxiety and decisions to continue in education. Meece, Wigfield and Eccles (1990) conducted a study on 250 children from grades 7 to 9. One of the items on the Student Attitude Questionnaire (Eccles, 1983; Eccles, Wigfield, Meece, Kaczala & Jayarante, 1986) they administered related to the extent to which students would take more maths (classes) in the future even if they did not have to. Meece et al. found that maths anxiety was significantly correlated with intentions to study maths, such that higher maths anxiety was related to students being less likely to take more maths (classes) in future. Considering this study was conducted on a young sample with an approximate age range of 12 to 15 years, this finding may be an important indicator of students' intentions for post-secondary education, that is, University or other tertiary courses. In addition, in a study of over 1000 female students, Chipman, Krantz and Silver (1992) found that more than 25% of participants agreed with the statement "The desire to avoid mathematics is affecting my career choice", thus providing further evidence that the desire to avoid maths can have wide reaching consequences.

Hembree's (1990) meta-analysis also reported moderately high correlations of -.31 and -.32 between maths anxiety and enrolment on high school maths courses and intent to enrol on maths courses, respectively. A causal relationship between anxiety towards maths to avoidance of maths within jobs or educational courses has also been reported using a qualitative methodology (Curtin & Maier, 2001), further substantiating the argument that experience of maths anxiety can impact upon voluntary engagement with maths later on.

1.8 Maths anxiety and attitudes towards maths

A further factor to take into account when considering the relationship between maths anxiety and course choice is attitudes towards maths. Hembree's (1990) meta analysis found an unsurprising strong negative correlation (r = -.75) between maths anxiety and enjoyment of maths amongst pre-college students, and a smaller but still moderately strong correlation (r = -.47) among college students. Interestingly, he also found a significant but small negative correlation between maths anxiety and the desire for success in maths (r = -0.12). However, a stronger correlation (r = -.37) was found between maths anxiety and perceived usefulness of maths, indicating that maths anxiety may be related to perceived practical applications of maths rather than academic success.

In Fennema's (1989) autonomous learning behaviour model, she suggests three factors that are considered to be precursors to learning maths: maths attitudes, maths anxiety and external sources such as the attitudes of parents, teachers and peers. According to the model, if maths anxiety is high and internal and external attitudes negative, a student's 'autonomous learning behaviours', for example activities leading to competence or mastery, such as paying attention, doing homework or enrolling onto maths courses, are depressed. Therefore, this results in low maths competence and low scores on maths tests. As Ashcraft, et al. (1998) note, however, this approach is correlational. It is plausible that anxiety and negative attitudes can result in less time and effort spent trying to improve maths competency, although, it is also plausible that negative attitudes towards maths and learned maths anxiety may arise out of difficulties or poor performance in maths aptitude or achievement tests. Other factors may also need to be considered, such as anxiety related to being evaluated or tested on maths performance, and also individuals' level of maths self-efficacy.

1.9 Maths self-efficacy

Many researchers have implemented Bandura's (1986) work in the area of self-efficacy into research investigating perceived self-efficacy in mathematics. Bandura defined perceived self-efficacy as "people's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances" (p.391). According to Bandura (1977, 1982, 1986) there are several factors associated with low perceived self-efficacy. For example, such people are likely to give up easily. They are also likely to dwell on their perceived deficiencies, which can detract their attention from the task at hand. Individuals low in perceived self-efficacy are also more likely to attribute their success to external factors and are more likely to suffer from stress and anxiety.

A consistent finding within the maths anxiety literature is the strong relationship between maths anxiety and maths self-efficacy. For example, Haynes et al. (2004) found that undergraduates' perceived maths ability significantly predicted their level of maths anxiety such that the higher the perceived maths ability the less maths anxiety they reported. Further, Zeidner (1992) observed a significant and strong negative correlation between maths anxiety and perceived maths ability among 431 University students in Israel. More recently, Hoffman (2010) reported a significant positive relationship between maths self-efficacy and performance, with maths self-efficacy accounting for 6.6% and 8.4% of the variance in problem solving accuracy and time, respectively (based on squared semi-partial correlations after controlling for maths anxiety and verbal working memory capacity). Hembree's (1990) meta-analysis also revealed that, whilst subtly different from self-efficacy, self-confidence in maths was significantly negatively correlated with maths anxiety ($r = -.71$).

In a study of 68 undergraduate participants enrolled on a mathematics course as preparation for a teaching course, Alkhateeb and Taha (2002) measured mathematics self-concept (using the Self-concept sub-scale of the Self-description Questionnaire, Marsh, Parker & Smith, 1983). They also measured maths anxiety using the 12-item Mathematics Anxiety Scale (Fennema & Sherman, 1976). Results demonstrated a very strong, significant, positive correlation between maths self-concept and maths anxiety. The authors tentatively concluded that anxiety towards maths is therefore related to a desire to do well in maths. Alkhateeb and Taha compare their findings to previous findings that have shown a significant *negative* correlation between perceived maths ability and maths anxiety (Meece et al., 1990). However, this is a good example of how maths self-concept should be clearly distinguished from maths self-efficacy. The Self-concept sub-scale of the Self-description Questionnaire (Marsh et al., 1983) used by Alkhateeb and Taha includes statements such as "I am interested in mathematics" and "I hate mathematics" and therefore may represent a measure of attitudes towards maths rather than maths self-efficacy. Pajares and Miller (1995) highlight the distinctiveness of maths self-efficacy from maths self-concept. In particular, they use the example question of "Are you a good math student?" to represent the tapping of different cognitive and affective processes (related to self-concept) to a more context specific question such as "Can you solve this specific problem?" that may be more of a measure of maths self-efficacy. Indeed, their previous findings demonstrated maths self-efficacy to be a stronger predictor of maths problem solving ability than maths self-concept was (Pajares & Miller, 1994).

In a path analysis including maths self-efficacy, maths anxiety and maths performance, Pajares and Miller (1995) observed a significant direct path between maths self-efficacy and maths anxiety in which the standardized beta coefficient was negative. Pajares and Miller suggest this provides evidence in support of the theoretical view that maths self-efficacy is a major contributor towards maths anxiety. In addition, both maths self-efficacy and maths anxiety were found to significantly predict overall maths performance covering a range of 18 problem-types.

<u>1.10 Maths anxiety and mathematics performance</u>

Whilst there are several potential variables associated with maths anxiety, as described above, the main focus of the current thesis is on the relationship between maths anxiety and performance. Early research suggests that maths anxiety can exist even in those who are otherwise academically successful (Dreger & Aitken, 1957; Gough, 1954). In describing the relationship between maths anxiety and maths achievement, Ashcraft and Ridley (2005) state that “Although reasonable, this relationship is more complex than is usually acknowledged and more troublesome for researchers than is customarily recognized” (p.319) and while there has been much research that has focused on the general finding that maths anxiety is negatively related with maths achievement one of the main problems that researchers have faced is in determining whether such a relationship exists because of poor maths ability among those high in maths anxiety or whether poor performance is in fact due to the anxiety. In Ma’s (1999) meta-analysis of 26 studies maths anxiety was found to correlate quite weakly with overall IQ (r = -.17) and a non-significant correlation of -.06 was found with verbal aptitude sections of standardized tests, although this was based on samples of primary school aged children, rather than adolescents or adults. Maths anxiety and IQ were found to correlate at a small but significant -.17 in Hembree’s (1990) meta-analysis of 151 studies. However, as Ashcraft, et al. (1998) suggest, this is likely to be due to poor performance on quantitative sections of the IQ test. Indeed, in Hembree’s meta-analysis, even though verbal aptitude/achievement was found to correlate at -.06, maths anxiety and maths aptitude/achievement were found to correlate at -.34 for pre-college ages and -.31 for college ages.

Ma and Xu (2004) made use of the data available from a longitudinal study (Longitudinal Study of American Youth, LSAY, see Miller, Kimmel, Hoffer & Nelson, 2000). This was an American panel study spanning six years throughout secondary schooling. The sample was randomly taken from the initial data and included 3116 students (1626 boys and 1490 girls). Maths anxiety was measured using two items on a five-point Likert-type scale, including “mathematics often makes me nervous or upset” and “I often get scared when I open my mathematics book”. Maths achievement scores were based on performance across four subscales measuring basic skills, algebra, geometry, and quantitative literacy. Ma and Xu used structural equation modelling in which maths anxiety and maths achievement were treated as latent variables where the causal relationship between the two variables was assessed across Grades 7-12. The main finding from the study was that prior low maths achievement predicted higher levels of maths anxiety across the range of years assessed. Ma and Xu suggest that their results provide support for the deficits model of the causal relationship between maths anxiety and maths achievement more than support for other models, such as the reciprocal model or the interferences model (Newstead, 1998). That is, maths anxiety in later years of secondary schooling may be caused by poor achievement in the early years. However, the results of Ma and Xu should only be tentatively interpreted given the validity issues surrounding the use of only two questions to measure self-reported maths anxiety. In particular, these were not taken from previously validated scales for measuring maths anxiety, so the validity and reliability of the questions are unknown. Furthermore, regarding the first question, it could be argued that reference to “upset” taps into a more general affective domain than “nervous” does. There is strong evidence (e.g. Hunt et al., in press) to suggest that maths anxiety is a multidimensional construct, so using just two questions to measure maths anxiety may fail to encompass its multidimensionality.

Cates and Rhymer (2003) examined the relationship between maths anxiety and mathematics performance. They presented low and high maths anxious individuals with basic arithmetic problems and took measures of fluency (number of correct digits per minute) and error rates. They found that error rates did not differ between anxiety groups. However, across addition, subtraction, multiplication, division and linear equations, the low maths anxiety group performed significantly more fluently than the high anxious group. That is, the low maths anxious individuals gained more correct digits per minute than the high maths anxiety group. Their findings suggest that differences in mathematics performance between anxiety groups may not be due to accuracy, but may be due to level of learning. That is, both anxiety groups had clearly reached the acquisition of arithmetic facts stage, but the high maths anxious group had failed to reach the higher stage of learning of fluency. These findings may provide an important contribution to suggestions as to the causes of maths anxiety. In relation to basic arithmetic, differences in factual knowledge may not be an issue between anxiety groups, rather, it may be the way in which problems are processed which results in or contributes towards maths anxiety.

The findings of Hembree's meta-analysis (1990) suggested that a high level of maths anxiety is associated with low maths competence. This perhaps explains why research into maths anxiety and mathematical cognition failed to be examined further for some time after this; the relationship was seen as straightforward. However, there are several lines of research to suggest that maths competence can be quite distinct from maths anxiety effects. Hembree found that behavioural and cognitive-behavioural, but not relaxation, techniques for reducing maths anxiety also improved maths performance scores by an effect size (d) of 0.57, often resulting in an increase in maths performance to a level comparable to groups of individuals low in maths anxiety. Ashcraft et al. (1998) interpret this as being due to pre-therapeutic maths tests underestimating an individual's true competence. That is, before maths anxiety is therapeutically reduced, the on-line maths-anxious reaction depresses an individual's test score. Furthermore, they argue that the relationship reported by Hembree between maths anxiety and competence (-.31) is exaggerated and does not reflect the true nature of the relationship. In other words, a global maths test is likely to contain specific types of maths which the maths-anxious reaction may have more of an effect over than others. In line with this argument, Ashcraft et al. administered the sMARS and the Wide Range Achievement Test (WRAT; Jastak Associates, 1993). The WRAT contains several types of maths problem line by line. Ashcraft et al. therefore analysed problem type as a function of maths anxiety. Their findings demonstrated that performance on simple, whole number, problems did not differ as a function of maths anxiety. Maths anxiety effects appeared as problems became more complex; that is, fractions and long division through to algebra. These effects were also observed by Faust, Ashcraft and Fleck (1996). As Ashcraft et al. note, an understanding of underlying mental processes of arithmetic and maths can be ascertained from measures of response time and accuracy. Therefore, Ashcraft has implemented these across several studies to show that anxiety can impinge upon performance even when there are no initial differences in competence among individuals. Using a verification task, Ashcraft and Faust (1994) found no effect of maths anxiety on performance in response to true basic addition and multiplication facts, as well as no differences in response to changes in problem size. Although, in response to false problems, response times and errors produced differential effects between anxiety groups, suggesting a difference in procedural knowledge and/or estimation strategies. However, when more complex arithmetic is presented, maths anxiety effects were evident. For example, Faust et al. (1996) found that highly maths anxious individuals took significantly longer and were more error prone when problems involved two columns and a carry operation. Indeed, it was estimated that carry operation time was three times longer for highly maths anxious individuals than it was for those low in maths anxiety. Ashcraft et al. note the important difference between these results and those obtained by Faust et al. (1996) in a further experiment, in which the same stimulus was used, yet differences between anxiety groups were minimized because problems were in paper-and pencil format, therefore eliminating the need to maintain the carry operation in working memory; it was shifted from a mental to a physical task. Two-column (two-digit) addition problems are the most commonly used problems for testing performance among groups who are low or high in maths anxiety. Two-digit addition problems have been shown to require greater reliance on working memory resources than single-digit problems (e.g. Imbo, Vandierendonck & De Rammelaere, 2007) and research has shown that two-digit problems take longer to solve and are also associated with more errors (e.g. Ashcraft & Kirk, 2001).

Ashcraft and Faust (1994) conducted a study in which 130 undergraduate students on an introductory psychology course took part. They presented participants with 192 problems involving an equal mix of simple addition, complex addition, simple multiplication and mixed operations arithmetic. Problems were presented using a verification task and contained half that called for a true response and half that called for a false response. Groups performed equally in terms of response time and errors when complex addition (true problems) did not involve a carry operation, but a trend existed whereby more anxious individuals took longer to respond when a carry was involved. A similar trend was observed in response to false problems. Interestingly, in response to true problems, they observed that individuals in the highest quartile of anxiety scores actually responded almost as quickly as those in the lowest anxiety group and this was associated with an increase in the number of errors. Ashcraft and Faust explain the latter effect in terms of a local avoidance hypothesis. That is, very highly maths anxious participants are more likely to respond quickly in order to avoid the immediate situation of having to solve the problem. Such a quick response, however, is then more likely to result in greater inaccuracy. No differences were found between anxiety groups on single-digit addition problems. Ashcraft and Faust explain the finding that high maths anxious individuals perform poorly on carry problems in terms of an "online" effect of anxiety on performance. That is, anxiety effects appear when problems are solved in timed conditions, mentally.

Faust et al. (1996) also presented participants with verification tasks involving true and false problems. They found a linear increase in response time as a function of anxiety when four maths anxiety levels were compared. Error rates were also greatest in the group with the highest level of maths anxiety. In the same paper they also report on a further experiment in which the relationship between maths anxiety and response time is partially replicated. They found low and medium maths anxious groups to have similar response times to problems involving a carry operation but response time was considerably longer in the high maths anxious group. The previous error rate finding was not replicated in the second experiment, however. Also, in a second, untimed experiment Faust et al. observed no relationship between maths anxiety and error rates to either single digit addition or two digit addition problems. However, little information is provided regarding the instructions to participants and response time was not measured. This makes it difficult to judge the exact context in which participants performed the task and also whether response time would have still correlated with anxiety anyway. In other words, it should not necessarily be assumed that maths anxiety effects on response time are eliminated when external time pressure is removed. To test the influence of time pressure on maths performance among low and high maths anxious individuals, Kellogg, Hopko and Ashcraft (1999) gave low and high maths anxious groups a series of maths problems under timed and untimed conditions. They report an overall positive relationship between maths anxiety and number of errors made, but this did not vary according to timed or untimed conditions, suggesting that time pressure may not be as important as first predicted in explaining the effect of maths anxiety on performance.

To summarise the key findings relating to the effects of maths anxiety on arithmetic performance, it appears that whilst very high levels of maths anxiety may at times be related to comparatively fast response times (Ashcraft & Faust, 1994), the majority of studies have reported a positive and linear relationship between maths anxiety and both error rate and response time to problems that involve a carry operation (e.g. Faust et al., 1996; Ashcraft & Kirk, 2001).

1.11 Conclusion to Chapter One

This chapter has presented an overview of the academic literature concerning maths anxiety and sets the scene for the remaining work presented in this thesis. From the evidence reviewed, findings suggest that math anxiety shares similarities with other forms of anxiety but remains a unique construct. Also, research evidence suggests a possible gender difference in maths anxiety, with females generally reporting slightly higher levels of maths anxiety than males. Findings have also revealed that maths anxiety is related to a general avoidance of maths, such as avoiding studying maths in post-compulsory education. In addition, those who report high levels of maths anxiety are more likely to have low maths self-efficacy, have had more negative maths experiences, and generally have more negative attitudes towards maths. Finally, specifically related to the focus of this thesis, several studies have highlighted the negative relationship between maths anxiety and maths performance. The following chapter will discuss some of the mechanisms thought to underpin this relationship.

CHAPTER TWO

2. Mechanisms underpinning the relationship between maths anxiety and performance

2.1 Introduction

The previous chapter presented a broad overview of research into maths anxiety and reviewed evidence that suggests maths anxiety is a construct that, whilst related to other forms of anxiety, is distinguishable from them. In particular, evidence indicating a relationship between maths anxiety and maths performance was reviewed. The purpose of this chapter is twofold. Firstly, it will consider previous attempts in which factors thought to explain the relationship between maths anxiety and performance have been manipulated. Secondly, some key theoretical models for explaining the effects of maths anxiety on arithmetic performance will be discussed. During the design and implementation stages of all but the last of the empirical studies reported in this thesis, Eysenck and Calvo's (1992) processing efficiency theory represented the major theoretical model available to explain maths anxiety effects on performance. An update to this theory, attentional control theory (Eysenck, Derakshan, Santos & Calvo, 2007), became available during the design of the final empirical study and the design of this study reflects the update in theory. Inhibition theory (Hasher & Zacks, 1988; Connelly, Hasher & Zacks, 1991) represents another key explanation for maths anxiety effects on performance and this will also be discussed within this chapter. The overall aim of this chapter, then, is to provide a sound theoretical foundation for the empirical studies reported throughout chapters four to seven. Finally, the structure of the thesis will be described.

2.2 Manipulations of components of maths anxiety

There is surprisingly little research that has attempted to manipulate suggested components of maths anxiety, although studies that do exist provide a useful indication of specific aspects of the maths anxiety concept thought to be related to performance. One factor thought to contribute to maths anxiety is time pressure. Kellogg et al. (1999) presented low and high maths anxious individuals with maths problems of varying complexity in both untimed and timed conditions. They found that being in a timed condition adversely affected performance across both low and high maths anxious groups, but anxiety groups were not differentially affected. This is important because it suggests that time pressure is not a critical component of the relationship between maths anxiety and performance. However, it is important to bear in mind that much research has provided support for the argument that maths anxiety is a multidimensional construct (see Chapter One and Chapter Five) and studies that manipulate maths anxiety should analyse data using the various maths anxiety sub-scales that exist. Also, Kellogg et al. used a small sample resulting in a statistically under-powered study. Consequently, further research is needed to explore the effect of timing on a larger sample. In addition, it is not clear what time limits Kellogg et al. used and this is something that could be explored in future work. Kellogg et al. suggest that negative cognitions experienced by individuals high in maths anxiety may relate more directly to the presentation of mathematical stimuli, physiological arousal, and/or a fear of negative evaluation by others, although this was not tested in their study, so further research is needed that does this.

Hopko et al. (2003) identify two components of test anxiety as outlined by Salame (1984): worry and emotionality. An increase in self-focused attention, lack of confidence, cognitions about failure, and worry about time pressure constitute the worry component, whereas feelings of apprehension and somatic symptoms associated with autonomic arousal constitute the emotionality component. Since a manipulation of the worry (time pressure) component had previously failed to explain differential performance between individuals low or high in maths anxiety (Kellogg et al., 1999), Hopko et al. explored performance after manipulating the emotionality component of anxiety by testing the effects of physically induced anxiety (through inhalation of carbon dioxide) on performance among individuals low or high in maths anxiety. On a range of simple and complex addition and multiplication problems, they found that performance across all participants did not differ as a function of carbon dioxide inhalation. Although individuals displaying a high level of maths anxiety performed poorly, exhibiting a high rate of errors, particularly on tasks involving greater demands on working memory. This suggests that it is not simply the heightened physiological arousal accompanying increased levels of maths anxiety that is associated with poor arithmetic performance and further research is needed to explore alternative manipulations of components of maths anxiety. According to processing efficiency theory (Eyenck & Calvo, 1992) worry can lead to a draining of cognitive resources needed for efficient task performance, but it is unclear from Hopko et al.'s study what exactly participants focused their attention on. That is, it is not clear whether attention became focused on performance, or whether attentional resources focused on a secondary target, such as breathing changes caused by inhalation of carbon dioxide. Study three in this thesis addresses this issue by asking participants to self-report on intrusive thoughts that they experienced during a mental arithmetic task (see Chapter six).

2.3 Inhibition theory

Inhibition theory (Hasher & Zacks, 1988; Connelly, et al., 1991; Stoltzfus, Hasher & Zacks, 1996) provides a useful way of conceptualising the effects of distractors on performance. According to the theory, attentional suppression (inhibitory) processes are required to control the negative impact that distractors may have on task-relative objectives. Thus, when this mechanism is operating successfully, an individual can avoid interference effects and perform a task effectively. However, if the inhibitory mechanism is working inadequately, working memory resources become consumed by task-irrelevant thoughts and performance is negatively affected. Initially, investigation of inhibitory processes was carried out on general reading tasks (Connelly et al., 1991) and demonstrated that reading performance was negatively affected by the inclusion of unrelated distractor words. In particular, time taken to read passages of text was much greater when distractors were present, with this effect being emphasised when distractors were semantically meaningful rather than a symbol-string.

Subsequently, inhibition effects on task performance have been taken into account within processing efficiency theory (Eysenck & Calvo, 1992) and attentional control theory (Derakshan et al., 2007), in which its relationship with anxiety effects is considered. In an early attempt to integrate inhibition theory and maths anxiety, Hopko, Ashcraft, Gute, Ruggiero, and Lewis (1998) gave low, medium and high maths anxious participants paragraphs of words containing control distractor words (rows of x's) and paragraphs containing experimental distractor words (maths-related). All three groups read the control paragraphs in similar times. However, groups with high levels of maths anxiety took longer to read the paragraphs containing distractor words. When tested on comprehension of the paragraphs, all groups had similar knowledge of the content, suggesting that more anxious participants did not take longer to read because of greater effort to memorise the content. A more plausible explanation is that those who were more maths anxious failed to inhibit the task-irrelevant distractors and therefore took longer to read the paragraphs. However, the type of distractor was not found to be important in explaining the maths anxiety effect. That is, maths anxious individuals performed as poorly when distractors were rows of x's as when the distractors were made up of maths-related words. The ecological validity of the maths-related distractors is questionable, however, since they may not represent typical maths phrases. For example, distractors included the phrases "add negative ten" and "formula ninety".

In addition to the distractor task adopted by Hopko et al. (1998), the Stroop task paradigm has been used to measure the inability of maths anxious individuals to inhibit task-irrelevant information. The Stroop interference effect (Stroop, 1935) refers to the difficulty in inhibiting attention to meaningful yet conflicting information in a task, even when the information is irrelevant. With respect to maths anxiety, it could be expected that, when presented with maths-related stimulus, maths anxious individuals may experience the Stroop effect. In a Stroop task involving maths words, McLaughlin (1996) found no evidence of a Stroop effect among maths anxious individuals in the form of longer response times to maths words. Although, as Hopko, McNeil, Gleason and Rabalais (2002) point out, a split-half sample based on mean maths anxiety score may not be a representative sample of low and high maths anxiety, that is, it may not necessarily be the case that the spread of maths anxiety scores in the sample is representative of the spread of scores displayed in the population under study. Hopko et al. compared low and high maths anxious participants on two tasks; a Stroop-like card counting task involving numeric and letter stimulus, and a computer-based Stroop task that used maths and neutral word stimulus. Participants were divided into low and high maths anxious groups based on their scores on the Mathematics Anxiety Rating Scale – Revised (MARS-R; Plake & Parker, 1982), a valid and reliable measurement of maths anxiety. After an initial sampling of 459 participants, only those scoring in the top or bottom 20% of their same-gender distributions of maths anxiety were selected. It was predicted that performance time of individuals high in maths anxiety would be longer than for those low in maths anxiety. Indeed, highly maths anxious individuals took significantly longer than the low anxious group to count cards containing letters, but particularly those containing numerals. Error rates were not a cause of the increased response times as there were no significant differences in error rates between the anxiety groups. Regarding the computer-based task, no significant differences in response time or error rates were observed as a function of maths anxiety. Therefore, bearing in mind the findings of McLaughlin (1996) as well, it appears as though the Stroop effect does not differentiate between maths anxiety levels when the stimuli are maths-related words, but the effect is apparent when numbers are used. Also, maths-related words have a disinhibitory effect when contained within stimuli that could be regarded as more ecologically valid, that is, actual paragraphs of words (Hopko et al., 1998). Hopko et al. (2002) partly explain their findings in relation to high maths anxious individuals not entirely being able to rely upon declarative knowledge during the card-counting task. Although, the foremost explanation they offer is in relation to a trait-like inability of high maths anxious individuals to suppress attention to distracting information. They argue that the greatest difference observed between anxiety groups (that of response time for counting cards containing numerals) is due to the emotionality elicited by the fear-inducing stimuli, that is, the numbers, consequently affecting task performance. This is further explained with reference to Eysenck and Calvo's (1992) processing efficiency theory, in which it is suggested that anxiety causes a reduction in the amount of on-line working memory storage and processing capacity available, as discussed in more detail later. According to Hopko et al., the excitation hypothesis (Phaf, Christoffels, Waldorp & den Dulk, 1998), would suggest that the higher response times seen amongst high maths anxious individuals are an effect of stronger verbal connections resulting from the threat-related (maths) words. However, as already noted no differences between maths anxiety groups were observed on the computer-based task using maths-related words. Hopko et al. recognise that the stimuli used in the computer task may not have been representative of the kind of stimuli needed to evoke an anxious reaction, and subsequently cause an excitatory response. They included words such as ‘polynomial’ and ‘theorem’, whereas as they appropriately suggest, words which could more plausibly evoke a maths anxious reaction could be those such as ‘number’ or ‘division’; such words may be more typical of the kinds of maths words that individuals are familiar with and therefore have the potential to carry more meaning. A further finding worth noting is that the effect of maths anxiety on processing time remained after including other measures of anxiety, including state, trait and general test anxiety, as covariates. This provides further support for the specific influence of maths anxiety on performance. Overall, the research suggests that maths anxiety may be related to a general deficient inhibition mechanism, but inhibition processes in maths anxious individuals are particularly affected by numeric stimuli.

2.4 Processing efficiency theory

Processing efficiency theory (Eysenck & Calvo, 1992) represents a general model of the effects of anxiety on performance. It is concerned with the effects of worry (e.g. self-preoccupation, concern over evaluation, worry about performance) on cognitive performance and proposes that some of the processing and storage resources of the working memory system may be pre-empted by worry, and recent research (e.g. Watkins, 2004) has demonstrated that higher levels of anxiety do significantly predict higher levels of worry. As Eysenck and Calvo note, active processing and transient storage of information are essential features of the working memory system. The working memory model (Baddeley & Hitch, 1974; Baddeley, 1986) consists of three major components, each of which has a limited capacity: a central executive (modality–free) that resembles attention and plays a key role in active processing (including task switching), an articulatory (phonological) loop used for transient storage of verbal information through rote rehearsal, and a visuo-spatial sketch pad that is specific to visual and/or spatial information. More recently, Baddeley (2000) incorporated a further component: the episodic buffer, which represents an interface between the three sub-systems and long-term memory.

According to processing efficiency theory, anxiety is likely to detrimentally affect efficiency over effectiveness of task performance. That is, anxiety may sometimes be found to be related to increased error rates, but much research suggests that anxiety is associated with longer response times in order to achieve successful task completion. It also posits that worry limits available working memory resources (temporary storage capacity) and worry can motivate individuals to minimise the aversive state of anxiety. This can be in the form of increased effort and compensatory strategies, resulting in no detriment to performance effectiveness but at the cost of reduced efficiency. It is assumed that worry mainly affects the central executive and is also more likely to affect phonological, over visuo-spatial, processing due to the verbal nature of worry.

Processing efficiency theory includes several specific predictions. Of particular relevance to explaining maths anxiety effects, one prediction linked to performance inefficiency is the notion that high anxious individuals may set themselves unrealistically high standards of performance. This may result in an increased probability of a performance-expectation mismatch. Also, the theory predicts that when performance between low and high anxious participants is comparable, high anxious individuals should report higher levels of subjective effort in order to counteract inefficient processing. Eysenck and Calvo (1992) note early research by Dornic (1977; 1980) which supports this prediction, finding that task performance did not vary across anxiety groups, but subjective effort was greater among high anxious individuals, particularly when task demands were high. Furthermore, Eysenck and Calvo's theory predicts that when a primary and secondary task are concurrently performed, anxiety will typically adversely affect performance on the secondary task and will also reduce spare processing capacity during the performance of a central task. A further key feature of processing efficiency theory is that motivational factors that are introduced to enhance performance will typically benefit individuals low in anxiety more than those who are highly anxious. Eysenck and Calvo suggest that this occurs as a result of high anxious individuals already exerting greater effort than those who are low-anxious. Processing efficiency theory also postulates that performance on a central task will be impaired by an additional load to a greater extent in anxious compared to non-anxious groups. In particular, impairment in processing efficiency produced by anxiety can be detected by a greater (lengthened) processing time. In addition to the latter point, according to the theory, psychophysiological measures can be used to detect anxiety effects on efficiency, e.g. via an increased number of physical movements (Weinberg & Hunt, 1976).

Another major prediction of processing efficiency theory relates to the interaction between anxiety and working memory, starting with the general argument that the effects of anxiety on performance become greater as working memory capacity is reduced as a result of task demands. More specifically, Eysenck and Calvo propose that anxious individuals are more likely than non-anxious individuals to engage in worry, which in turn pre-empts some of the resources of the central executive and phonological loop. They further postulate that effects of anxiety on task performance are dependent on the amount of working memory resources required by the task.

Related to this, it is proposed that anxiety has the specific effect of reducing transient storage capacity. Indeed, several studies have demonstrated an impairment of digit span as a result of increased stress (Eysenck, 1979). Further to this, Eysenck and Calvo's theory predicts that adverse effects of anxiety on performance should be greatest when tasks place high demands on both the central executive and phonological loop components of working memory, but particularly the central executive, with empirical findings supporting this claim (e.g. Darke, 1988a; Hamilton, Hockey & Rejman, 1977). In addition, processing efficiency theory posits that in tasks not involving the central executive or phonological loop, anxiety does not generally impair performance. Evidence for this claim comes from studies that have included tasks requiring very little working memory demands (e.g. Mayer, 1977; Eysenck, 1989) and found no difference in performance between low and high anxious groups.

Processing efficiency theory may be useful in explaining maths anxiety effects, particularly in relation to i) the finding that maths anxiety is more consistently related to processing efficiency more than performance effectiveness, and ii) it is concerned with the role of worry; a factor that is often discussed in the context of maths anxiety effects. However, as discussed below, processing efficiency theory is limited and has been extended to account for research findings that have emphasised the role of attentional control when considering the relationship between anxiety and task performance.

2.5 Attentional control theory

Attentional control theory (Eysenck et al., 2007) represents an extension of Eysenck and Calvo's (1992) processing efficiency theory and proposes that attentional processes are integral to understanding anxiety effects. The theory also postulates that attention is often directed to threatening stimuli (whether internal, e.g. worrisome thoughts, or external, e.g. threatening task-related distracters) and to ways in which the individual can respond. This means that attention is then directed away from the concurrent (goal-related task), that is, attentional control is reduced. This, according to Eysenck et al., places considerable demands upon the central executive. They also note that previous findings relating to worry and performance are mixed, that is, worry has been shown to be related to better and worse performance, and also no differences in performance between low and high anxious groups. One major problem is that worry is often measured retrospectively making it difficult to examine its relationship with attentional processes.

The view that there are two attentional systems (stimulus-driven and goal-directed) that contain commonalities provides a framework for attentional control theory, in that anxiety disrupts the balance between the two systems. Anxiety causes automatic processing (and therefore increased attentional processing) of threat-related stimuli. This results in a decreased influence of the goal-directed attentional system. Eysenck et al. outline three key central executive functions important to attentional control theory.

1. Inhibition: inhibiting attentional resources being directed towards task-irrelevant information.
2. Shifting: directing attentional resources to task-relevant stimuli and remain goal-oriented.
3. Updating/monitoring: anxiety will likely adversely affect the ability to transiently maintain information.

One feature of attentional control theory is that inhibition (of task-irrelevant, threat-related, stimuli) and shifting are impaired when demands on the central executive are high. Eysenck et al. outline the following hypotheses and empirical support of attentional control theory:-

1. Anxiety impairs processing efficiency to a greater extent than performance effectiveness on tasks involving the central executive:

   This hypothesis is specifically related to anxiety effects on inhibition and shifting. Performance effectiveness is often comparable amongst low and high anxious groups, but an increase in effort (decrease in efficiency) is needed to achieve this. Effort can be measured using i) self-report measures, ii) psychophysiological measures and iii) incentive manipulation. Specifically:

   i) High anxiety is related to increased effort
   ii) High anxiety is related to increased cardiovascular reactivity pre and post-test, but not during task performance.
   iii) Incentives increase performance in low anxious individuals, but not high. Possibly because effort is already increased in those who are highly anxious.

In the current thesis, this assumption is specifically relevant to the overall hypothesis that maths anxiety will be related to reduced processing efficiency (longer response times) to a greater extent than reduced performance (more errors).

Eysenck et al. further note compensatory strategies that are employed by those who are highly anxious:

i) Experiments testing reading comprehension suggest that regression (looking back at previous text) is the most common strategy, with articulatory rehearsal (vocal and sub-vocal articulation during reading) being used when regression was not possible (if previous text could not be observed) (e.g. Calvo & Castillo, 1995; Calvo & Eysenck, 1996).

ii) A neuroimaging study (Santos, Wall & Eysenck, in preparation) showed that high anxiety was related to greater activation in a prefrontal area known to be related to shifting, suggesting that shifting was a compensatory strategy used to produce comparable performance effectiveness but reduced efficiency.

iii) The probe technique involves emphasising the importance of performing well on a main task, but then asking participants to respond to stimuli, for example occasional auditory or visual signals, on a secondary task. Findings have shown that response time is longer (poorer efficiency) to the secondary task stimuli amongst high anxious individuals, suggesting fewer working memory resources were available in those who were highly anxious. Eysenck and Payne (2006) found that response time was further decreased in high anxious individuals in an evaluative compared to non-evaluative condition, with reaction time being directly related to the number of letters on a letter-transformation task.

Relating to point (i) above, this is relevant to the final experimental study reported in this thesis (see Chapter Seven) in which it is hypothesised that, in an arithmetic verification task, maths anxiety moderates the relationship between maths performance and the number of regressions from the proposed solution to the proposed problem. Relating to point (ii), study one (Chapter Four) in this thesis tests the hypothesis that event-related potentials may vary according to level of maths anxiety, but this will be specific to the frontal region of the cortex.

2. Adverse effects of anxiety on performance become greater as overall task demands on the central executive increase.

This hypothesis relates to the view that performance effectiveness is likely to decrease as task demands increase. Performance efficiency is more likely to be adversely affected by anxiety than performance effectiveness is. However, performance effectiveness is likely to deteriorate as the need to expend greater effort increases. This has been demonstrated in studies where increased demands on the central executive and working memory as a whole lead to poorer performance amongst high-anxious individuals (e.g. Ashcraft & Kirk, 2001). Also, attentional control theory is supported by research using a loading paradigm in which primary task performance is worse amongst high-anxious individuals when a secondary task is performed, perhaps due to shifting attention (e.g. MacLeod & Donnellan, 1993). In the studies reported in the current thesis, arithmetic problems are presented in which problems involving a carry operation are assumed to be place greater demands on working memory, in particular on the central executive. Therefore, it is hypothesised that participants will perform more poorly on problems involving a carry operation, but also that the expected effect of maths anxiety on performance will increase in response to solving problems involving a carry operation.

3. Anxiety impairs attentional control by increasing the influence of the stimulus-driven attentional system.

Anxiety is related to an increase in the impact of the stimulus-driven attentional system. Dual-task paradigms have demonstrated that, amongst high-anxious individuals, secondary task (infrequently presented in the periphery) performance is negatively affected when a primary task (presented in the centre of the field of vision) is more salient (e.g. Murray & Janelle, 2003). However, when primary task stimuli are as equally salient (or less) than the stimuli in the secondary task then secondary task performance will not be affected (e.g. Dusek, Kermis & Mergler, 1975). Performance may actually be enhanced when a task requires responding to threatening stimuli, because of the preferential attention given to those stimuli, that is, only when a task requires the stimulus-driven attentional system, such as responding to angry faces in a crowd (e.g. Byrne & Eysenck, 1995).

The final experimental study in the current thesis (Chapter Seven), based on an eye-tracking methodology, tests the general hypothesis that maths anxiety is related to a reduction in the goal-orientated attentional system and an increase in the stimulus-driven attentional system, as assessed by measuring a range of eye-movements.

4. Anxiety impairs efficiency (and often effectiveness) on tasks involving the inhibition function, especially with threat-related distracters.

   According to attentional control theory, the efficiency of inhibitory control is reduced in anxious individuals. This occurs in two ways; reduced inhibitory control of prepotent or dominant responses, and (relatively automatic) directed attention towards irrelevant stimuli. These effects will be greater amongst anxious individuals when i) task processing demands are high, and ii) stimuli are threat-related rather than being neutral. The following findings relate to external distracting stimuli, although, according to the theory, internal distracters, e.g. worrisome thoughts, can also direct attention away from primary tasks and impair performance.

i) *Prepotent response inhibition*: Studies using i) paired word associations (e.g. Standish & Champion, 1960) or ii) the Stroop task (e.g. Pallak, Pittman, Heller & Munson, 1975), have demonstrated that, under high stress conditions, anxious individuals perform worse than those under low stress conditions, that is, decreased speed in inhibiting responses that had previously been correct.

ii) *Resistance to Distractor Interference*: Attentional control theory suggests that anxious individuals will attend to distracting stimuli more than will non-anxious individuals. This has been demonstrated using a variety of paradigms: i) Eye-movement studies have shown that off-task eye-glancing or eye-movements towards distracting stimuli are greater amongst anxious individuals (e.g. Janelle, Singer & Williams, 1999). ii) Inclusion of distracting information can reduce performance in anxious individuals, for example Hopko et al.'s (1998) reading task performance as a function of maths anxiety when inhibition of distracting phrases was necessary. iii) The assumption that inclusion of distracting information can reduce performance in anxious individuals seems to be more consistent (and the effects greater) when task demands are high, for example when comprehension tasks are highly demanding or when concurrent task processing is required (e.g. Calvo & Eysenck, 1996).

iii) *Inhibition: Threat-Related Stimuli Versus Neutral Stimuli*: Adverse effects of anxiety on task performance are greater when stimuli are threat-related. This has been observed using i) Emotional Stroop tasks that involve inhibiting a threat-related word in order to attend to the physical colour of it; when words are threat-related anxious individuals take longer to name the colour of the text (e.g. Mogg, Matthews, Bird & MacGregor-Morris, 1990). A longer response time therefore suggests poorer ability to inhibit the threat-related words. ii) Target detection performance as a function of threat-related distracters; response time to identify a target stimulus is longer when distracters are threat-related (e.g. Eysenck & Byrne, 1992). iii) Spatial-cueing paradigm; this is where invalid cues are presented to participants, that is, cues which are presented in a different location to where a target stimulus is to be presented, and participants must disengage from the invalid cue. Fox, Russo and Dutton (2002) found that anxious individuals took longer to disengage from invalid cues when they were threat-related; in this case angry faces. iv) Bishop, Duncan, Brett and Lawrence (2004) provided neurophysiological evidence to suggest that lateral prefrontal cortex activation (associated with attentional control) was lower in anxious individuals in an experimental condition with threat-related distracters, compared to a control condition. Non-anxious individuals actually had increased activation in the lateral prefrontal cortex during the experimental condition. They suggested a lack of top-down control over threat-related distracters amongst individuals high in state anxiety.

Based on hypothesis four above, the study reported in Chapter Six of this thesis tests the assumption that maths anxiety is related to a pre-occupation with task-related intrusive thoughts and this may explain the relationship between maths anxiety and task performance.

5) Anxiety impairs processing efficiency (and often performance effectiveness) on tasks involving the shifting function.

According to attentional control theory anxiety will impair performance efficiency and often effectiveness when task switching is required.

i) *Task Switching*: Several findings (e.g. Goodwin & Sher, 1992; Santos & Eysenck, 2006) show that anxious individuals take longer on tasks involving task switching, for example the Wisconsin Card Sorting Task. Research has also demonstrated that in tasks involving shifting anxious individuals showed greater brain activation in areas known to be important in relation to the central executive (Santos et al., in preparation).

ii) *Prospective Memory*: Prospective memory requires task switching. Anxious individuals have been shown to have poorer prospective memory (e.g. Cockburn & Smith, 1994), particularly when the primary task is demanding (Harris & Menzies, 1999; Harris & Cumming, 2003). This suggests a deficit in attentional control amongst anxious individuals where anxiety causes adverse effects on the goal-oriented attentional system.

6) Anxiety impairs processing efficiency (and sometimes performance effectiveness) on tasks involving the updating function only under stressful conditions.

Updating can be assessed by testing reading span and operation span. These require recalling the last words from sentences (reading) or arithmetic problems (operation). Span tasks are different to other tasks assessing inhibition and switching in that they focus on memory rather than ongoing processes, and rehearsal or grouping processes are prevented by task demands, for example reading comprehension or arithmetic problem solving. Span tasks also place few demands on attentional control. Several studies have shown that anxious individuals perform more poorly than non-anxious individuals on span tasks under stressful conditions (e.g. Darke, 1988a). However, studies have also shown no effect of anxiety on span performance (e.g. Santos & Eysenck, 2005).

In sum, whilst processing efficiency theory (Eysenck & Calvo, 1992) and attentional control theory (Eysenck et al., 2007) both focus on the central executive component of the working memory model in terms of explaining anxiety effects on cognitive processing, attentional control theory refers to specific aspects of the central executive, that is, shifting and inhibition, in explaining anxiety effects. In particular it postulates that anxiety increases the influence of the stimulus-driven attentional system and that anxiety adversely affects processing efficiency (and sometimes performance) by a combination of impaired attentional control and preferential processing of threat-related stimuli. According to attentional control theory, distracting stimuli can be external or internal (worry) and threat-related stimuli are associated with poorer processing efficiency than neutral stimuli are. Eysenck et al. refer to several empirically tested effects that suggest that anxiety disrupts the functioning of the goal-oriented attentional system in terms of: i) reduced ability to inhibit incorrect prepotent responses, ii) increased susceptibility to distraction, iii) impaired performance on secondary tasks when dual-task performance is required, and iv) task switching performance is impaired.

There have been recent updates to attentional control theory (Eysenck & Derakshan, in press) since the completion of the studies that form the current thesis. Consequently, within the General Discussion, the findings of the studies will be discussed in light of these updates.

2.6 Supporting empirical evidence

Empirical work has focused on general anxiety and Elliman, Green, Rogers and Finch (1997) report research findings in support of processing efficiency theory. They separated participants into three groups classified as low, medium and high anxiety based on anxiety scores obtained using the Hospital Anxiety and Depression Scale (HADS, Snaith & Zigmund, 1994). Performance was then measured across tasks of sustained attention, response time and motor speed (tapping). Elliman et al. found that number of errors did not vary across task type. However, they did observe that high anxious individuals took longer to respond on the sustained attention task, with no difference in response time observed between anxiety groups on the response time and motor speed tasks. The authors explain their results in terms of processing efficiency, whereby the high anxious group attempted to maintain sufficiently high performance effectiveness by increasing the amount of time spent on the task, that is, with the consequence of reduced performance efficiency. In addition, Elliman et al. point to the possibility that such performance inefficiency among high anxious individuals may be the result of the presence of pre-occupying worry-related cognitions. In addition, however, they acknowledge the issue of identifying such cognitions. In support of their explanation, though, they note that anxiety was found to be significantly positively correlated with the Tension, Worry and Bodily Symptoms sub-scales of the Reactions to Tests scale (RTT, Sarason, 1984), suggesting a correlation between anxiety and worry and emotionality. However, such measures still fail to adequately address assumptions surrounding preoccupation with worry-related cognitions. That is, it would have been beneficial to include measures that explicitly test the self-reported existence of in-task intrusive thoughts and also participants' perception of how such thoughts interfered with task performance.

Evidence for a relationship between working memory capacity and suppression of intrusive thoughts comes from Rosen and Engle (1998). They found that individuals with a high working memory capacity (operation span) produced fewer intrusions and also performed better than individuals with a low working memory capacity on a paired-associate learning task. In addition to this, those with a high working memory capacity were better able to suppress intrusive thoughts, suggesting that intrusive thoughts are more likely to negatively impact on performance among those with a low working memory capacity. Whilst Rosen and Engle's findings do not necessarily indicate a reduction in working memory capacity as a result of intrusive thoughts, the results do lend support to the general assumption of processing efficiency theory (Eysenck & Calvo, 1992) and attentional control theory (Derakshan et al., 2007) that performance may be affected by an interaction between working memory processes and experience of intrusive thoughts. More recently, Brewin and Beaton (2002) presented evidence for the prediction of inhibition of intrusive thoughts as a result of greater working memory capacity. They found that greater working memory capacity was associated with better ability in suppressing thoughts related to a specified phrase.

Crowe, Matthews and Walkenhorst (2007) investigated the effects of worry on working memory performance in 61 adults in Australia. In addition to a measure of general worry frequency, they also took measures of self-reported thought suppression. On both of the central executive tasks used Crowe et al. found that worry significantly predicted task performance, with higher levels of worry related to poorer performance.

Contrary to expectations, though, they observed no relationship between worry and verbal task performance. They concluded that worry may not be a simple verbal process, but may tap into the central executive component of working memory, with increased thought suppression predicting higher levels of performance.

In a study of attentional resources and intrusive thoughts, Yee, Hsieh-Yee, Pierce, Grome and Schantz (2004) conducted a study concerned with task-related thoughts that involve self-evaluation and the influence they may have on search performance on the internet. They asked participants to respond to statements such as "I thought about how poorly I was doing" and "I thought about how much time I had left". Results showed that self-evaluative intrusive thoughts significantly predicted internet search performance. In particular, a greater frequency of task-related intrusive thoughts predicted slower search times and fewer correctly identified web sites. In opposition to this, Yee et al. found that performance was not predicted from task-irrelevant thoughts, even though such thoughts were reported more frequently than task-related thoughts, thus emphasising the importance of the content of thoughts rather than simple frequency. According to Yee et al., such self-regulation involved in the suppression of task-related intrusive thoughts involves a switching of attentional resources and results in an increase in overall effort.

Murray and Janelle (2003) recorded visual search rate and driving performance between low and high trait-anxious groups in a driving simulation task. In addition, a further task was later introduced in which participants' reaction time to peripherally presented target lights was measured. Results showed little change in performance effectiveness on the driving simulation task between the anxiety groups, but reaction times to the target lights were longer among the high anxious individuals, suggesting that dual-task performance affected processing efficiency. Analysis of visual search rate provided a method of supporting claims regarding processing efficiency, with the expectation that high anxious individuals would make more fixations during the task. Murray and Janelle's results provide some support for this, with both anxiety groups showing an increase in the number of fixations made. More research is needed in order to fully understand potential links between anxiety and visual search as a tool for assessing processing efficiency. There have been several studies that have used saccade-based tasks to directly investigate the utility of eye-tracking as a correlate of attentional control and inhibitory processes (Derakshan & Koster, in press; Nieuwenhuis, Broerse, Nielen & de Jong, 2004; Massen, 2004; Ansari, Derakshan & Richards, 2008; Cherkasova, Manoach, Intriligator & Barton, 2002; Derakshan, Ansari, Hansard, Shoker & Eysenck, 2009) and these will be discussed in more detail in Chapter Seven.

Recently, in a direct test of Eysenck et al.'s (2007) attentional control theory, Hayes, MacLeod and Hammond (2009) tested participants' performance on a demanding rule-based learning task and a less demanding family-resemblance learning task. In addition to this, participants were tested under either incidental or intentional learning conditions. They found that high anxious individuals, relative to low anxious individuals, performed disproportionately poorly on the capacity-dependent rule-based task compared to the capacity-independent family-resemblance category task. Further to this, this anxiety-linked performance effect was only present under incidental learning conditions and was eliminated under intentional learning conditions in which participants were aware of the learning objective of the task. Hayes et al. explain their finding in terms of attentional control and in particular Eysenck et al.'s prediction that increased effort among high anxious individuals can lead to an attenuation of an anxiety-linked performance decrement, thus lending support towards attentional control theory.

Dugas, Letarte, Rheaume, Freeston and Ladouceur (1995) gave participants a set of questionnaires measuring worry and problem solving abilities in terms of skill on the one hand and orientation on the other. That is, the ability to solve a problem including the relevant skill set, but also measures of the way in which an individual approaches a problem, such as the immediate cognitive-behavioural-affective response to a problematic situation. They found that, contrary to expectations, worry was not related to actual problem solving skills, such as articulating goals, generating solutions and implementing solutions. Worry was, however, significantly related to problem orientation, such as perceived confidence in ability to solve a problem, level of personal control and generally perceiving a problem as a threat. Specifically, increased worry was related to lower personal control, although it is not clear what control exactly refers to. Also, increased worry was related to a more negative-affective response upon facing a problem. Dugas et al. propose that the findings may suggest that when individuals perceive a problem as a threat it may impede their attempts at defining the problem in an operational way. They suggest it may also discourage individuals from actually generating solutions and could even keep them from making a decision. This general worry-problem orientation relationship could be useful in explaining findings in more specific domains, such as the relationship between maths anxiety and performance.

Turning to maths anxiety, Hopko et al. (2005) studied maths anxiety in 100 undergraduate students in the U.S. Specifically, they were interested in the relationship between various forms of anxiety on performance on a series of attentional tasks, including two subtests of the Wechsler Adult Intelligence Scale – Third Edition (WAIS-III; Wechsler, 1997), the Golden (1994) version of the Stroop task, and the Paced Auditory Serial Addition Task computer version (PASAT-C; Lejuez, Kahler & Brown, 2003). Hopko et al. found that test anxiety accounted for the most variance in predicting performance on the WAIS-III subtests of letter-number sequencing and digit span and that trait anxiety and fear of negative evaluation accounted for the most variance in Stroop task performance. Importantly, results showed that maths anxiety was the best predictor of PASAT-C scores. This is pertinent because the PASAT-C distinguishes itself from the other tasks as a computation task, so it is clear to see how maths anxiety may be related to that specific facet of attention. Hopko et al. explain this finding in terms of processing efficiency theory (Eysenck & Calvo, 1992) and this can be partly understood in terms of the significant positive correlation they observed between maths anxiety and fear of negative evaluation. For example, it is possible that intrusive thoughts such as this reduced the processing resources available to efficiently perform the task.

As noted in Chapter One, Hunsley (1987), in part, explored the role of internal dialogue in relation to the cognitive processes involved in maths anxiety. Hunsley observed that self-reported negative internal dialogue during a maths exam was significantly positively correlated with maths anxiety. Specifically, negative internal dialogue during maths performance accounted for 15% unique variance in maths anxiety scores, providing support for a cognitive theory of maths anxiety based on negative internal dialogue and cognitive interference. However, unfortunately, performance efficiency was not assessed and results showed that achieved grades were not predicted from maths anxiety. Therefore, further study is needed to investigate the role of negative internal dialogue in relation to performance efficiency. It may also be important to differentiate frequency of intrusive thoughts from self-reported impact of such thoughts.

While the current thesis is not concerned with an investigation of models of mathematical cognition per se, the links between maths anxiety and mental arithmetic performance do draw on the influence of working memory in explaining certain aspects of mathematical cognition in relation to maths anxiety. As outlined in Ashcraft's (1995) review, there is now substantial support for the role of working memory in mental arithmetic. More recently, Furst and Hitch (2000) investigated the roles of the phonological and executive components of working memory in mental arithmetic, specifically mental addition. Related to the current thesis, they highlight carrying and borrowing within mental arithmetic and in particular these can be seen as being of special interest because of the interruption to the normal sequence of operations they can cause. Further to this, the use of carrying or borrowing within mental arithmetic may involve inhibiting the tendency to continue a calculation sequence, thus requiring supervisory attentional control. Furst and Hitch presented participants with three-digit addition problems that included either zero, one or two carries. On trials involving carrying, participants performed significantly worse (more errors and longer response times) when mental arithmetic was performed at the same time as a task designed to draw on executive processes involved in switching, therefore emphasising the role of the central executive in carrying.

Ashcraft & Kirk (2001) suggest that maths anxiety effects on arithmetic performance can be explained in terms of Eysenck and Calvo's (1992) processing efficiency theory. Ashcraft and Kirk suggest that individuals already high in maths anxiety use a substantial amount of working memory simply caused by the anxious reaction to arithmetic. Therefore, a task involving complex arithmetic, particularly incorporating a carry operation, is likely to result in poor performance. Indeed, the findings of Kirk & Ashcraft showed that a high working memory load (maintaining a string of six random letters for later recall) caused poorer performance among a high maths anxious group compared to a low maths anxious group. However, when the memory load was reduced to two letters performance was hardly differentiated between anxiety groups. The findings therefore suggest that working memory capacity was exceeded among the high anxious group when a large memory load was introduced, potentially because the high maths anxious group had already largely consumed working memory resources. A series of studies set out by Ashcraft and Kirk (1998) demonstrated that, firstly, working memory capacity decreased as a function of maths anxiety, and secondly, recall time and accuracy of transformations in a secondary working memory task were worse as a function of maths anxiety. Therefore, maths anxiety may consist of worries that are consuming an already almost-full working memory capacity, thus having a negative impact on performance.

2.7 Conclusion to Chapter Two

This chapter has introduced some of the mechanisms previously considered to underpin the relationship between maths anxiety and maths performance. Research evidence has suggested that manipulating time pressure has little effect on low and high maths anxious groups differentially (Kellogg et al. 1999). Further evidence suggests that physically induced anxiety failed to differentially affect performance across low and high maths anxious groups (Hopko et al. 2003). Thus, attempts to manipulate the components thought to constitute maths anxiety have failed to help explain why high maths anxious individuals perform more poorly than individuals low in maths anxiety. In addressing a deficient inhibition approach to maths anxiety effects, researchers have also failed to provide convincing evidence for the argument that maths anxious individuals experience problems inhibiting anxiety-inducing stimuli that may interfere with effective task performance (Hopko et al. 1998; Hopko et al. 2002). However, as noted earlier, there are several factors to consider before accepting these findings at face value. Despite the limited number of attempts at exploring the effects of manipulating maths anxiety in an experimental setting, several studies have found a negative relationship between maths anxiety and performance, particularly on those problems that involve a carry operation. Such studies have also consistently demonstrated that maths anxiety is related to longer response times more than increasing error rates (e.g.

Ashcraft & Kirk, 2001). Processing efficiency theory (Eysenck & Calvo, 1992) is typically used to explain such effects, emphasising the interfering effect of anxiety on the efficiency of task performance, particularly in relation to the consumption of working memory resources by worry. The recent update to processing efficiency theory, attentional control theory (Eysenck et al. 2007) may also be useful in explaining the relationship between maths anxiety and performance. Based on the information provided here, the next Chapter will describe the main aims of the current thesis and the methodologies it will adopt.

CHAPTER THREE

3. Thesis aims and methodologies adopted

As discussed in Chapter One, previous research findings suggest that maths anxiety may mask an individual's true maths ability (Hembree, 1990). Consequently, in measuring the relationship between maths anxiety and performance, studies have tended to limit the mathematical stimuli used to either addition or multiplication problems (e.g. Faust et al., 1996). This has enabled researchers to more easily classify maths problems as difficult or easy in terms of the processing demands they require and helps ensure researchers are testing effects of maths anxiety rather than general maths competence. In the studies outlined in chapters four, six, and seven of this thesis, performance is assessed on addition problems. In particular, two-digit addition problems are used and these are separated according to the inclusion of a carry operation or no carry operation. It is the manipulation of number of digits (Imbo et al., 2007) and inclusion of a carry term (Furst & Hitch, 2000; Imbo, De Rammelaere & Vandierendonck, 2005) that provides a method for assessing the working memory demands on problem solving.

The overarching aim of the current thesis is to empirically investigate possible mechanisms underpinning the relationship between maths anxiety and performance. More specifically, the thesis is concerned with performance according to the processing demands of the problems presented in an experimental setting, that is, whether performance is differentially affected by the inclusion of a carry term in two-digit addition problems. According to previous research, it can be assumed that an overall maths anxiety effect on performance will emerge, such that performance will be poorer amongst those who are high in maths anxiety, but also that this relationship will be greater on those problems that involve a carry operation (e.g. Faust et al., 1996; Ashcraft & Kirk, 2001).

A second major assumption across studies is that maths anxiety will be related to processing efficiency more than performance effectiveness, an assumption proposed by processing efficiency theory (Eysenck & Calvo, 1992) and attentional control theory (Eysenck et al., 2007) in explaining general anxiety effects on processing. As predicted by these theories, there is less consistency in findings related to maths anxiety and number of errors made on maths tasks, but a more consistent finding is that maths anxiety is positively correlated with response times, particularly to those problems that include a carry term (e.g. Faust et al., 1996).

The current thesis includes three experimental investigations based on different methodologies designed to assess some possible theoretical explanations for the previously observed relationship between maths anxiety and performance. There are currently no studies that have investigated neuropsychological correlates of maths anxiety. Accordingly, in an initial study (see Chapter Four), event-related potentials will be recorded and investigated in the frontal region of the cerebral cortex, that is, the region that is typically regarded as being closely associated with working memory processes (Miyake & Shah, 1999), to assess whether event-related potentials vary as a function of maths anxiety. Such evidence may therefore provide some insight into the role of working memory with regard to the relationship between maths anxiety and performance, particularly in relation to performance on problems that require more working memory resources to solve, that is, those involving as carry operation, compared to those that do not require a carry operation. This study therefore examines a possible neuropsychological basis for maths anxiety effects.

The next experimental study (see Chapter Six) is a direct attempt at exploring the suggestion that cognitive intrusions may play an important role in explaining the effect of maths anxiety on performance (Hunsley, 1987; Ashcraft & Kirk, 2001). In particular, a methodology will be employed whereby participants report on cognitive intrusions experienced during problem solving. A modified version of the Cognitive Intrusions Questionnaire (Freeston, Ladouceur, Letarte, Thibodeau, & Gagnon, 1991) will be used and this allows for an investigation of the relationship between specific thoughts and performance, along with a study of the influence of measures of perceived influence, such as the extent to which intrusive thoughts impeded participants' ability to calculate the presented problems. Self-reports of experiences of cognitive intrusions have rarely been used in previous studies of maths anxiety. However, where they have been used the findings suggest they are a useful tool in investigating maths anxiety and maths performance (see e.g. Hunsley, 1987, reported in Chapter Two). The self-reporting of cognitive intrusions and maths anxiety provides the data to test the hypotheses pertaining to whether maths anxiety moderates the relationship between intrusive thoughts and maths performance.

The final experiment employs an eye-tracking methodology. This provides a method of precisely measuring eye-movement and, as will be discussed in Chapter Seven, this methodology gives some insight into mental operations being performed (Suppes, 1990; Grant & Spivey, 2003). Eye-tracking has previously been used to investigate mental processes specifically in response to mental arithmetic (Green, Lemaire & Dufau, 2007) but has not been used in an attempt to explain maths anxiety effects on maths performance. Also, as discussed in Chapter Seven, an eye-tracking methodology has previously successfully been employed across various studies that have investigated attentional control processes on task performance (e.g. Hermans, Vansteenwegen & Eelen, 1999). Therefore this provides a novel way of assessing that relationship in the context of maths anxiety, enabling the testing of hypotheses pertaining to the potential moderation of the relationship between eye-movement and performance by maths anxiety.

Whilst the above methodologies could be viewed as being mutually exclusive in terms of the measures that are taken, each address key approaches in developing a greater understanding of the mechanisms underpinning the relationship between maths anxiety and maths performance. In addition, following on from the initial EEG study, the second and third experimental studies represent specific ways of addressing the overall hypotheses that the relationship between maths anxiety and performance can be explained with regard to reduced processing efficiency and attentional control. Indeed, the laboratory settings in which participants will be tested in each of the experiments will provide a controlled environment that minimises extraneous and confounding factors. A further methodological point to note that is consistent across experimental studies presented in this thesis is that maths anxiety scores are not reduced to produce groups, for example low or high maths anxiety. There are two reasons for this decision: i) there is no theoretical basis for creating maths anxiety groups based on continuous scores. That is, there is no evidence to suggest cut-off points for classifying individuals according to various levels of maths anxiety, and ii) reducing continuous variables to groups can lead to a reduction in statistical power (Cohen, 1983; MacCallum, Zhang, Preacher & Rucker, 2002; Royston, Altman & Sauerbrei, 2006).

As discussed in more detail in Chapter Five, a further study developed out of a potential problem with the validity of the current, North American-based, maths anxiety scales. As such, as part of the current thesis a new maths anxiety scale has been developed and provides i) a useful tool for measuring maths anxiety among participants in the final two experimental studies, and ii) some much needed normative data on maths anxiety in a U.K undergraduate population. Finally, in response to the mixed findings regarding gender differences in maths anxiety reported in past research (see Chapter One), the studies reported in this thesis will address this by comparing self-reported maths anxiety between males and females.

As noted above, the overall aim of the current thesis is to empirically investigate possible mechanisms underpinning the relationship between maths anxiety and performance from a processing efficiency and attentional control perspective. This will be achieved using methodologies including electroencephalogram, self-reported cognitive intrusions, and eye-tracking. All hypotheses are listed below. Hypotheses that pertain to performance all relate to performance on verification tasks involving two-digit addition.

General hypotheses:-

i) Maths anxiety will be positively related to response time when solving two-digit addition problems.
ii) The relationship between maths anxiety and response time will be greater in response to problems that involve a carry operation compared to those that do not.
iii) There will be a relationship between maths anxiety and percentage of errors when solving two-digit addition problems.
iv) The relationship between maths anxiety and gender will be explored in a U.K sample.

Study one: Are there neuropsychological correlates of maths anxiety? (Chapter Four)

i) In the time period preceding a proposed solution slow wave event-related potential negativity will increase as a function of problem difficulty.
ii) Maths anxiety will be positively related to event-related potential amplitude in response to problems involving a carry operation.

iii) Any maths anxiety effects will be observed in the frontal brain region.

Study two: The development and part-validation of a new scale for measuring maths anxiety in a U.K undergraduate population (Chapter Five)

i) Several psychometric properties of a newly developed scale for measuring maths anxiety in a U.K undergraduate population will be tested.
ii) Maths anxiety will be explored across academic subject areas.

Study three: Explaining the relationship between maths anxiety and performance: An exploration of the role of cognitive intrusions (Chapter Six)

i) There will be a positive relationship between self-reported impact of in-task intrusive thoughts and performance.
ii) As maths anxiety and self-reported impact of intrusive thoughts increase together performance will decrease.
iii) Maths anxiety will be positively related to self-reported effort to reduce the impact of intrusive thoughts.
iv) Maths anxiety will be positively related to increased self-reported effort in reducing the impact of intrusive thoughts, to which response time will increase.
v) Maths anxiety will be positively related to increased self-reported effort in reducing the impact of intrusive thoughts, to which percentage of errors made will decrease.

Study four: Explaining the relationship between maths anxiety and performance: An eye-tracking approach (Chapter Seven)

i) Maths anxiety will be positively related to dwell-time on the tens digits of a proposed arithmetic problem, to which response time will be longer.
ii) Maths anxiety will be positively related to fixations on the tens digits of a proposed arithmetic problem, to which response time will be longer.
iii) Maths anxiety will be positively related to the number of saccades made across a proposed arithmetic problem, to which response time will be longer.
iv) Maths anxiety will be positively related to eye movements between the proposed solution and the digits that form the proposed problem, to which response time will be longer.
v) The hypothesised effects noted above are likely to be greatest in response to problems that involve a carry operation.

CHAPTER FOUR

4. Are there neuropsychological correlates of maths anxiety?

4.1 Introduction

The study reported in this chapter examines the relationship between event-related potentials and maths anxiety. Neuroimaging and EEG techniques have proved to be useful methods of depicting the way in which cognitive processes and emotions are activated. As Miyake and Shah (1999) note, the pre-frontal cortex, a part of the brain known to be integral to the working memory system, has been shown to be closely connected to parts of the brain associated with the processing of emotions, in particular the amygdala (LeDoux, 1996). Other studies have shown dorsolateral prefrontal cortex activation during maintenance and retrieval of information, suggesting its importance in organizing processes involved in working memory (Rypma, Berger & D'Esposito, 2002; Postle, Berger, Taich & D'Esposito, 2000; Owen et al., 1999; D'Esposito, Postle, Ballard & Lease, 1999). Also, task switching has been found to show prefrontal cortex activation (Smith et al., 2001).

Closely linked to the working memory system is mental calculation (Hitch, 1978b). Jackson and Warrington (1986) report the high correlation (0.6) between digit span and simple arithmetic in 100 normal adults, suggesting an involvement of working memory in simple arithmetic. There is also a wide range of studies, using advanced technological neuroimaging techniques, that have investigated this link (e.g. Zago et al., 2001). In more recent years, such techniques have been used to consider the links between working memory and emotion, and working memory and mathematical processing. To date, though, no research has used neuroimaging or EEG techniques to consider the relationship between emotion and mathematical processing from a working memory perspective.

After initial consideration of the specificity of mathematics and "number sense" in the brain, this chapter will consider how neuroimaging techniques, along with electroencephalogram and event-related potentials (ERPs), have been used in studies of cognition and emotion, beginning with those investigating neurological mechanisms underpinning mathematical cognition, in particular mental arithmetic. Finally, an outline of research into anxiety and cognitive performance using ERPs will be given. This will introduce the main aim of the current study; attending to Ashcraft's (2002) request that "We need research on the origins of math anxiety and on its 'signature' in brain activity, to examine both its emotional and its cognitive components" (p. 181).

4.2 A neurological basis for mathematics

Butterworth (1999) hypothesises a "number module", that is, an automatic brain mechanism that identifies numerosities. A numerosity, according to Butterworth, is the number you get when you count a collection. A simple example is the use of fingers on a hand as a collection that represents a numerosity of five. Butterworth suggests that our ideas of number are based on numerosities and the relations among them. For example, we know that to add the sum of two sets of numbers we need to include the two numerosities together. The fact that one set may be larger in numerosity than the other is irrelevant because it is the unification of the two which is important.

Early work by Henschen (1920, in Butterworth, 1999) suggested that there was an independent sub-system within the brain responsible for arithmetic. This was determined after Henschen studied data on 260 neurological patients with disturbances to their numerical abilities, concluding that arithmetic is separate from other cognitive processes, such as speech or music.

Within the past few decades there have been many studies that highlight the role of specific brain regions in numerical ability. For example, Cipolotti, Butterworth and Denes (1991) report the case of a stroke victim who had selective impairment of arithmetic for numbers greater than 4. She had normal to good language and reasoning abilities, even to the extent of answering questions regarding quantity, for example 'which is heavier, a kilo or a gram?'. Her general knowledge for facts was also very good. However, when asked to count to numbers greater than 4, she was forced to stop after 4, simply not knowing what comes next. She was also unable to subitize when there were more than two items or objects in view. If given a number, such as 20, she was only able to say it was greater than 4 because it did not belong to the small amount of numbers she did know. If given two numbers outside her range of 1 to 4, she was unable to state which of the two numbers was the smallest or largest. The patient had damage to the left fronto-parietal site of the brain, assessed using MRI, and was one of the first cases to be reported regarding acalculia and specific brain damage.

Rossor, Warrington and Cipolotti (1995) report the case of a patient who presented with the degenerative Pick's disease affecting the left temporal lobe and possibly the left frontal lobe, thus deeply affecting his language abilities. He was only able to utter a few phrases and was almost completely unable to understand speech or written language. However, his calculation abilities were still more or less intact. He was able to accurately add and subtract and was able to select the larger of two presented three-digit numbers. This is an important case as it is one of the first to suggest that there is a separate brain area responsible for calculation, and this may be distinct from language or reasoning capacities within the brain; therefore providing evidence of a 'number module', as Butterworth (1999) argues. However, the exact brain area responsible for calculation was still not certain from Rossor et al.'s findings. Some insight into this came from a study reported by Delazer and Benke (1997) who describe the case of a patient with brain damage to the left parietal lobe. She had intact language abilities, as well as being accurate on tests of multiplication. However, the interesting fact is that she had severely impaired addition performance. Even when given basic addition problems to solve her performance was extremely poor. It appeared that her knowledge of addition, that is, what to do to gain the sum of numbers (additive composition) was practically non-existent. The brain damage, then, appeared to have only affected number knowledge for addition, and spared the rote-rehearsed facts for multiplication, suggesting a potential fragmentation of a 'number module'.

Warrington and James (1967) provide evidence to suggest that only the most basic arithmetic is represented in both hemispheres, with right parietal lobe damage affecting subitizing in some cases. In the case of subitizing though, one could argue that subitizing involves greater visual awareness or increased processing in the visual domain than other types of arithmetic, thus needing the involvement of the right hemisphere. Butterworth (1999) describes the case of a patient with post-stroke damage to the left hemisphere, affecting his speech, but not his understanding of speech. He had a very poor digit span of two digits, suggesting severely impaired short-term memory. It was therefore expected that, when given arithmetic problems to solve, his performance would be extremely poor due to his restricted digit-span. However, his arithmetic ability was actually very good, even correctly answering addition problems involving three-digit addends. Butterworth points out that he and his colleagues came to the conclusion that arithmetic prompts the use of specialised verbal coding within short-term memory.

Studies have shown that patients with neurological damage can have quite specific deficiencies in operational procedure in arithmetic. For example, deficiencies in the carrying procedure alone or combining elements of both multiplication and addition when only one is required (Caramazza & McCloskey, 1987), or consistently making erroneous subtractions due to a deficient subtraction procedure (Girelli & Delazer, 1996). Furthermore, memory for arithmetic facts can be disturbed, as in the case of one of Warrington's (1982) patients who appeared to have an access deficit, sometimes recalling facts, other times not. Moreover, evidence from other case studies suggests that numerals activate distinct brain circuits and are processed perhaps separately to words or letters. For example, Cipolotti (1995) reports the case of a patient in the early stages of Alzheimer's disease who was able to read aloud written numbers, for example "twenty", but could not read aloud numerals of two-digits or more, for example "20". Another patient presented with left parietal lobe damage. He could also read written numbers but not numerals of two-digits or more (Cipolotti, Warrington, & Butterworth, 1995). Similarly, Anderson, Damasio and Damasio (1990) showed how a patient was able to read and write numbers in numerical format but unable to read and write words generally. These examples all suggest that arithmetical processing is separate to other types of processing and provide support for the concept of mathematical cognition as a unique cognitive domain; as such research highlights the potential usefulness of neuroimaging techniques to explore mathematical processing in the brain.

4.3 Neuroimaging/electroencephalography and mathematical processing

Dehaene, Piazza, Pinel and Cohen (2003) outline three parietal circuits for number processing: the horizontal segment of the intraparietal sulcus (HIPS), the left angular gyrus and the posterior superior parietal lobe, each of which has much supporting research evidence. Dehaene et al. point out that the HIPS is activated in response to a variety of number processing tasks, particularly those requiring access to semantic representation of the numbers. Therefore, they suggest that the way the HIPS is employed is perhaps analogous to a mental "number line" which forms a spatial representation of number. Dehaene et al. also note that the HIPS seems to be active whenever an arithmetic operation that requires a quantitative representation is needed, for example actual calculation over simple reading of numbers (Pesenti, Thoux, Seron & De Volder, 2000; Rickard et al., 2000), comparing two numbers (Le Clec'H et al., 2000; Pesenti et al., 2000), and even when an individual is unaware that they have seen a number symbol via presentation of masked (Dehaene, Naccache, Le Clec'H, Koechlin, Mueller et al., 1998b) or subliminal (Naccache & Dehaene, 2001) numerical primes. Despite these findings, others have found that activity in the HIPS was modulated by processes other than number magnitude processing (Knops, Nuerk, Fimm, Vohn & Willmes, 2006).

There is much neuroimaging evidence that emphasises left lateralisation of the angular gryus in number processing, in particular those tasks that place greater emphasis on verbal processing. For example, in an fMRI study, Simon, Mangin, Cohen, Le Bihan and Dehaene (2002) found the left angular gyrus to be the only parietal area to show overlapping activation on a calculation task and a task involving phoneme detection. Interestingly, the left angular gyrus also appears more active in response to small problems (sum below 10) than large problems (Stanescu-Cosson et al., 2000). Dehaene, Piazza, Pinel and Cohen (2005) suggest this latter finding is likely to be due to how such small numbers are stored in rote verbal memory. They make a final point that the left angular gyrus seems related to the linguistic basis of arithmetical computations, but its role seems specific to the retrieval of arithmetic facts, rather than other, more complex, calculations, such as subtraction. Of particular interest in the study of localisation of arithmetic processing in the brain is the posterior superior parietal system (PSPL). This is because, as Dehaene et al. point out, it appears to be related to both number processing and attention orienting, evidence of which comes from studies such as Gobel, Walsh and Rushworth (2001) in which they found a negative effect of magnetic stimulation of dorsal posterior parietal sites on performance on a visual search task. Similarly, stimulation of the same area reduced performance on a number comparison task.

Zago et al. (2001) conducted a PET study on six participants performing arithmetic (simple and complex multiplications problems) and language (reading) tasks. Results of the PET indicated activation of certain areas specific to the task undertaken. For example, those areas activated in response to calculation of more complex multiplication problems (as opposed to simple fact retrieval of single digit multiplication) included the left superior frontal gyrus, the anterior part of the right intraparietal sulcus, the superior part of the supramarginal gyrus, the bilateral inferior and middle occipital gyri, the bilateral fusiform gyri, and the right cerebellar vermis. Indeed, basic fact retrieval failed to produce activation in parts of the language areas (Broca's area and Wernicke's area). The authors conclude that some of the areas activated in response to complex calculation are also those areas involved in visuo-spatial working memory. In particular, those areas appear to form what they refer to as a "finger counting circuit", implementing the role of visuo-spatial working memory in more complex mental arithmetic. However, it is not known whether participants actually physically used a finger-counting strategy. It is also difficult to generalise to other problem types, such as addition. Participants reported using mental imagery to transpose parts of the problems presented, from horizontal to vertical (presumably due to the way in which the calculation of such problems was taught at school), possibly providing some explanation for the activation in areas known to be implemented in visuo-spatial working memory.

In another PET study, Houde and Tzourio-Mazoyer (2003) compared brain activation in response to a task involving reading digits and a task involving actual arithmetic computation. They found that compared to the reading task, the arithmetic task produced bilateral parietofrontal activation, suggesting employment of working memory resources. Also, Gruber, Indefrey, Steinmetz and Kleinschmidt (2001) found greater fMRI activation in left inferior frontal areas in response to mental arithmetic compared to control tasks. Finally, Menon, Mackenzie, Rivera and Reiss (2002) also found fMRI activation in the dorsolateral and ventrolateral prefrontal cortex regions in response to mental arithmetic. This indicates that mental calculation occurs in areas known to subserve working memory.

To summarise, neuroimaging and EEG techniques have been highly useful tools for investigating neuropsychological correlates of arithmetical processes. In particular, such research has highlighted the involvement of working memory in mental arithmetic by noting activation of brain regions known to be related to working memory processes. One, more specific, tool for studying arithmetic and also working memory processes is described below, and introduces the methodology implemented in the current study.

4.4 Event-related potentials and mathematical processing

Research has shown that event-related potentials can give some indication of the higher-order processes involved in mental arithmetic. Pauli et al. (1994) studied ERPs of participants in response to single digit multiplication problems after practice and when problem difficulty (problem size) was increased. It was found that ERPs were characterized by a late P3-like component. The following late positive slow wave was concentrated in the frontal areas, suggesting conscious calculation (further supported by Pauli, Lutzenberger, Birbaumer, Rickard & Bourne, 1996). It was also found that parietal positivity was unaffected by practice. Pauli et al. suggest that this may reflect simple fact retrieval, with little need for increased effort. Whalen, McCloskey, Lesser and Gordon (1997) report a case study of a participant whose performance on simple arithmetic was impaired when a left parietal site of the cortex was stimulated to cause transitory disruption of brain activity, suggesting that this region is important for fact retrieval. Iguchi and Hashimoto (2000) provide strong evidence in support of ERP slow waves being reflective of the calculation process in mental arithmetic. In a verification task they presented 15 participants with three tasks: a number task in which participants were required to simply count the number of digits presented, a more complex calculation task in which participants were required to add a series of presented single-digits, and a comparative counting task in which participants were presented with meaningless patterns. A positive slow wave was only elicited in response to the adding task where subsequent digit presentation initiated the calculation process. Indeed, without the adding task, baseline levels of the ERPs were quickly reached. In Pauli et al.'s (1994) study, the offset latency of the positive slow wave was proportional to the difficulty level of the calculation problems presented, thus providing further support that slow waves reflect mental calculation processes. Importantly, in Iguchi and Hashimoto's study, the slow wave was restricted to frontal regions in the time window leading to the presentation of the next digit in the sequence. The time-course of the slow wave therefore suggests that the frontal region is involved in mental arithmetic. More specifically, the enhanced positive slow wave restricted to the frontal region is consistent with previous studies that have found this effect in response to temporary maintenance of information in working memory generally (e.g. Monfort & Pouthas, 2003). Thus, it may appear that in Iguchi and Hashimoto's study, the frontal slow wave effect may be indicative of the temporary maintenance of numerals just prior to when a proposed solution is given in a verification task. A further interesting finding by Iguchi and Hashimoto was that frontal activity was delayed and prolonged when the time interval of the digit presentation increased. They suggest this is further evidence that the slow waves reflect maintenance of numerical information until the presentation of the next digit (or proposed solution).

Jost, Beinhoff, Henninghausen and Rosler (2004) presented multiplication problems with varying difficulty (increasing in size) and observed a slow negative wave following a late positive peak after presentation of a second operand. Further, they observed that large problems evoked a more negative slow wave. They suggest that the increase in negativity in the slow wave is reflective of an increase in mental load for large (more difficult) problems. In particular, they also found more substantial slow wave negativity over the central-frontal area FZ in response to more difficult problems. P300 amplitude on the other hand did not vary as a function of problem difficulty. Jost et al. conclude that the frontal region may therefore be indicative of the implementation of working memory processes when memory load increases.

Núñez-Pena, Cortinas and Escara (2006) presented participants with addition and subtraction tasks which varied in difficulty level (problem size). They found that a positive slow wave was greater in amplitude to more difficult subtraction problems and that no amplitude modulation was found for addition problems. Their conclusion focuses on the positive slow wave being related to non-retrieval methods in mental arithmetic, as evidenced from the use of subtraction problems that can be considered more difficult than addition problems generally. The addition problems they used were only single digit problems and could therefore be considered simple and easy. Other studies, using more complex addition problems, for example those that involve a carry operation (Kong et al., 1999), have demonstrated that the amplitude of late positive waves can indeed be modulated by the difficulty level of addition problems.

Kong et al. (1999) studied ERPs of individuals performing semi-complex two-digit plus one-digit additions in a verification task, involving a carry operation or not. This study may be regarded as being particularly important in that it brings closer together the relationship between mental arithmetic, ERPs and working memory. The inclusion of a carry operation in half of the problems provides the researcher with a method of examining how ERPs may differ if extra demands are placed on the working memory system. Kong et al. found that, after presentation of the second addend, P2 amplitude at the F3 site was greater for problems involving the carry operation compared to problems not containing a carry, implicating the pre-frontal cortex in the early stages of simple fact retrieval in mental arithmetic. They argue that the following P3b wave reflects cognitive closure processes, with the subsequent slow wave being a reflection of a preparatory motor response. However, the slow waves they observed were significantly more negative at left frontal sites F3 and F7 when problems did not include a carry term and, as others, for example Garcia-Larrea and Cezanne-Bert (1998), have found, the slow wave can exist despite the absence of a required motor response. Thus, such a frontal slow wave effect may be further evidence of cognitive processing prior to the presentation of a proposed solution.

However, it is important to point out that to date there is little research that has used an ERP methodology to study arithmetic problem solving in which both addends are two-digits. Previous studies have used multiplication problems involving single digit numbers, often requiring direct fact retrieval, or they have used arithmetic problems in which simple counting takes place or where the second addend is a single digit, again requiring simple fact retrieval or minimal involvement of a carry term. Thus, it would make little sense to argue that a P3-like component and subsequent slow wave reflect the complete calculation process when complex problems are used. A verification task involving the addition of two two-digit addends clearly requires observation of a substantial time window in the ERP recording; much longer than the majority of studies have previously tested. For example, El Yagoubi, Lemaire and Besson (2003) observed ERPs lasting over 3000 ms in response to two-digit addition problems presented via a verification task.

Only three studies employing an ERP methodology could be identified where more complex (multi-digit) arithmetic problems were used and late slow waves were measured: Rosler, Schumacher and Sojka (1990), Chwilla and Brunia (1992) and El Yagoubi et al (2003). Rosler et al.'s study focused on slow event-related potentials in response to arithmetic problems involving the addition, multiplication or subtraction of one or two numbers, for example 13 + 37, or 9 x 22. Accordingly, participants were given a longer-than-typical time frame (4500ms) before the presentation of a proposed solution. They found prominent slow waves that appeared in response to both mental arithmetic and mental rotation tasks and these were most prominent at central frontal and parietal sites FZ and PZ, lasting over 2000ms during the calculation process. Rosler et al. also found that slow wave positivity at the frontal site FZ was greater for more difficult problems, providing a general conclusion that the frontal region must be involved in the memory processes required for mental arithmetic. Such a frontal positivity effect was not observed in response to other task types, namely those involving mental rotation, suggesting that frontal positivity seems to be specific to mental calculation. In a similar study, Chwilla and Brunia presented two numerical values to which participants were required to add single digits to in an easy condition and also add the square of single digits to in a difficult condition. They too allowed a considerable time window, in this case 6000ms, before participants could respond. Chwilla and Brunia's findings demonstrated an obvious negative-going slow wave shift from the onset of the calculation-inducing stimulus to the presentation of the proposed solution. This negative slow wave shift was prominent in left hemisphere regions, maximising at frontal sites, and increased as a function of problem difficulty. This specific finding is not fully explained by the authors and they disregard the possibility that the negative slow wave may reflect any preparatory motor response because of the delayed response request that was incorporated into the design of the study. That is, they asked participants to respond to whether the proposed solution was correct or incorrect "approximately" 1500ms after the presentation of the proposed solution. However, it is argued i) this time window does not necessarily reduce any preparation for a motor response, and ii) participants are likely to have maintained preparation for a motor response because the time period was estimated by participants rather than being set as a parameter within stimulus presentation. Thus, it appears that the negative slow wave preceding the proposed solution could have been a reflection of a preparatory motor response. However, it is still not clear why negative slow wave amplitude varied as a function of task difficulty. One possibility is that the more difficult task required participants to exert greater attentional control, thus implementing the left frontal regions known to be integral to executive processes (e.g. Jahanshahi, Dirberger, Fuller & Frith, 2000; Markela-Lerenc et al., 2004; Kondo, Morishita, Osaka, Osaka, Fukuyama et al., 2004). El Yagoubi et al (2003) observed the typical early and late ERP responses to complex arithmetic, in this case as a function of varying the level of split from the correct solution on false problems. They observed more positive amplitudes in response to splits that were 10% or 15% from the correct solution compared to smaller splits of 2% or 5% suggesting that different strategies may be employed according to the magnitude of proposed solutions in verification tasks. In particular, the authors argue that small splits may require a whole (rather than approximate) calculation strategy. Level of split is therefore an important factor to consider when conducting ERP and arithmetic research.

4.5 Event-related potentials and anxiety

Studies measuring event-related potentials (ERPs) to investigate the relationship between anxiety and processing of verbal information are limited in number. Research has tended to focus on either early processing of negative visual stimuli, for example faces (Carretie, Mercado, Hinojosa, Martin-Loeches, & Sotillo, 2004) or inhibition effects using negative distractor stimuli (e.g. Huang, Bai, Ai, Li, Yu et al., 2009).

Of the research that has been conducted one finding is that ERP amplitude is related to processing in response to presentation of anxiety-inducing stimuli (Yoshida & Iwaki, 2000; Weinstein, 1995). However, such research has tended to use tasks that do not appear comparable with arithmetic tasks. For example, Yoshida and Iwaki used unpleasant tones to induce anxiety amongst participants rated as either low or high in trait anxiety. Such tasks/stimuli are clearly different to typical arithmetic tasks, inducing only very early ERPs and involving very limited processing. It is therefore difficult to generalise to other types of task, particularly those involving working memory and temporary maintenance of verbal information.

However, one study has demonstrated that slow waves can vary according to ratings of negative valence of stimuli. For example, van Hoof, Dietz, Sharma and Bowman (2008) recently found that an emotional Stroop task induced a more negative slow wave in incongruent conditions where stimuli were rated more negatively. The authors concluded that the slow wave negativity was associated with a longer response time due to stimuli (word) meaning suppression. That is, participants were seen as having reduced attentional control over allocating resources towards interpretation of the negative stimuli. The extent to which the stimuli could be specifically perceived as anxiety-inducing, though, was not reported. Thus, evidence of a specific anxiety influence on processing of verbal information processing in a slow wave ERP paradigm is extremely limited, but closely related research does give some indication that anxiety effects are reflected in ERPs.

4.6 Introduction to study one

Considering the lack of research in the field of maths anxiety and its potential relationship with ERPs, the present study therefore investigated ERPs of individuals in response to complex (two-digit addend) maths problems with or without a carry operation. As previous research has indicated maths anxiety and performance to be related mostly in response to complex arithmetic the focus of the current study was on those components of ERPs previously found to be related to online mental arithmetic in which conscious calculation is required. Thus, the study aimed to investigate two broad ERP time windows. Firstly, the initial 500ms window post second addend onset and, secondly, the time window ranging from 500ms to the forced participant response time, that is, 6000ms post second addend onset. The 500ms time window has been found to contain early ERP components related to general information processing processes (Pauli et al., 1996) and whilst it may have differentiated between responses to simple numerical processing (Kong et al., 1999), and contains the operationally defined slow wave, it is unlikely to differentiate between more complex information such as two-digit addends. Indeed, Jost et al. (2004) found no effect of problem difficulty on the amplitude of a late positive component. Therefore, within the 0-500ms time window, no differences in ERP patterns were expected in response to problems with or without a carry term. Similarly, it was predicted that no relationship between maths anxiety and ERP amplitude would be found. Regarding the time period preceding the proposed solution, that is, when active calculation is expected to take place, it was hypothesised that, as Chwilla and Brunia (1992) and Jost et al. (2004) found, slow wave negativity would increase as a function of problem difficulty. Further to this, it was expected that maths anxiety would be positively related to ERP amplitude in response to problems involving a carry operation. This may be seen as an effect of the interaction between cognitive processes and any emotions involved in the processing of maths problems amongst those with high maths anxiety. Due to the proposition that the pre-frontal cortex is integral to working memory and other areas are not, it was expected that any maths anxiety effects would be observed in the frontal area, based on the argument that maths anxiety interferes with the efficiency of working memory processes (Ashcraft & Kirk, 2001). Therefore, of the seven cortical sites analysed in this study, five were located in the frontal region and serve as the main focus of this study. Based on the consistent finding that the late positive component observed in response to arithmetic verification tasks typically has a centro-parietal maximum, EEG was also recorded from a central and centro-parietal site. Maths anxiety was not expected to be related to amplitude of ERPs at the parietal site. It was assumed that maths anxiety has no influence on the neurophysiological processing of arithmetic in terms of the brain's response to the implementation of fact retrieval or of the calculation process. Rather, it is the ability to maintain sufficient levels of attention and to hold transient numerical information in the form of a carry term that is of most importance in this study.

4.7 Method

4.7.1 Design

The study incorporated a completely within-subjects design. Independent variables included problem type (inclusion or exclusion of a carry term), cerebral location (CZ, PZ, FZ, F3, F4, F7 and F8), and ERP time window (early and late components). The dependent variables were error rates to maths problems and the ERP amplitude (μV) as derived from a continuous EEG recording. Stimuli consisted of 150 two-digit-addend arithmetic problems; 75 included a carry term and 75 did not. Addends were randomly selected but replaced and randomly selected again if they were too large to ensure that all solutions remained below 100. In order to compensate for the problem size effect, problem size was counterbalanced between carry and no-carry conditions. To create a valid verification task, of the 150 problems, there were 15 false problems including a carry term and 15 problems with no carry term, to which plausible yet incorrect splits of +/- 1, +/- 3 and +/- 5 were randomly assigned. A delayed verification task was chosen over a standard verification task in order to reduce motor responses during processing of the presented operands.

4.7.2 Participants

The initial sample consisted of 31 undergraduate Psychology students from Staffordshire University, U.K. Although, after data screening, six participants were excluded from further analysis (see ERP data screening later). The final sample consisted of 25 participants (6 men, 19 women). Ages ranged from 18 to 45 years (mean = 25.72; SD = 8.73). Participants took part in exchange for undergraduate research scheme vouchers and came from an opportunity sample gained via advertising at the University. All participants were right-handed and had normal or corrected-to-normal vision.

4.7.3 Materials and procedure

4.7.3.1 Maths anxiety

The Mathematics Anxiety Rating Scale (MARS, Richardson & Suinn, 1972) was used to measure participant's level of maths anxiety. This self-report scale contains 98 items asking how anxious an individual would feel in particular situations involving mathematics. For example, 'Being asked to add up 976 + 777 in your head' or 'Taking an examination (final) in a math course'. Participants are asked to rate (from 1 'not at all' to 5 'very much') how anxious each situation described would make them.

Participants' scores are then calculated and can range from 98 to 490, with 98 being the lowest possible score and reflecting low maths anxiety and 490 being the highest possible score and reflecting high maths anxiety.

4.7.3.2 Maths problems

Maths problems were programmed into a computer using SuperLab Pro for Windows. After presentation of seven practice trials, presentation of the maths problems in the main experiment consisted of one block containing 150 trials. Each trial consisted of six events. The arithmetic problems were presented in the following order: i) presentation of first addend lasting 1000ms; ii) a '+' sign lasting 1000ms; iii) presentation of the second for 3000ms; iv) presentation of an '=' sign for 1000ms; v) presentation of a proposed answer in which participants had 2000ms to respond 'incorrect' or 'correct' by pressing the appropriate key on the key pad (on which two coloured buttons were available to press). Kong et al. (1999) presented maths problems for 2000ms in total prior to requiring a participant response. However, in the present study, it was felt that 6000ms would be appropriate considering the more complex nature of the maths problems and the fact that responses were hoped not to be a product of being given such a short time limit. After a response or the time limit, a pause screen appeared until participants pressed any key to continue to the next trial. All stimuli were presented in the centre of a VDU, in Times New Roman size 40 bold font.

4.7.3.3 EEG

Continuous EEG was recorded using an EEG quick cap. Electrodes (Ag/AgCl sintered) were positioned according to the international 10-20 system. A reference electrode was placed on each mastoid. Eye movements were measured from electrodes placed horizontal to the right eye and horizontal, vertical and below the left eye. Signals were amplified using a Neuroscan Synamps (Compumedics, El Paso, TX, USA) amplifier. DC correction was enabled. EEG waveforms were recorded as continuous files in DC mode. A notch filter was set at 50 Hz. Artefact rejection was used to remove eye blinks. EEG was recorded with a sampling rate of 1000, with a low pass filter set at 100 Hz and a high pass filter set at 0.10 and a gain of 1000. All EEG analyses had impedances below 5 kΩ EEG data were analysed off-line using Neuroscan Edit 4.3 software (Compumedics, El Paso, TX, USA). Epoched files were then created based on the time window from second addend onset to the onset of the proposed solution.

4.7.4 General procedure

Participants were informed of the nature of the maths task and the procedure required to establish the EEG recording, including any potential risks as laid out in the University's risk assessment documentation. Once the correct positioning of the EEG cap and acceptable impedance of electrodes had been established, the researcher then confirmed with the participant that they were sitting comfortably and were in a position to press the keypad without too much movement. Participants were asked to place their left index finger on the red button of the keypad and their right index finger on the green button of the keypad. They were then informed that they would be monitored via CCTV and the researcher would speak to them from the control room through a speaker system. Participants were asked to make as little movement of the head or body as possible and preferably to avoid blinking during the presentation of the problem. They were told that any movement or eye blinks should preferably be made during the pauses.

An introduction to the experiment, explaining the instructions to participants, was presented on the computer screen and participants were told to proceed as soon as they were ready. It took approximately 25 minutes to complete the series of maths problems.

4.8 Results

4.8.1 ERP data screening

Individual EEG data files were initially visually scanned to identify and remove any unwanted obviously apparent artefacts. To reduce eye blink artefacts a linear derivation transform was computed using a minimum of 50 eye blinks per participant. This correction was then applied to the raw data. An artefact rejection transform was also performed for the detection and rejection of general artefacts +/- 100µV. Epochs were created after a pre-stimulus interval baseline correction was performed. Data for two participants were excluded based on an unusually large number of muscular artefacts. Data for two participants were excluded because of missing channels. Finally, data were excluded from further analysis for two other participants based on the number of incorrect or no-responses exceeding 50%, thus affecting the validity of averaged epochs. Once epochs were averaged for each participant these were smoothed using seven adjacent data points.

4.8.2 General data screening and diagnostic checks

To test for differences in performance across problem types and to test for differences in ERP amplitude, within-subjects t-tests and within-subjects ANOVAs were planned, respectively. Also, a series of simple linear regressions were planned, regressing ERP amplitudes to problems at each location and window separately onto maths anxiety. Visual inspection of histograms of the data showed the data to be sufficiently univariately normally distributed. Mauchley's test of sphericity indicated a significant violation of the sphericity assumption for the location variable including all those effects including that variable. However, adjustments made little difference to the significance of observed effects. For each regression, normality of standardised residuals was tested by visual inspection of histograms; these were found to be normal. Standardised residuals and standardised predicted residuals were also plotted against each other and no obvious curvilinear relationships were apparent. Checks for bivariate outliers were also made using scattergraphs and no outliers were identified. Homoscedasticity was also present. (see Appendix for examples of each of the above).

4.8.3 Behavioural analysis

4.8.3.1 Problem type analysis

A within-subjects t-test was used to compare the difference in percentage of errors between problems with a carry term (mean = 7.28; SD = 5.74) and problems without (mean = 6.68; SD = 6.45). There was no significant difference in error rate between the two types of problem, $t(24) = .721$, $p = .478$, two-tailed test. The effect size d was 0.1[2], indicating a small effect (Cohen, 1988). Response time analyses were not made because of the forced ceiling that had been implemented, that is, a two-second time limit given the delay that had already been put in place.

[2] See Appendix for an example of how d was calculated

4.8.3.2 Maths anxiety analysis

The mean maths anxiety score for the sample was 209.48 (SD = 72.63). Maths anxiety was significantly positively correlated with percentage of errors in response to problems involving a carry operation, $r(23) = .43$, $p = .031$, two-tailed test. However, there was no significant correlation between maths anxiety and percentage of errors in response to problems that did not involve a carry operation, $r(23) = .26$, $p = .21$, two-tailed test. As above, response time analyses were not considered.

4.8.4 ERP analysis

4.8.4.1 Observation of ERP waveforms

As shown in figures 1 to 7, three clear ERP components are evident. Firstly, a positive deflection appears soon after the presentation of the second added, with a clear parietal maximum peaking at around 500ms. This is followed by a slow wave until the presentation of the equals symbol at 3000ms. The slow wave is mostly apparent at the frontal sites and appears to be in the negative direction. The amplitude of the slow wave at the parietal site is less obvious. The subsequent presentation of the equals symbol produces a small deflection in the wave followed by what appears to be a temporary CNV prior to the presentation of the proposed solution at 4000ms. The presentation of the proposed solution resulted in a very clear positive deflection followed by slow wave typically reaching baseline before 5000ms. Based on these observations, time window analyses of 0-500ms (after presentation of the second addend), 500-3000ms (before presentation of the equals symbol) and 4000-5000ms (after presentation of the proposed solution) were analysed using mean amplitudes.

4.8.4.2 Problem type analysis

A series of 2 (problem) x 7 (location) two way within-subjects ANOVAs were conducted on ERP amplitudes in each time window. For the 0-500ms time window there was no significant interaction between problem type and location, $F(6, 144) = .893$, $p = .502$, $\eta^2 = .004$, and there was no significant main effect of problem type, $F(1, 24) = 2.209$, $p = .150$, $\eta^2 = .006$. There was, however, a significant main effect of location, $F(6, 144) = 7.039$, $p < .001$, $\eta^2 = .139$.

A set of 21 post hoc pairwise contrasts were conducted using Tukey's HSD to compare amplitude between each of the locations. The family-wise error rate was set at .05 and calculated within-subjects t-values were compared against critical t values of 3.21 ($\alpha = .05$) and 4.05 ($\alpha = .01$). Amplitude was significantly more positive at PZ compared to most other sites and amplitude was significantly more positive at CZ compared to all frontal sites except F3 (for all significant results effect sizes were large, according to Cohen, 1988; see Table1). ERP positivity was much more positive at the left frontal site F7 than at the contra-lateral right frontal site F8 ($d = 1.64$), despite the contrast being non-significant; although, observation of the 95% confidence interval shows that the lower limit was only just below zero.

For the time period 500ms to 3000ms post-second addend onset, that is, after presentation of the second addend but prior to the presentation of the equals symbol, there was no significant interaction between problem type and location, $F(6, 144) = .688$, $p = .660$, $\eta^2 = .002$. There was also no significant main effect of problem type, $F(1, 24) = 1.372$, $p = .253$, $\eta^2 = .008$, but there was a significant main effect of location, $F(6, 144) = 15.981$, $p < .001$, $\eta^2 = .134$, with post-hoc contrasts again showing that PZ amplitude was significantly more positive than amplitude at all other sites (see Table 2). CZ amplitude was also significantly more positive than frontal sites FZ and F7, again showing large effect sizes, according to Cohen's (1988) criteria. Amplitudes were therefore more negative in frontal regions compared to the central and parietal sites.

For the time period 4000ms to 5000ms, that is, following the presentation of the proposed solution, once again there was no significant interaction between problem type and location, $F(6, 144) = .029$, $p = 1.00$, $\eta^2 < .001$. Nor was there a significant main effect of problem type, $F(1, 24) = .152$, $p = .700$, $\eta^2 < .001$. However, as with the previous time windows, there was a significant main effect of location, $F(6, 144) = 36.726$, $p < .001$, $\eta^2 = .273$, with post hoc contrasts showing that PZ amplitude was significantly more positive than amplitude at all other sites (see Table 3). CZ amplitude was also significantly more positive than amplitude at all frontal sites. All significant differences had large effect sizes according to Cohen's (1988) criteria. Across all time windows, amplitude negativity was consistently the greatest at F7.

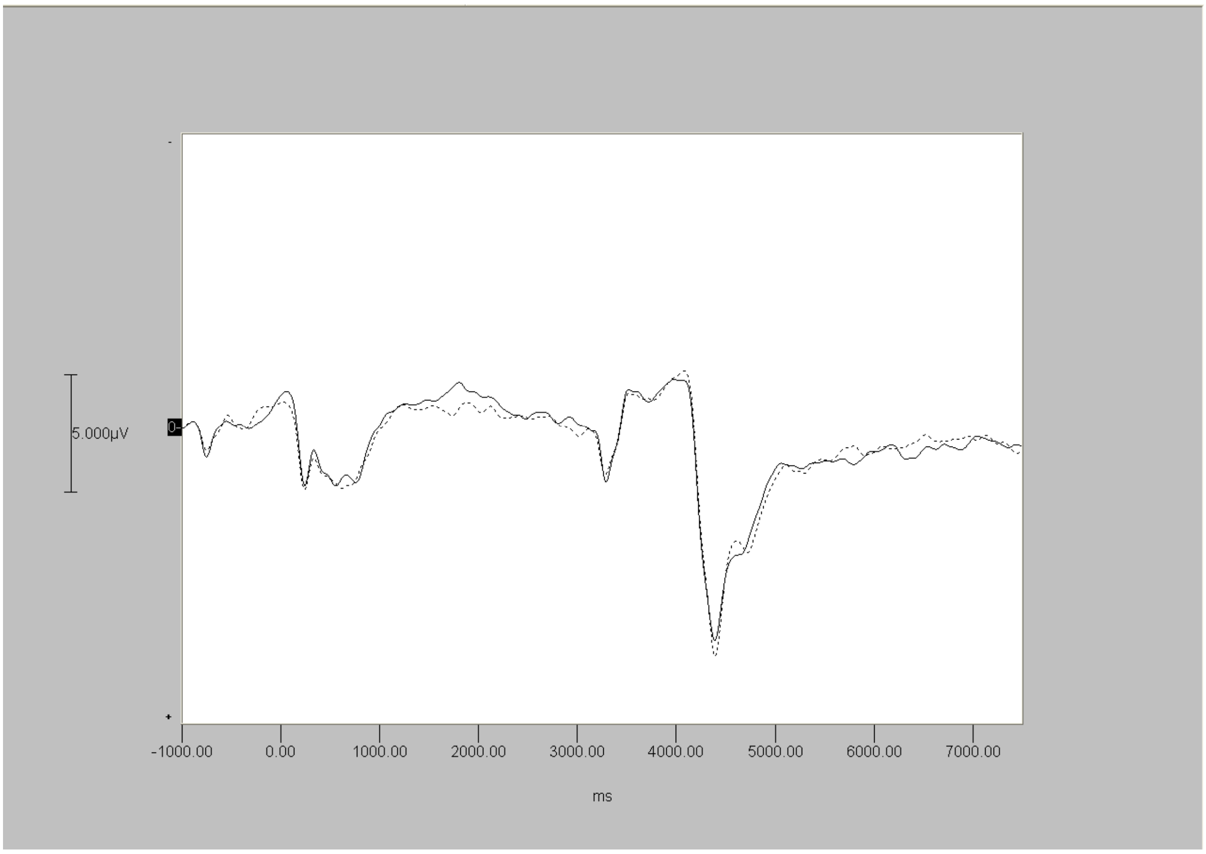


Figure 1. ERP waveform at mid-central site CZ showing responses to both carry and no-carry problems. Solid line represents carry problems and dotted line represents no-carry problems

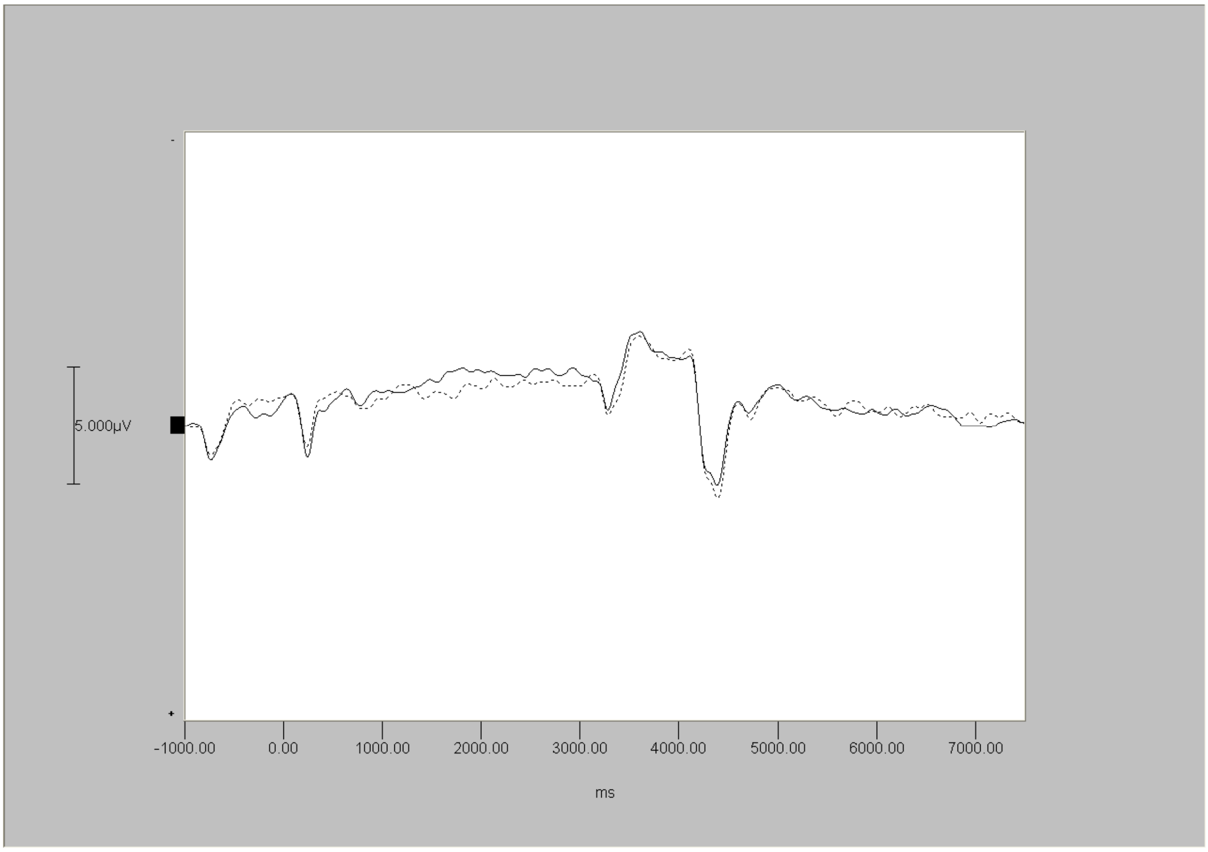


Figure 2. ERP waveform at left frontal site F3 showing responses to both carry and no-carry problems. Solid line represents carry problems and dotted line represents no-carry problems

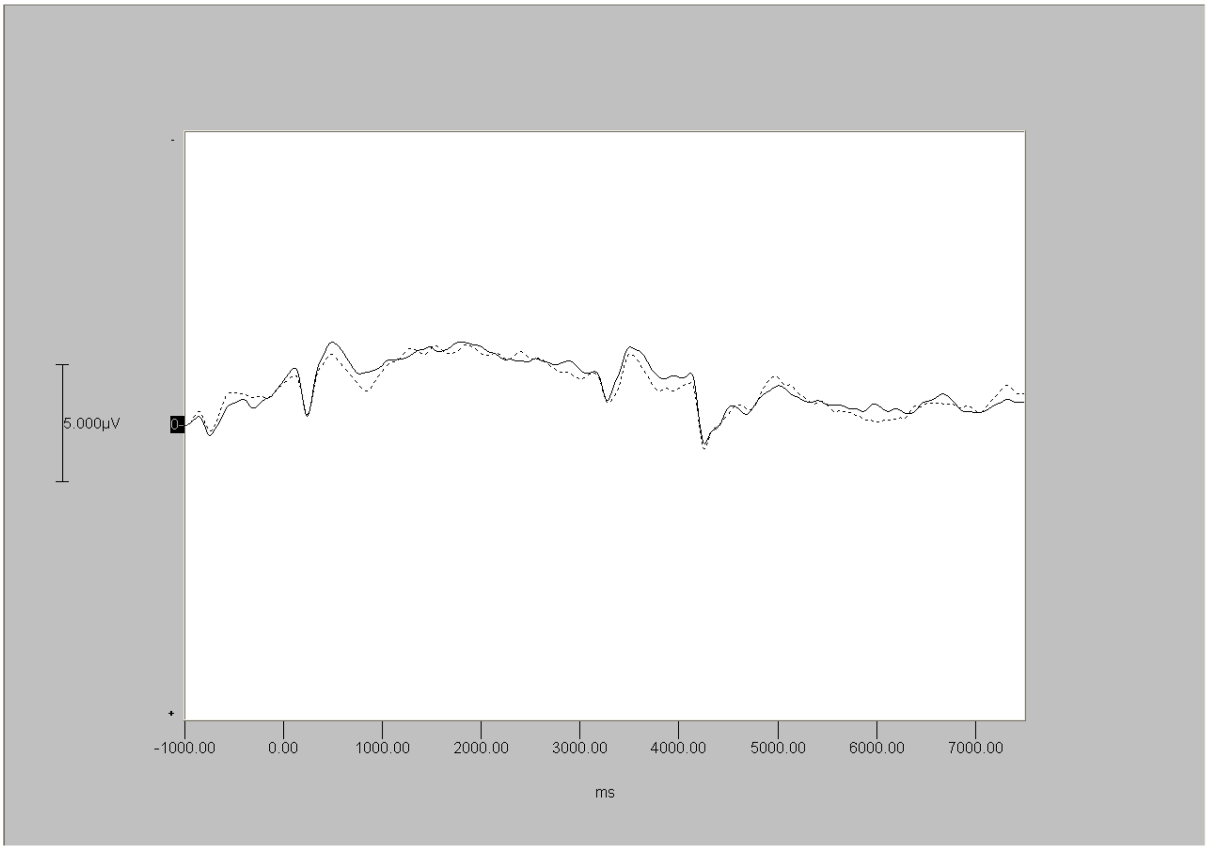


Figure 3. ERP waveform at left frontal site F7 showing responses to both carry and no-carry problems. Solid line represents carry problems and dotted line represents no-carry problems

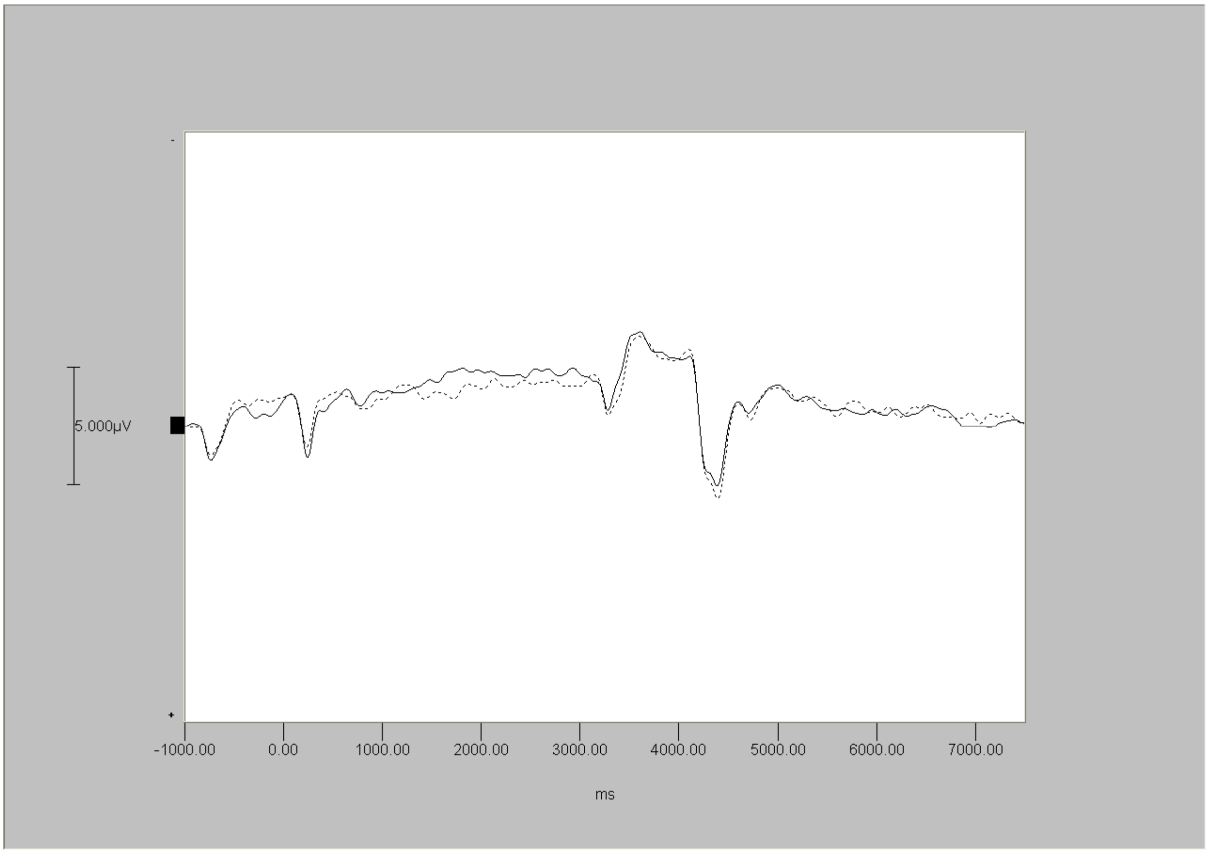


Figure 4. ERP waveform at right frontal site F4 showing responses to both carry and no-carry problems. Solid line represents carry problems and dotted line represents no-carry problems

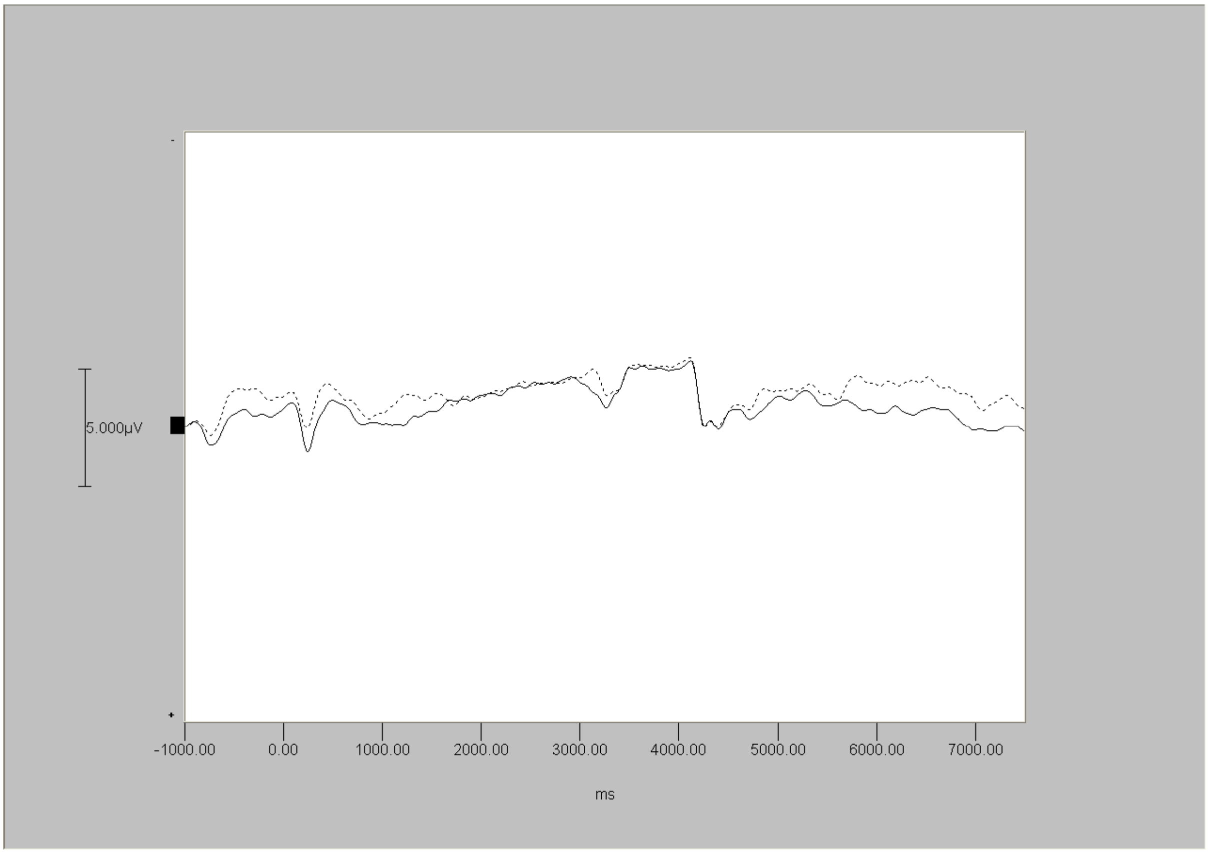


Figure 5. ERP waveform at right frontal site F8 showing responses to both carry and no-carry problems. Solid line represents carry problems and dotted line represents no-carry problems

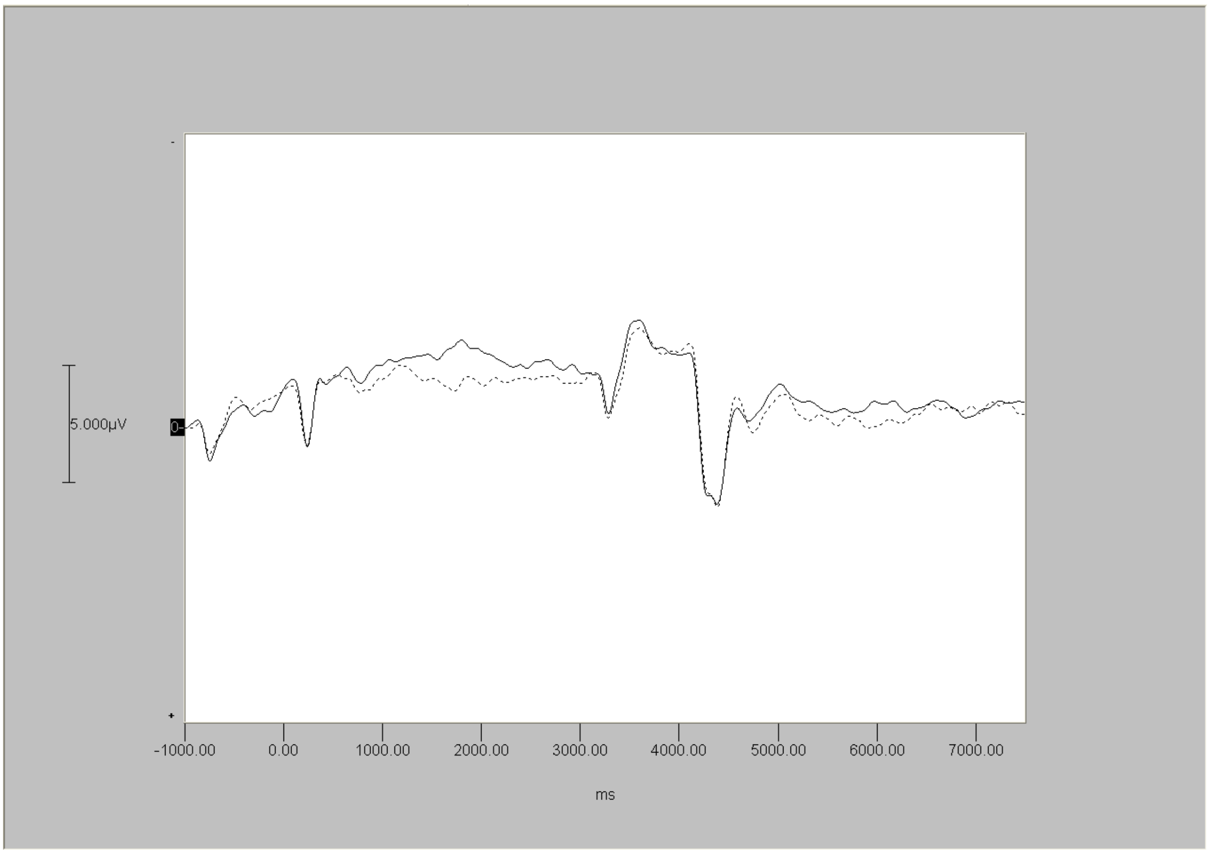


Figure 6. ERP waveform at mid-frontal site FZ showing responses to both carry and no-carry problems. Solid line represents carry problems and dotted line represents no-carry problems

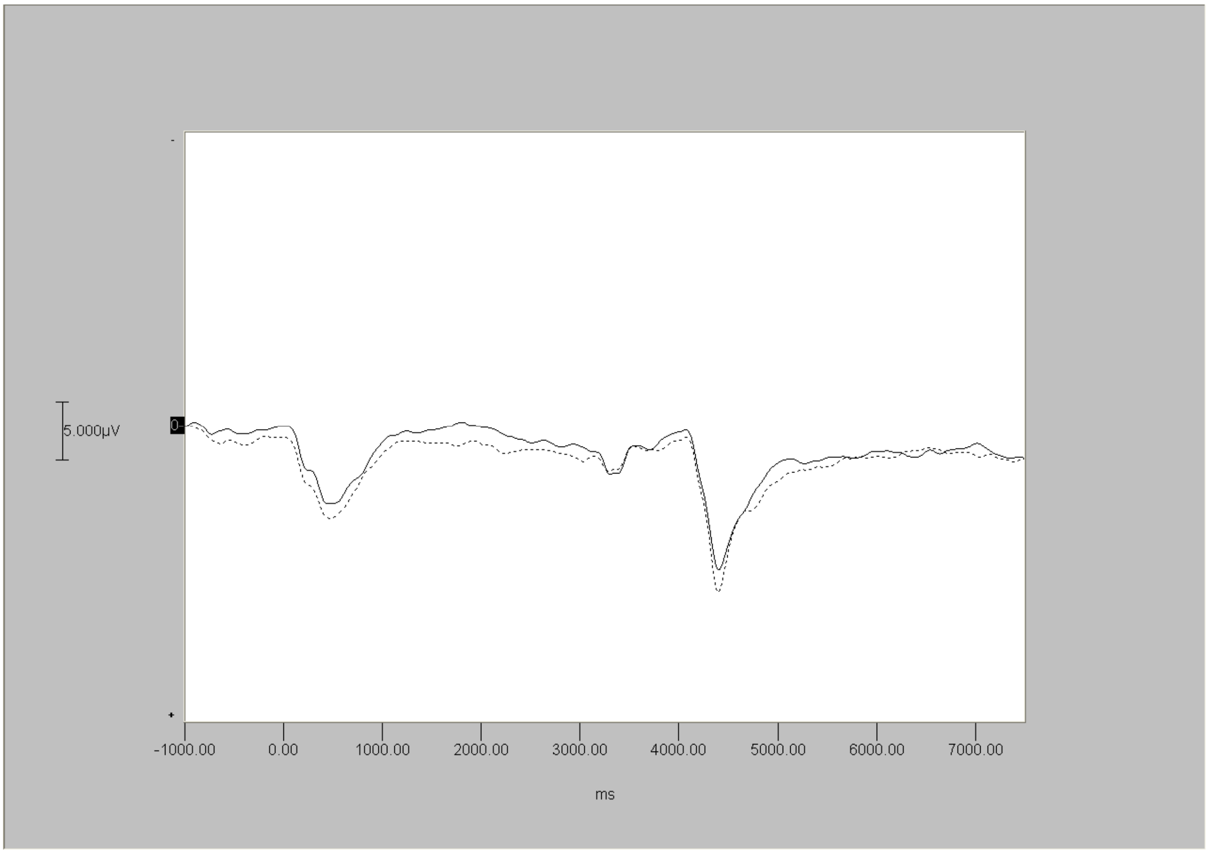


Figure 7. ERP waveform at mid-parietal site PZ showing responses to both carry and no-carry problems. Solid line represents carry problems and dotted line represents no-carry problems

Contrast	Calculated t	d	95% CI[3] (lower / upper limit)
PZ – CZ	3.15	0.81	-0.02 / 2.33
PZ – FZ	6.40**	1.96	1.47 / 4.42
PZ – F4	7.20**	1.85	1.60 / 4.16
PZ – F8	6.36**	1.84	1.42 / 4.31
PZ – F3	1.83	0.58	-1.73 / 6.35
PZ – F7	7.37**	2.11	2.04 / 5.18
CZ – FZ	6.75**	1.42	0.94 / 2.64
CZ – F4	6.77**	1.31	0.91 / 2.55
CZ – F8	6.50**	1.29	0.86 / 2.55
CZ – F3	1.09	0.30	-2.25 / 4.57
CZ – F7	6.34**	1.63	1.21 / 3.70
FZ – F4	0.33	0.04	-0.54 / 0.07
FZ – F8	0.33	0.06	-0.71 / 0.87
FZ – F3	0.67	0.16	-0.15 / 1.42
FZ – F7	1.79	0.42	-0.53 / 1.87
F4 – F8	0.11	0.01	-0.49 / 0.53
F4 – F3	0.52	0.14	-0.29 / 4.07
F4 – F7	2.55	0.45	-0.19 / 1.65
F8 – F3	0.50	0.14	-2.99 / 4.10
F8 – F7	3.00	1.64	-0.06 / 1.56
F3 – F7	1.03	0.32	-2.75 / 5.35

** $p \leq .01$ based on critical t of 3.92

Table 1. Pairwise contrasts of mean amplitudes across locations for 0-500ms time window

[3] For the mean difference based on critical t for Tukey's HSD

Contrast	Calculated t	d	95% CI (lower / upper limit)
PZ – CZ	4.67**	0.62	0.41 / 2.21
PZ – FZ	5.99**	1.47	1.48 / 4.90
PZ – F4	5.32**	1.15	1.06 / 4.31
PZ – F8	4.21**	0.86	0.47 / 3.47
PZ – F3	5.71**	1.14	1.15 / 4.09
PZ – F7	7.18**	1.46	1.81 / 4.74
CZ – FZ	4.50**	0.91	0.54 / 3.23
CZ – F4	3.20	0.62	-0.00 / 2.76
CZ – F8	1.40	0.30	-0.85 / 2.17
CZ – F3	2.61	0.60	0.08 / 2.54
CZ – F7	4.70**	0.92	0.62 / 3.31
FZ – F4	1.32	0.22	-0.72 / 0.63
FZ – F8	2.31	0.54	-0.48 / 2.93
FZ – F3	1.52	0.25	-0.64 / 1.79
FZ – F7	0.21	0.04	-1.12 / 1.36
F4 – F8	2.23	0.30	-0.31 / 1.75
F4 – F3	0.22	0.03	-0.88 / 1.01
F4 – F7	1.64	0.25	-0.56 / 1.74
F8 – F3	1.76	0.28	-1.44 / 1.84
F8 – F7	3.16	0.56	-0.02 / 2.63
F3 – F7	2.27	0.28	-0.27 / 1.55

** $p \leq .01$ based on critical t of 3.92

Table 2. Pairwise contrasts of mean amplitudes across locations for 500-3000ms time window

Contrast	Calculated t	d	95% CI (lower / upper limit)
PZ – CZ	4.82**	0.52	0.59 / 2.93
PZ – FZ	9.77**	1.69	3.75 / 7.42
PZ – F4	9.05**	1.92	3.85 / 8.08
PZ – F8	8.12**	2.12	3.78 / 8.72
PZ – F3	8.23**	1.63	3.10 / 7.06
PZ – F7	8.28**	1.82	3.55 / 8.05
CZ – FZ	8.56**	1.15	2.39 / 5.26
CZ – F4	6.79**	1.34	2.22 / 6.19
CZ – F8	5.62**	1.51	1.93 / 7.05
CZ – F3	6.47**	1.06	1.67 / 4.97
CZ – F7	6.40**	1.26	2.02 / 6.07
FZ – F4	0.09	0.12	-1.00 / 1.75
FZ – F8	0.94	0.27	-1.59 / 2.91
FZ – F3	1.57	0.16	-0.53 / 1.55
FZ – F7	0.38	0.07	-1.62 / 2.06
F4 – F8	0.71	0.11	-1.00 / 1.57
F4 – F3	2.34	0.31	-0.33 / 2.10
F4 – F7	0.32	0.05	-1.45 / 1.77
F8 – F3	2.04	0.43	-0.67 / 3.01
F8 – F7	0.66	0.16	-1.71 / 2.60
F3 – F7	1.70	0.24	-0.65 / 2.10

** $p \leq .01$ based on critical t of 3.92

Table 3. Pairwise contrasts of mean amplitudes across locations for 4000-5000ms time window

4.8.5 Maths anxiety analysis

A series of simple linear regressions were performed in which ERP amplitudes to problems at each location and window were regressed separately onto maths anxiety. This was done for both problems including a carry term and those not including a carry term. A Bonferroni correction was applied for time window analysis so that alpha was divided by the number of locations, resulting in an adjusted alpha of .007. Maths anxiety did not significantly predict amplitude to any of the problems. As shown in

Table 4, for problems including a carry term, the R-squared values are quite small with maths anxiety explaining a mean average of just 3.20% , 1.50%, and 2.20% of the variance in amplitude for time windows 0 – 500ms, 500 – 3000ms, and 4000 – 5000ms, respectively. One anomaly is found at F8 in the 0-500ms time window, in which 14.6% of the variance in amplitude could be explained by maths anxiety; however, this remained non-significant (at the adjusted and non-adjusted alpha levels) and, as can be seen from the 95% confidence interval after maintaining a family-wise error rate of .05, the confidence limits for the unstandardised coefficient B pass through zero. As can be seen in Table 5, for problems not including a carry term, most of the R-squared values are again quite small with maths anxiety explaining a mean average of just 1.40% and 2.30% of the variance in amplitude for time windows 0 – 500ms and 4000 – 5000ms, respectively. Unexpectedly, maths anxiety explained a mean of 7.90% of the variance in amplitude for the 500 - 3000ms time window. However, this appears to be restricted to sites FZ, F3 and F7, explaining 10.4%, 18.2% and 15.4% of the variance in amplitude, respectively. F3 was a significant predictor at the unadjusted alpha level ($p = .034$) and F7 was approaching significant ($p = .053$). The direction of the beta values indicate a negative relationship between maths anxiety and slow wave amplitude, suggesting that higher levels of maths anxiety were related to a more negative slow wave after the presentation of the second addend, albeit not reaching significance at the adjusted alpha level.

Location / Window(ms)	R^2	Adj. R^2	B	t	95% CI for B (lower limit / upper limit)
PZ 0-500	.037	-.005	-.004	-0.934	-0.014 / 0.005
CZ 0-500	.008	-.035	-.003	-0.430	-0.016 / 0.010
FZ 0-500	.023	-.020	.004	0.732	-0.008 / 0.017
F3 0-500	.001	-.042	-.003	-0.163	-0.044 / 0.037
F7 0-500	.012	-.031	-.004	-0.532	-0.017 / 0.010
F4 0-500	.004	-.040	-.001	-0.294	-0.012 / 0.009
F8 0-500	.011	-.032	-.002	-0.495	-0.012 / 0.008
PZ 500-3000	.031	-.011	.006	0.860	-0.009 / 0.022
CZ 500-3000	.010	-.033	-.004	-0.479	-0.019 / 0.012
FZ 500-3000	.104	.065	-.009	-1.637	-0.021 / 0.002
F3 500-3000	.182	.146	-.015	-2.259*	-0.029 / -0.001
F7 500-3000	.154	.117	-.013	-2.044	-0.003 / 0.000
F4 500-3000	.064	.024	-.009	-1.258	-0.024 / 0.006
F8 500-3000	.006	-.037	-.003	-0.367	-0.022 / 0.015
PZ 4000-5000	.024	-.019	.008	0.744	-0.015 / 0.032
CZ 4000-5000	.038	-.004	.011	0.951	-0.013 / 0.034
FZ 4000-5000	.026	-.017	.009	0.779	-0.015 / 0.033
F3 4000-5000	.007	-.036	-.004	-0.402	-0.023 / 0.015
F7 4000-5000	.0002	-.043	-.001	-0.065	-0.017 / 0.016
F4 4000-5000	.011	-.032	-.005	-0.513	-0.026 / 0.016
F8 4000-5000	.055	.014	-.009	-1.158	-0.024 / 0.007

* $p \leq .05$

Table 4. ERP amplitude (µV) in response to problems including a carry term regressed onto maths anxiety

Location / Window(ms)	R^2	Adj. R^2	B	t	95% CI for B (lower limit / upper limit)
PZ 0-500	.037	-.005	-.004	-0.934	-0.014 / 0.005
CZ 0-500	.008	-.035	-.003	-0.430	-0.016 / 0.010
FZ 0-500	.023	-.020	.004	0.732	-0.008 / 0.017
F3 0-500	.001	-.042	-.003	-0.163	-0.044 / 0.037
F7 0-500	.012	-.031	-.004	-0.532	-0.017 / 0.010
F4 0-500	.004	-.040	-.001	-0.294	-0.012 / 0.009
F8 0-500	.011	-.032	-.002	-0.495	-0.012 / 0.008
PZ 500-3000	.031	-.011	.006	0.860	-0.009 / 0.022
CZ 500-3000	.010	-.033	-.004	-0.479	-0.019 / 0.012
FZ 500-3000	.104	.065	-.009	-1.637	-0.021 / 0.002
F3 500-3000	.182	.146	-.015	-2.259*	-0.029 / -0.001
F7 500-3000	.154	.117	-.013	-2.044	-0.026 / 0.000
F4 500-3000	.064	.024	-.009	-1.258	-0.024 / 0.006
F8 500-3000	.006	-.037	-.003	-0.367	-0.022 / 0.015
PZ 4000-5000	.024	-.019	.008	0.744	-0.015 / 0.032
CZ 4000-5000	.038	-.004	.011	0.951	-0.013 / 0.034
FZ 4000-5000	.026	-.017	.009	0.779	-0.015 / 0.033
F3 4000-5000	.007	-.036	-.004	-0.402	-0.023 / 0.015
F7 4000-5000	.0002	-.043	-.001	-0.065	-0.017 / 0.016
F4 4000-5000	.011	-.032	-.005	-0.513	-0.026 / 0.016
F8 4000-5000	.055	.014	-.009	-1.158	-0.024 / 0.007

* $p \leq .05$ Table 5. ERP amplitude (μV) in response to problems not including a carry term regressed onto maths anxiety

4.9 Discussion

ERPs in response to two-digit addition problems resulted in waveforms with three clear peaks, each occurring in synchrony with the presentation of the components of the arithmetic problem: the second addend, the equal symbol, and the proposed solution. Consequently, mean amplitude was analysed across three time windows (0-500ms post second addend onset, 500-3000ms following the second addend and preceding the proposed solution, and 4000-5000ms after presentation of the second addend and following presentation of the proposed solution). The findings from this study can be separated into two independent components. Firstly, an analysis of ERPs as a function of problem type: inclusion or exclusion of a carry operation, and, secondly, an analysis of ERPs in relation to maths anxiety.

Consistent with the prediction that ERP slow-wave amplitude would not vary as a function of problem type in the 0-500ms time windows immediately following presentation of the second addend and proposed solution, no effects of problem type were observed. This supports previous findings (Pauli et al., 1996) that suggest amplitudes of P3-like components are unrelated to problem size at frontal sites and that frontal ERPs are related to general task analysis and are not task specific. That is, they reflect a general orienting response towards stimuli that are presented. One consistent finding across all three time windows was that amplitude positivity was greater at the parietal site (PZ). This is in line with the established finding that the parietal lobe is integral to arithmetic processing (e.g. Cohen, Dehaene, Chochon, Lehericy & Naccache, 2000; Delazer, et al., 2003). According to Prieto-Corona et al. (2010), other studies have demonstrated the late positive component to have a centro-parietal maximum: a finding supported by the current study. Interestingly, Prieto-Corona et al. found that adults produced a late positive component to both correct and incorrect problems, suggesting that the late positive component must be related to more than simple congruencyincongruency decisions. Also, in children, they found the late positive component to only be present in response to the correct solutions. They suggest that the late positive component may be related to confidence in one's response. In the present study, though, maths anxiety did not predict amplitude of the late positive component and considering that maths anxiety is heavily related to maths self-efficacy (Alkhateeb & Taha, 2002) it therefore seems unlikely that late positive component amplitude is related to confidence in one's response.

Unexpectedly though, ERP amplitude did not vary as a function of problem type in the time window following second addend onset and preceding the proposed solution (500-3000ms), therefore providing no evidence that the slow wave indexes the calculation process, or more specifically working memory load when a carry term is maintained. However, it is important that the findings on slow waves in the extant literature on cognitive processing should not be taken at face value. Researchers are far from agreed over the exact processes that are responsible for such post-stimulus slow waves. Garcia-Larrea and Cezanne-Bert (1998) point out that the slow wave noted in the literature relates to the time window succeeding the P3 (or P3-like) component to the point at which baseline is reached, and has been related to the amount of processing involved in a task, task difficulty itself, decision processes, sustained attention, response selection, preparation for the next trial, evaluation of a response, and even assessment of the meaning of a completed trial. In other words, according to Garcia-Larrea and Cezanne-Bert, "positive slow wave may reflect some non-specific feature common to all experiments that manipulate response demands in one way or another" (p.261). The current findings seem to provide some support for this conclusion, with a positive slow wave appearing after presentation of both the second addend and the proposed solution, that is, not specific to one aspect of cognition: the second addend and the proposed solution signify distinct points in the calculation process. Garcia-Larrea and Cezanne-

Bert found that the positive slow wave varied according the experimental paradigm that was employed and observed that the positive slow wave is likely to reflect the end-point of the first cognitive process – whatever that may be. They also suggest that the positive slow wave may reflect memory retrieval, context updating or response selection. Regarding the current study, one possible conclusion, then, is that the positive slow wave following presentation of the second addend and proposed solution may indicate immediate evaluation of the importance of a stimulus within the cognitive processing string, thus incorporating an update of the context and also evaluation of the response that is required; in the current study problem type was not related to slow wave amplitude immediately following a P3-like component. Rather, in response to the proposed solution, slow wave amplitude, irrespective of problem type, was greater than it was in response to the presentation of the second addend, which in turn was greater than the amplitude of the component that followed the presentation of the equals symbol. This was consistent across cortical locations. Therefore, it appears that a general ERP effect may be present whereby the size of the positive deflection may be indicative of the perceived importance of the stimulus. In other words, to successfully complete a proposed sum in a verification task, the most important component of the sum is the proposed solution, that is, it does not matter what the addends themselves are – the final decision will rest with the solution that is proposed. Next, the presentation of the second addend could be seen as an important component of the sum due to its obvious involvement in the calculation; much more so than the presentation of the equals symbol (which remains consistent across trials, thus eradicating any need for a context updating process).

An important aspect of the current study that should be highlighted is what constitutes problem difficulty. In the extant literature studies have consistently used problem size as an indicator of problem difficulty, with the exception of some studies (e.g. Kong et al., 1999) that have included “small” carry terms in the form of single digits. In order to use the same type of arithmetic problems used in previous maths anxiety research, the current study used more complex two-digit addition problems than those used by Kong et al. Importantly, though, the current study counterbalanced problem size across conditions in which there was or was not a carry operation. Therefore, the current findings do not represent an investigation of ERPs as a function of problem size. This is a particularly salient point because it places previous findings into context and further suggests that previously observed effects may be specifically applicable to problem size rather than problem difficulty per se. This issue was successfully addressed by the current study which highlighted the significant positive correlation between maths anxiety and percentage of errors to problems involving a carry irrespective of problem size.

Regarding the relationship between maths anxiety and ERP amplitude, as expected, no relationship was observed between maths anxiety and the early 0-500ms component (and the 4000-5000ms component). This is likely to be due to the general information processing that occurs in response to visual stimuli and is independent of anxiety. Interestingly, regarding the 500-3000ms time window, the results showed the opposite pattern to what was expected. Rather than maths anxiety being positively related to amplitude in response to problems involving a carry, a positive relationship was observed in response to problems not involving a carry operation. Somewhat consistent with the hypothesis, though, this relationship was confined to the central-to-left frontal sites FZ, F3 and F7 and explained 10.4%, 18.2% and 15.4% of the variance in amplitude, respectively. Whilst the location of this effect is consistent with the location of the negative slow wave found elsewhere (Chwilla & Brunia, 1992), it is still not clear why the effect appears to be almost entirely specific to no-carry problems. As suggested earlier though, Chwilla and Brunia’s argument that a slightly (only 1500ms) delayed motor response reduced motor preparation effects is somewhat tenuous. As many others have noted (e.g. Brunia & Damen, 1988; Brunia, 2004; van Boxtel & Bocker, 2004), pre-stimulus negativity has been related to preparation for a motor response. The positive relationship between maths anxiety and slow wave negativity to no-carry problems is hard to explain but one possible conclusion is that maths anxious individuals showed a greater willingness to respond when a problem requires little in the way of cognitive demands and it could be argued that this is the case with maths problems not involving a carry operation. For maths anxious individuals, this could be likened to a form of "cognitive relief" where online processing demands are immediately relaxed and the participant is keen to respond to a problem to which they have greater perceived self-efficacy in their ability to respond correctly. However, it is unclear why the reverse was not true for problems involving a carry operation. It is tentatively suggested that the linear increase between maths anxiety and left frontal slow wave negativity is a specific effect observed when maths anxious individuals are temporarily relieved of anxiety, that is, when problems are presented that do not require the increased cognitive demands of performing a carry operation and where preparedness to respond increases as anxiety increases. However, further research is needed to explore this.

In conclusion, the current study provides little support for the idea that event-related potentials actually vary as a function of problem difficulty per se. Rather, once problem size is controlled for, inclusion of a carry operation has little effect on the amplitude of the resultant ERPs. This suggests that current literature findings of ERP changes as a function of problem difficulty may in fact be more specific to changes in problem size: a specific aspect of arithmetic processing that is distinct from the cognitive load imposed by inclusion of a carry term that is common in research into maths anxiety and performance. Most relevant to the current thesis, maths anxiety was found to be positively related to slow wave negativity in response to problems that did not involve a carry operation, suggesting that maths anxiety may be related to an increased preparedness to respond to less cognitively demanding arithmetic, although further research is clearly needed to substantiate this suggestion. Returning to Ashcraft's earlier request that the "signature" of maths anxiety needs to be investigated in the brain, the current findings provide little support for the suggestion that maths anxiety is related to ERPs to arithmetic problems recorded from areas known to subserve working memory processes. Partial support for this comes from recent findings of Li, Chan and Luo (2010) who found that post-stimulus slow wave negativity was affected by negative stimuli in a spatial task (retention phase) only. Such an effect was not observed when participants performed a verbal task, suggesting that an ERP methodology may be more suited to the study of attentional processes related to anxiety and visual/spatial processing.

In addition, the current study was partly limited by the number of electrode sites that were recorded from. A greater number of sites would enable source localisation to take place, perhaps giving greater insight into the relationship between maths anxiety and arithmetic processing across a wider range of brain regions.

4.10 Conclusion to Chapter Four

The purpose of this chapter was to report on the first study that formed the current thesis. As the first study, the main aim was to investigate the neuropsychological mechanisms related to the maths anxiety-to-performance relationship. Having established whether ERPs vary as a function of maths anxiety in relation to responses to problems with or without a carry operation, it is then possible to make an informed decision about the appropriate course the next stage of research should take. In the current study the consistent maths anxiety-to-performance relationship was observed. That is, despite the general finding that problem type did not affect error rates, maths anxiety was significantly positively related to an increased percentage of errors to complex addition involving a carry operation, but was unrelated to percentage of errors to problems not involving a carry operation. Thus, it appears that the stimuli implemented in the current study were suitable for substantiating this finding that is so consistent in the literature (e.g. Faust et al., 1996). Despite this behavioural observation, ERPs in response to carry problems did not vary as a function of maths anxiety, suggesting that further research is needed to investigate the maths anxiety-to-performance relationship. The finding that slow wave negativity following second addend onset was related to maths anxiety does provide some evidence to suggest that maths anxiety may be related to heightened preparatory control in advance of a motor response when participants are presented with less demanding (no-carry) problems. This, however, still says little about the observed relationship between maths anxiety and error rate to problems involving a carry operation. One possible explanation that stems from past literature (e.g. Faust et al., 1996) is that error rates may be related to a speed-accuracy trade-off amongst individuals high in maths anxiety. However, there are two reasons this is unlikely: firstly, participants were given a reasonably lengthy time period before a decision could be made, and secondly, a linear relationship, rather than the cubic function typically observed with the speed-accuracy trade-off, was observed between maths anxiety and error rates in response to problems involving a carry operation. Therefore, the following chapters present studies that build on the current study by exploring the maths anxiety-to-performance relationship from alternative angles, attempting to explain the mechanisms that underpin it.

CHAPTER FIVE

5. The development and part-validation of a new scale for measuring maths anxiety in a U.K undergraduate population

5.1 Introduction

Discussion with individuals taking part in study one revealed a potential problem with the validity of existing maths anxiety scales. Upon returning to participants after they were given time to complete the Mathematics Anxiety Rating Scale (Richardson & Suinn, 1972) the researcher regularly had to respond to requests for clarification over some of the items that comprised the scale. Such requests mainly focused on terminological issues based on North American language. The following study was therefore conducted to address this problem. It aimed to provide a more valid measure of maths anxiety for use on a British undergraduate student population and provide some much needed normative data on maths anxiety levels in the aforementioned population.

5.2 The use of scales in measuring maths anxiety

In 1958 Dreger and Aiken produced the Numerical Anxiety Scale, but research into maths anxiety accelerated with the publication of the Mathematics Anxiety Rating Scale (MARS, Richardson & Suinn, 1972). The MARS consists of 98 items relating to involvement with maths across a range of settings. Respondents are asked to rate, on a five-point Likert-type scale, how anxious they would feel in those situations. Responses can range from “not at all” to “very much”. Richardson and Suinn reported a sevenweek test-retest reliability of .85 and a Cronbach's alpha of .97. Capraro, Capraro and Henson (2001) reported that, across twenty-eight studies, the MARS yielded a mean alpha of .915, and, across seven studies, it yielded a mean test-retest of .841, providing support for the MARS as a reliable scale. A decrease in maths anxiety, as assessed using the MARS, following behaviour therapy, further validated its use (Suinn, Edie & Spinelli, 1970; Suinn & Richardson, 1971). However, the administration of the 98-item MARS has proved to be somewhat cumbersome and there have been several attempts to produce shorter equivalents of the MARS. These have included a 24-item revised MARS (Plake & Parker, 1982), a 25-item abbreviated version (Alexander & Martray, 1989), a 30-item version (Suinn & Winston, 2003), and a 9-item abbreviated scale (Hopko, Mahadevan, Bare & Hunt, 2003). Other, multi-dimensional, scales have included the Anxiety Towards Mathematics Scale (Sandman, 1979), the Attitudes Towards Mathematics Inventory (Tapia & Marsh, 2004), the Fennema-Sherman Mathematics Attitude Scales (Fennema & Sherman, 1976), and a reduced, 10-item, scale created from the sub-scale of the Fennema-Sherman Mathematics Attitude Scales (Betz, 1978). Specific versions of the MARS have been developed for use with children or adolescent samples, such as the Mathematics Anxiety Scale for Children (Chiu & Henry, 1990), the Mathematics Anxiety Rating Scale for Elementary School Students (Suinn, Taylor & Edwards, 1988) and the Mathematics Anxiety Rating Scale for Adolescents (Suinn & Edwards, 1982). Whilst several maths anxiety scales are available, issues surrounding terminology may question their validity in measuring maths anxiety in British undergraduate student samples.

There has been an increasing number of studies investigating the dimensionality of maths anxiety in recent years. Rounds and Hendel (1980) performed a factor analysis, using principal axis factoring, on 94 of the 98 items on the MARS and found two factors, with oblique and orthogonal rotations resulting in similar outcomes. The first factor they termed Mathematics Test Anxiety and consisted of items such as "thinking about an upcoming maths test one day before" and "listening to a lecture in a maths class". The second factor they termed "Numerical Anxiety" and consisted of items such as "adding up 976 + 777 on paper" and "determining the grade point average for your last term". Thus, factor one pertained to items related to having maths ability tested and also general learning of maths. Factor two, on the other hand, pertained to items related to more direct calculations and everyday use of maths. Plake and Parker (1982) proposed the revised-MARS; they too identified two dominant factors, the first of which they labelled Learning Mathematics Anxiety, and the second of which they labelled Mathematics Evaluation Anxiety. The former consisted of items related to the learning of maths, such as classroom activities and looking through the pages of a maths book. The latter consisted of items related to being tested, such as being given a "pop" (surprise) quiz in a maths class. Alexander and Martray (1989) proposed an abbreviated version of the MARS that revealed three factors: "Maths Test Anxiety", "Numerical Task Anxiety", and "Maths Course Anxiety", which appeared to encompass those factors previously suggested. Resnick et al. (1982) also identified three dimensions in the MARS. The first two, "Evaluation Anxiety" and "Arithmetic Computation Anxiety" closely resemble the two factors outlined by Rounds and Hendel (1980), whereas the third factor, "Social Responsibility Anxiety", relates to social maths settings, such as accounting and secretarial duties in clubs and organisations (Bessant, 1995). Whilst most studies appear to report maths anxiety having two or three dimensions, using a reduced, 80-item, version of the MARS, Bessant used factor analysis, involving quartimax rotations, to extract six factors: "General Evaluation Anxiety", "Everyday Numerical Anxiety", "Passive Observation Anxiety", "Performance Anxiety", "Mathematics Test Anxiety", and "Problem-Solving Anxiety". However, intuitively, these seem to fall into the general dimensions of numerical-based and evaluation-based maths anxiety.

5.3 Introduction to study two

The majority of normative data for maths anxiety, along with studies of psychometric properties of maths anxiety scales, has been conducted on an American student population. In the published literature there appears to be no normative data available for a British population (Sheffield & Hunt, 2007). The purpose of the present study was threefold. Firstly, the issue of terminology needed to be addressed. U.K samples may find some terminology difficult to understand. For example, the original MARS contains several such items, for example the term "being asked to make change" is not common in Britain. Likewise, the item "being given a "pop" quiz in maths class" has resulted in several students having to ask the researcher what this means. This item appeared on the original MARS through to the revised version proposed by Hopko (2003). A further example is the term "sales tax" (MARS and abbreviated version, Suinn & Winston, 2003). In Britain this is more commonly referred to as value added tax (VAT) and has resulted in some participants being unsure of the meaning of the term sales tax. Such terminological problems are clearly a concern for the validity of the scales. Therefore a scale was designed to measure maths anxiety in a British population, using terminology appropriate to the population. The second purpose of the study is to provide some much needed normative data concerning maths anxiety levels in a British student population, including separate analyses for gender and different academic subject areas. Thirdly, the study aims to present the psychometric properties of the newly devised scale, including its factor analytic structure. Reliability and validity measures will help to determine the usefulness of the scale as a diagnostic tool in the adult education sector, as well as being an important measure for subsequent empirical research.

5.4 Method

5.4.1 Participants

Participants were 1, 153 (544 males, 609 females) undergraduate students at Staffordshire University; a post-1992 University in the Midlands, U.K. The proportion of males and females in the sample was equivalent to the national University average of 48.64% and 51.36% for males and females, respectively (Higher Education Statistics Agency, HESA, 2008-09). The sample predominantly consisted of participants of white ethnic origin, although it also included participants from other backgrounds, including Asian and Afro-Caribbean. The proportion of white participants was in the region of the national University average (approximately 79.2%: HESA, 2008-09). The mean age of students was 21.1 years (SD = 4.9). The sample included participants from all three years of undergraduate study and the mean age is typical of the age of a student mid-way through their studies. The mean age is slightly higher than would be expected from a student sample at traditional Universities, but is consistent with the slightly higher ages of students in post-1992 Universities in the U.K, which actually make up approximately half of the number of Universities in the U.K (Universities and Colleges Admissions Service, 2009). Therefore, the sample was representative of the U.K undergraduate population enrolled on full-time taught degrees. Participants were recruited using opportunity sampling from various lectures, workshops and seminars. The retest sample consisted of an opportunity sample of 131 of the original sample (41 males, 96 females, mean age 20.1 years, SD = 5.4). Retest occurred between four and ten weeks, depending on when lectures containing the same students were scheduled.

Unfortunately, the programme of lectures finished earlier than scheduled for some subjects, resulting in fewer students than expected available for retest.

Specific degree subjects fell into five main faculties; these were: Sciences (29.9%), Arts, Media and Design (28.9%), Health (21.3%), Business (13.8%), and Computing, Engineering and Technology (6.1%). The general subjects that are included within each faculty can be seen in Table 6.

		Faculty				
		Arts, Media & Design	Sciences	Computing, Engineering & Technology	Health	Business
General Subject	Film Journalism & Broadcast Media	179 (55.2%)				
	Art & Design	141 (43.5%)				
	Humanities Community & Society	4 (1.2%)				
	Psychology & Mental Health		280 (83.6%)			
	Forensic Science		48 (14.3%)			
	Biological Sciences		4 (1.2%)			
	Geography		3 (0.9%)			
	Entertainment Technology			60 (87.0%)		
	Joint Hons with Major in CE&T			4 (5.8%)		
	Applied Technology & Engineering			4 (5.8%)		
	Applied Computing			1 (1.4%)		

	Faculty				
	Arts, Media & Design	Sciences	Computing, Engineering & Technology	Health	Business
Sport & Exercise				239 (100.0%)	
Accounting & Finance					86 (55.5%)
Business & Management					50 (32.3%)
Marketing					9 (5.8%)
Economics					7 (4.5%)
Human Resource Management					3 (1.9%)

Table 6. Sample summary of number (percentage) of academic subjects within each Faculty

It is worth pointing out that Psychology, sometimes classified as a social science, was part of the Science faculty, with Psychology students making up the majority of participants from this faculty in the current study. As can also be seen in Table 6, the Arts, Media and Design faculty mostly consisted of students studying Journalism or Art. The Computing, Technology and Engineering faculty mostly consisted of students studying Entertainment Technology, for example film production technology. The Health faculty included only those studying Sports and Exercise degrees. The Business faculty consisted of mostly students studying Accounting and Finance, and a large proportion studying Business Management.

To test construct validity a sample of 283 (87 males, 196 females; mean age = 23.19 years; SD = 7.08) undergraduate students was used. This included 64 (22.6%) of the same participants from the main study and consisted of those studying the following subjects: Psychology (49.8%), Applied Science (19.1%), Social Work (10.2%), Sport (7.9%), Geography (5.3%), Computing or Technology (4.2%), and other (<1%).

5.4.2 Missing values

A missing values analysis of the main study data showed that no variable had more than 5% missing cases. After listwise deletion, the sample size was reduced to 1, 123 (97.4%) for the factor analysis of items. The sample size was deemed to remain sufficiently large, with such a high proportion of the original sample, not to warrant an imputation method for missing values. Listwise deletion was employed for all other analyses, including the test-retest reliability analysis. There were no missing values in the sample used to test construct validity.

5.4.3 Mathematics Anxiety Scale U.K.

Consistent with previous maths anxiety measures, the newly devised Mathematics Anxiety Scale – U.K (MAS-U.K) includes a series of statements concerning situations involving maths. For each statement participants are required to respond by indicating how anxious they would feel on a five-point Likert-type scale, ranging from “not at all” to “very much”. Initially, 38 items were devised (see Appendix). These were based on the types of statements used within previously validated scales, along with statements that the researchers felt were appropriate for a British population based on discussions with undergraduate students taking part in the author’s previous research (e.g. Sheffield & Hunt, 2007). Of the initial 38 items, 10 were completely original in comparison to previously validated maths anxiety scales. These were designed to specifically reflect maths experiences of students from a British population. The remaining items were based on those currently available in the MARS (Richardson & Suinn, 1972) or subsequent versions (e.g. Suinn, 2004), but were either heavily or moderately re-worded.

Initial piloting of the scale on 160 undergraduate Psychology students revealed all items to be correlated with the overall scale (minimum r was .48), all items had strong discriminatory power (as assessed using t-tests, $p < .001$, comparing the top and bottom quartiles of the total scale score) and Cronbach's alpha was .96, with no removal of items leading to an improved alpha. All items were therefore retained for the main study, meaning that scores could potentially range from 38 to 190.

5.4.4 Other measures

In order to test the construct validity of the new maths anxiety scale, measures of general trait anxiety and maths ability were taken. Trait anxiety was assessed using the trait scale of the State-Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg & Jacobs, 1984). General maths ability was assessed using a set of 36 mental arithmetic problems, devised to include the four main problem types (addition, multiplication, subtraction & division). These ranged from relatively simple problems, for example 10 ÷ 2, to more complex problems, for example 926 – 763. Overall ability was calculated by the total number of correct responses.

5.5 Analyses

For the main study, prior to conducting an exploratory factor analysis of the 38-item scale, initial data screening revealed most of the items to be highly positively skewed, with some also being highly leptokurtic. Various transformations (reciprocals, logarithms and fractional powers) were attempted but none sufficiently normalised the data. Consequently, items five and ten were removed from the analysis as these had skewness greater than +/- 3 and/or kurtosis +/- 8 and could be considered to be extreme departures from normality (West, Finch & Curran, 1995). In order to attend to the issue of non-normality in the remaining data generally, later analysis included the implementation of the bootstrap procedure. Observation of a random selection of scatterplots revealed no indication of non-linearity amongst items. Plotting Mahalanobis' distance values indicated one potential multivariate outlier that was situated far from the other cases. Confirmatory analysis of the model on the overall sample showed no difference in the results when the outlier was included or excluded. The following results are based on analysis with the exclusion of the outlier. Three commonly used methods for identifying factors were used: eigenvalues greater than unity, observation of the point of inflexion on the scree plot, and parallel analysis. Unless otherwise stated, parametric assumptions for all other analyses, including homogeneity of variance, univariate normality and linearity of relationships, were met.

5.6 Results

5.6.1 Descriptive data

For the main sample, overall mean maths anxiety was 78.79, with a standard deviation of 26.37. A 2 (gender) x 5 (Faculty) two-way between-subjects ANOVA showed a significant main effect of gender, such that females (mean = 82.30; SD = 27.93) were significantly more anxious than males (mean = 74.84; SD = 23.92), $F(1, 1112) = 10.58$, $p < .005$, $\eta^2 = .008$. There was also a significant main effect of Faculty, ($F(4, 1117) = 18.67$, $p < .001$, $\eta^2 = .058$; see Table 7. Follow-up contrasts using Tukey's HSD (see

Table 8) showed that maths anxiety in the Arts, Media and Design faculty was significantly greater than all other faculties excluding Sciences, and the faculty of Sciences had significantly greater anxiety than the Health and Business faculties. Both the Computing and Health faculties also showed significantly greater anxiety than the Business faculty (all $p<.05$). There was no significant interaction between gender and Faculty, $F(4, 1112) = .05$, $p = .995$, $\eta^2 < .001$.

Separate analyses were conducted across degree type. Excluding 127 students who were on courses in which specific module choice results in either a BA or BSc, the sample comprised 540 Bachelor of Arts (BA) students and 455 Bachelor of Science (BSc) students. Results showed no significant difference in maths anxiety levels between BA and BSc students, $t(993) = 0.237$, $p = .81$, two-tailed, $d = 0.02$.

		Mean	SD
	Arts, Media & Design (n = 324)	85.79	27.86
	Sciences (n = 335)	82.12	27.12
Faculty	Computing, Engineering & Technology (n = 69)	76.55	22.25
	Health (n = 239)	74.14	22.26
	Business (n = 155)	65.13	22.44

Table 7. Means and SDs of maths anxiety across Faculties

Faculty Comparison	t	df	d
Arts – Sciences	1.72	657	0.15
Arts - Computing	2.59*	391	0.34
Arts - Health	5.33***	561	0.44
Arts - Business	8.07***	477	0.79
Sciences – Computing	1.60	402	0.25
Sciences – Health	3.74**	572	0.36
Sciences – Business	6.80***	488	0.76
Computing – Health	0.79	306	0.11
Computing – Business	3.53*	222	0.51
Health - Business	3.91**	392	0.40

*p ≤.05 **p≤.01 ***p≤.001

Table 8. Results of post-hoc comparisons of maths anxiety across Faculties

5.6.2 Exploratory factor analysis

Principal axis factoring was employed using a direct oblimin rotation. A high Kaiser-Meyer-Olkin measure (KMO = .973) indicated that sampling adequacy was met and very low values in the diagonal of the anti-image correlation matrix provided further evidence that the data were suitable for factor analysis (Tabachnick & Fidell, 2001). The mean correlation between extracted factors, based on eigenvalues above one, was .43, thus indicating non-orthogonality amongst factors and therefore validating the decision to use a direct oblimin rotation. Initially, using eigenvalues above one as criteria for factor extraction, four factors were extracted. The four factors explained a total of 53.7% of the variance, with 42.6%, 4.8%, 4.5%, and 1.9% of the total variance, being explained by factors one to four respectively. Based on Comrey and Lee's (1992) suggestion that factor loadings in excess of .45 can be considered good, the pattern matrix was explored for factor loadings .45 or higher. This revealed several items that did not load sufficiently on to a single factor. An observation of the scree plot indicated the existence of three factors (see Appendix). This was confirmed via parallel analysis in which only the first three eigenvalues exceeded the criterion values based on 100 random datasets. Therefore, the analysis was re-run specifying the extraction of three factors. The result was a much more parsimonious factorial structure in which 51.7% of the total variance was explained by the three factors. 42.5%, 4.7%, and 4.5% of the variance was explained by factors one to three respectively. Of the thirty six items, 27 had factor loadings of at least .45 but four of those items also loaded on to more than one factor. Therefore, twenty three items were retained and these can be seen in Table 9.

	Factor / Loading		
Item	Maths Evaluation Anxiety	Everyday/Social Maths Anxiety	Maths Observation Anxiety
1. Having someone watch you multiply 12 x 23 on paper	.69		
2. Being asked to write an answer on the board at the front of a maths class	.75		
3. Taking a maths exam	.68		
4. Being asked to calculate £9.36 divided by four in front of several people	.78		
5. Calculating a series of multiplication problems on paper	.47		
6. Being given a surprise maths test in a class	.75		
7. Being asked to memorise a multiplication table	.57		
8. Being asked to calculate three fifths as a percentage	.63		
9. Being asked a maths question by a teacher in front of a class	.80		
10. Adding up a pile of change		.65	
11. Being asked to add up the number of people in a room		.51	
12. Calculating how many days until a person's birthday		.62	
13. Being given a telephone number and having to remember it		.51	
14. Working out how much time you have left before you set off to work or place of study		.60	

15. Working out how much change a cashier should have given you in a shop after buying several items		.60	
16. Deciding how much each person should give you after you buy an object that you are all sharing the cost of		.54	
17. Working out how much your shopping bill comes to		.54	
18. Reading the word “algebra”			.51
19. Listening to someone talk about maths			.76
20. Reading a maths textbook			.77
21. Watching someone work out an algebra problem			.71
22. Sitting in a maths class			.71
23. Watching a teacher/lecturer write equations on the board			.62

Table 9. Factor loadings of retained items on the Mathematics Anxiety Scale-U.K

5.6.3 Internal consistency

Discriminative power analysis showed that all the items significantly ($p < .001$) distinguished between the top and bottom quartiles of the overall scale. A high level of discriminatory power was also found ($p < .001$) when the quartiles were based on sub-samples. Cronbach’s alpha for the overall scale was excellent ($\alpha = .96$), as well as for sub-scales one to three ($\alpha = .92$, $\alpha = .85$, & $\alpha = .89$, respectively).

5.6.4 Test-retest reliability

Test-retest reliability was excellent for the overall scale, $r(129) = .89$, $p < .001$, sub-scale one, $r(129) = .90$, $p < .001$, sub-scale two, $r(129) = .73$, $p < .001$, and sub-scale three, $r(129) = .80$, $p < .001$.

5.6.5 Factor labelling

Items loading on to factor one appear to relate to evaluation of maths ability. These items include reference to testing and examination and also calculation in front of others. Therefore, the first factor was labelled Maths Evaluation Anxiety. Items loading on to factor two appear to relate to calculations that occur in everyday situations, such as adding up a pile of change or having to remember a telephone number. Some of these items also include social implications, for example it is obvious to imagine the potential consequences related to the ability to calculate the number of days until a person's birthday or the ability to turn up to work on time. Therefore, the second factor was labelled Everyday/Social Maths Anxiety. The third factor includes items that appear to relate to observation of maths without any direct calculation. For example, watching a teacher or lecturer write equations on the board or reading a maths text book clearly involve being in a maths context but do not require any direct testing or manipulation of number on the part of the participant. Therefore, the third factor was labelled Maths Observation Anxiety.

5.6.6 Confirmatory factor analysis

A confirmatory factor analysis of the previously extracted factors was performed using AMOS 17. Data were initially assessed for multivariate normality using Mardia's coefficient for multivariate kurtosis, which revealed a high degree of multivariate non-normality (Mardia's coefficient = 203.36, critical ratio = 100.44, for $p = .01$). As goodness of fit indices have been shown to be affected by non-normality these were tentatively interpreted prior to performing the bootstrap procedure to assess the parameter estimates. Confirmatory analysis of the three factors using maximum likelihood estimation resulted in a very large and significant chi-square statistic, $\chi^2(227) = 1546.13$, $p < .001$. However, chi-square is sensitive to sample size (Tabachnick & Fidell, 2001) and non-normality (Henly, 1993; West et al., 1995). Other goodness of fit measures were also considered. CFI = .91 and TLI = .90, both representing an adequate fit by convention, and RMSEA = .07 (CI = .069 to .075), which is less than the .08 cut-off for an adequate fit (Browne & Cudeck, 1993) and close to the recommended .06 cut-off for a good-fitting model (Hu & Bentler, 1999). The standardised RMR was .05, which is less than the .08 cut-off recommended by Hu and Bentler and therefore represents a very good fit. No modification indices indicated obvious improvements to the model. As mentioned though, multivariate non-normality in the data was high, so the bootstrap procedure was employed, including 1000 bootstrap samples. Standardised path coefficients ranged from .502 (item 13) to .834 (item 20), with a mean of .72. Standard errors for the bootstrapped estimates were almost identical to the standard errors in the original model. The bias-corrected confidence intervals around the regression weights for path estimates indicated that each would have to be at least at the 99.9% level before the lower bound value would be zero, thus presenting strong evidence for a well-fitting model. Similarly, the model fitted well for both males (CFI = .90, TLI = .89, RMSEA = .07, SRMR = .06) and females (CFI = .91, TLI = .90, RMSEA = .08, SRMR = .06), with bias-corrected confidence intervals indicating that the regression weights for path estimates would have to be at least at the 99.7% level before the lower bound value would be zero. In addition, a multiple groups analysis provided further support that the model fitted well across both genders (CFI = .90, TLI

= .89, RMSEA = .05, SRMR = .06). A nested model comparison using separate samples of males and females showed almost no change (.002 to .003) in TLI between models in terms of measurement weights, structural covariances and measurement residuals, again providing support for measurement invariance. Indeed, observation of the standardised regression weights for path estimates confirms almost exactly the same values for both the male and female samples.

Due to the variation in sample size, including low participant numbers across faculties, the results of a confirmatory factor analysis were tentatively interpreted across four of the faculties, preferring to consider the standardised mean residuals and RMSEA, as these have been shown to be goodness of fit measures least affected by sample size (Hu & Bentler, 1998). Bootstrapped bias-corrected 90% confidence intervals around the regression weights were also considered as a key measure of model fit. The Computing faculty was excluded from the analysis due to a particularly low sample size ($n = 69$). Results showed that the standardised mean residuals ranged from .06 to .08. RMSEA ranged from .07 to .10. Bootstrapped bias-corrected confidence intervals around the regression weights for the path coefficients indicated that each would have to be at least at the 99.7% level before the lower bound value would be zero. Together, this indicated an adequate to good model fit across faculties.

5.6.7 Construct validity

The mean number of correct responses on the basic maths test was 29.04 (81%) with a standard deviation of 4.24. Mean maths anxiety was 79.18 ($SD = 26.08$) and mean trait anxiety was 45.36 ($SD = 4.82$). Using two-tailed tests, a significant but small correlation was found between maths anxiety and trait anxiety, $r(281) = .22$, $p < .001$. Maths anxiety was found to be significantly negatively correlated with basic maths performance, $r(281) = -.40$, $p < .001$, but no significant relationship was found between trait anxiety and performance, $r(281) = -.06$, $p = .31$.

5.6.8 Gender and maths anxiety sub-scales

Further analysis (alpha adjusted to .017 using a bonferroni correction) using the three sub-scales showed that females (mean = 20.30; SD = 6.97) were significantly more anxious than males (mean = 17.32; SD = 6.06) on the maths evaluation sub-scale, $t(1120) = 7.60$, $p < .001$, two-tailed, $d = 0.45$. Females (mean = 10.57; SD = 5.31) were also more anxious than males (mean = 9.95; SD = 4.62) on the maths observation anxiety sub-scale, $t(1120) = 2.11$, $p = .037$, two-tailed, $d = 0.16$. However, there was no significant difference between females (mean = 13.59; SD = 5.09) and males (mean = 13.50; SD = 4.70) on the everyday/social maths anxiety sub-scale, $t(1120) = .28$, $p = .79$, two-tailed, $d = 0.02$. Age was significantly positively correlated with total maths anxiety, $p = .004$, two-tailed. Nonetheless, the relationship was very small, $r(1196) = .09$.

5.7 Discussion

Using a large sample of undergraduate students, this study was designed to develop a measure of maths anxiety suitable for a British undergraduate student population. Three key aims were addressed. Firstly, items on the MAS-U.K include terminology suitable for a non-North American population. Until now researchers wishing to study maths anxiety within a British population have used scales previously validated largely on a North American population. This has resulted in terminological uncertainty that can potentially affect the scales' validity. It is hoped that the newly devised scale will aid researchers using participants from a British population and will eliminate the need to modify existing scales. This, along with the size of the scale (23 items), means that administration time is kept to a minimum. It is also possible that the MAS-U.K might be useful for European studies.

Secondly, the current study provides some much needed normative data regarding maths anxiety in a British population. Of particular interest is the observed gender effect; overall maths anxiety was significantly greater in females than males. This is consistent with several previous findings (e.g. Dew et al., 1983; Hembree, 1990; Ashcraft & Faust, 1994; Baloglu & Kocak, 2006). However, upon closer inspection the gender effect was mostly confined to the maths evaluation anxiety sub-scale, with only small effects observed for the everyday/social maths anxiety and observation maths anxiety sub-scales. Also, maths anxiety was compared across academic subject areas. The highest maths anxiety levels were found in the Arts, Media and Design faculty. This is no surprise given that such subjects as Art and Journalism involve little to no maths course content. The lowest maths anxiety levels were found in the Business faculty. Again, this is not surprising given that this faculty contains subjects such as Accountancy in which the maths content is comparatively high[4]. Maths anxiety levels amongst students studying in the Sciences faculty were higher than expected. One explanation for this could be that the majority of those students were studying Psychology, in which the maths content might far exceed students' expectations. Unfortunately the University does not provide degrees in other science subjects, such as Physics or Chemistry, from which comparisons could be made with Psychology students, but one assumption is that maths anxiety levels would be less amongst students in the natural sciences.

[4] It could be seen as counterintuitive that maths anxiety was lower in the Business Faculty than in the Computing, Engineering and Technology Faculty, but it should be noted that Accountancy and Finance students made up the largest proportion of students in the Business Faculty and the Computing, Engineering and Technology Faculty sample comprised mainly of Entertainment Technology students, in which the maths content of the course is much less than would be found in other specific subjects, e.g. Computing.

Thirdly, the MAS-U.K has a parsimonious factorial structure, with sub-scales that make intuitive sense. These are Maths Evaluation Anxiety, Everyday/Social Maths Anxiety, and Maths Observation Anxiety. The first sub-scale, Maths Evaluation Anxiety, explained the largest share (42.5%) of the variance in maths anxiety scores. This is in line with existing scales in which a maths evaluation or test anxiety sub-scale has been shown to explain most of the variance (e.g. Alexander & Martray, 1989; Suinn & Winston, 2003), and provides some support for the validity of the new scale. The Everyday/Social Maths Anxiety sub-scale includes items related to everyday numerical calculations, often in a social context, whereas the Maths Observation Anxiety sub-scale includes items related to experience of maths without immediate involvement or direct calculation. It is worthwhile noting that a separate numerical or calculation anxiety sub-scale has not been identified. Careful observation of items potentially pertaining to such a factor suggests that subtle wording may have forced those items on to factors specific to a type of numerical anxiety. For example, even though it contains an explicit calculation, the item "being asked to calculate three fifths as a percentage" pertains to an evaluation of the person's ability to calculate the problem successfully. This item loaded quite heavily on to the Maths Evaluation Anxiety sub-scale. Similarly, the item "calculating how many days until a person's birthday", again, involves "calculation" but is typical of items in the Everyday/Social Maths Anxiety sub-scale that pertain to maths specifically in a more everyday or social setting, as opposed to a learning environment.

A confirmatory factor analysis demonstrated that the proposed model was a good fit and further testing showed the MAS-U.K to have excellent internal consistency and high test-retest reliability. A separate study of construct validity found scores on the new maths anxiety scale to be significantly and moderately correlated with both basic maths performance and general trait anxiety. Absence of a correlation between trait anxiety and maths performance provided further support for the construct validity of the new scale.

Further testing of the psychometric properties of the MAS-U.K, including tests of concurrent validity, is needed prior to its implementation as a diagnostic tool. However, the information presented here provides strong support for the reliability and validity of the scale as a measure of maths anxiety and supports previous findings that demonstrate maths anxiety to be a multidimensional construct. It is hoped that the MAS-U.K proves to be a useful measure in future empirical research into maths anxiety and, compared to existing measures, may be more suited to a British and potentially European undergraduate student population. Further work is needed in order to acquire normative data for maths anxiety in the general British and European populations.

Having successfully addressed the terminological issues that arose with the use of the MARS in study one and as a result of the partial validation and high level of test-retest reliability and internal consistency found in the MAS-U.K, the MAS-U.K was employed in the subsequent studies described in chapters six and seven of this thesis.

Mathematics Anxiety Scale-U.K (MAS-U.K)

	How anxious would you feel in the following situations?........Please circle the appropriate numbers below.				
	Not at all	Slightly	A fair amount	Much	Very much
1. Having someone watch you multiply 12 x 23 on paper.	1	2	3	4	5
2. Adding up a pile of change.	1	2	3	4	5
3. Being asked to write an answer on the board at the front of a maths class.	1	2	3	4	5
4. Being asked to add up the number of people in a room.	1	2	3	4	5
5. Calculating how many days until a person's birthday.	1	2	3	4	5
6. Taking a maths exam.	1	2	3	4	5
7. Being asked to calculate £9.36 divided by four in front of several people.	1	2	3	4	5
8. Being given a telephone number and having to remember it.	1	2	3	4	5
9. Reading the word "algebra".	1	2	3	4	5
10. Calculating a series of multiplication problems on paper.	1	2	3	4	5
11. Working out how much time you have left before you set off to work or place of study.	1	2	3	4	5
12. Listening to someone talk about maths.	1	2	3	4	5
13. Working out how much change a cashier should have given you in a shop after buying several items.	1	2	3	4	5
14. Deciding how much each person should give you after you buy an object that you are all sharing the cost of.	1	2	3	4	5
15. Reading a maths textbook.	1	2	3	4	5
16. Watching someone work out an algebra problem.	1	2	3	4	5
17. Sitting in a maths class.	1	2	3	4	5
18. Being given a surprise maths test in a class.	1	2	3	4	5
19. Being asked to memorise a multiplication table.	1	2	3	4	5
20. Watching a teacher/lecturer write equations on the board.	1	2	3	4	5
21. Being asked to calculate three fifths as a percentage.	1	2	3	4	5
22. Working out how much your shopping bill comes to.	1	2	3	4	5
23. Being asked a maths question by a teacher in front of a class.	1	2	3	4	5

CHAPTER SIX

6. Explaining the relationship between mathematics anxiety and performance: An exploration of the role of cognitive intrusions

6.1 Introduction

Having established no apparent neuropsychological basis for the observed relationship between maths anxiety and performance in study one (Chapter Four), and using the newly developed Mathematics Anxiety Scale U.K (Chapter Five), the study reported in this chapter aimed to investigate one of the most common explanations given for maths anxiety effects: the role of cognitive intrusions and interference in working memory processes – in this case mental arithmetic. To date, to the best of the author's knowledge, no research into maths anxiety has attempted to measure self-reported impact of in-task intrusive thoughts. The study presented in this chapter will provide a much needed test of related theories and serves as the next step in identifying mechanisms underpinning the maths anxiety to performance relationship.

6.2 Background

As noted previously, mathematics anxiety can be described as "a feeling of tension and anxiety that interferes with the manipulation of numbers and the solving of mathematical problems in a wide variety of ordinary life and academic situations" (Richardson & Suinn, 1972, p.551). Increased physiological reactions to mathematical problem solving have been demonstrated in a wide range of studies that have used maths to purposely induce a high state of anxiety (e.g. Ley & Yelich, 1998; Gerra et al., 2001; Ring et al., 2002) and in relation to maths performance itself, two meta analyses have shown a negative correlation between maths anxiety and overall maths performance (Hembree, 1990; Ma, 1999). This relationship is often discussed in relation to working memory processes and there is now considerable evidence to support the role of working memory in mathematical cognition (Ashcraft & Krause, 2007). For example, findings have demonstrated that larger problems rely more heavily on procedural, and therefore working memory, processes, whereas smaller problems are often solved via direct retrieval (Ashcraft & Battaglia, 1978). Also, studies have shown the central executive to be important in handling carry operations (Imbo et al., 2007), and the phonological loop is clearly involved in mental arithmetic involving multiple digits (e.g. Ashcraft & Kirk, 2001).

More specifically, research has demonstrated that maths anxiety is negatively related to performance on complex, much more than simple, arithmetic (e.g. Ashcraft & Faust, 1994), and particularly when a problem involves a carry operation (Faust et al., 1996; Green et al., 2007). Further, Ashcraft and Kirk (2001) found that percentage of errors on carry problems was greatest when maths anxiety was aroused and participants had to perform a concurrent letter-recall task. They discussed their findings in relation to consumption of working memory resources. That is, high levels of maths anxiety already compromised working memory, so the additional demands of a secondary task consumed working memory resources even further, leading to poor performance.

Researchers have also discussed the maths anxiety to performance relationship in terms of the influence of intrusive thoughts. Hopko, Ashcraft, Gute, Ruggiero and Lewis (1998) suggested an integration of processing efficiency theory (Eysenck & Calvo, 1992) with inhibition theory (Hasher & Zacks, 1988; Connelly, et al., 1991). Processing efficiency theory, designed to explain the interactional effects of state anxiety and situational threat or stress on performance, posits that worry, that is, the cognitive component of state anxiety (Morris, Davis & Hutchings, 1981), pre-empts task-related working memory processes, particularly relating to the central executive component of the working memory model (Baddeley & Hitch, 1974; Baddeley, 1986). It also proposes that, as task demands on working memory capacity increase, adverse effects of anxiety on task performance generally become stronger. Further, efficiency, more than effectiveness, is characteristically impaired by anxiety.

Linked to processing efficiency theory is inhibition theory (Hasher & Zacks, 1988; Connelly et al., 1991), which proposes that there is a mechanism for suppressing, or inhibiting, task-irrelevant distracters. Therefore, according to the model, if information that is irrelevant to the task at hand is adequately inhibited by the mechanism, then the task can be performed effectively. If, however, the mechanism is not working adequately then task-irrelevant information may interfere with working memory processes and consequently result in poor performance. Indeed, Hopko et al. (1998) demonstrated that high and medium maths anxious groups took significantly longer than a low maths anxious group to read through text that included irrelevant, but maths-related, information. Interestingly, maths anxious participants also took longer to read text that contained non-maths related distracters, suggesting a relationship between maths anxiety and a general deficient inhibition mechanism. Later research (Hopko et al., 2002) also highlighted the relationship between maths anxiety and inhibitory deficits. They used a Stroop paradigm to demonstrate that response times were significantly longer on a Stroop-like numeric task, compared to the standard Stroop colour-naming task. Hopko et al. (1998) went on to propose that the existence of task-irrelevant thoughts (worrisome or troublesome thoughts) alone may not be responsible for poor performance amongst maths anxious individuals. Rather, it may be their inability to divert attention away from the worry and to the task at hand.

Eysenck et al. (2007) have more recently proposed the attentional control theory. This represents a development of Eysenck and Calvo's (1992) processing efficiency theory and focuses heavily on functioning of the central executive. In particular, attentional control theory proposes that attentional processes are integral to understanding anxiety effects and suggests that attention is often directed towards threatening stimuli (whether internal, e.g. worrisome thoughts, or external, e.g. threatening task-related distracters) and to ways in which the individual can respond. This means that attention is then directed away from the concurrent (goal-related) task, that is, attentional control is reduced. One particular feature of attentional control theory that may help explain maths anxiety effects is that related to the updating or monitoring of information. The theory suggests that anxiety is likely to adversely affect the ability to transiently maintain information. Thus, this may prove to be a useful explanation of the previous finding that, compared to those low in maths anxiety, individuals high in maths anxiety perform worse on mental arithmetic requiring the transitory maintenance of a carry term (e.g. Faust et al., 1996). A further specific feature of attentional control theory that can be strongly linked to maths anxiety effects is that which relates to increased effort. According to Eysenck et al. (2007), high anxiety is related to increased effort. Accordingly, performance effectiveness is not necessarily affected, but performance efficiency is. Furthermore, they note how incentives have been shown to increase performance in low anxious individuals, but not in high anxious individuals (e.g. Calvo, 1985; Eysenck, 1985); possibly because effort is already increased in those who are highly anxious.

To test hypotheses related to working memory, worry and maths anxiety effects, researchers have devised experiments in which specific aspects of anxiety are manipulated. Kellogg et al. (1999) tested the hypothesis that time pressure may be one component contributing to worry. They found that performance was negatively affected by a timed, compared to untimed, condition, but this was not differentiated by maths anxiety levels. Rather than continue to manipulate level of worry, Hopko et al. (2003) later manipulated the emotionality component of anxiety, outlined by Salame (1984). They found that the administration of carbon dioxide to participants during mental arithmetic and lexical decision tasks was a reliable method for inducing anxiety. However, performance did not differ as a function of carbon dioxide. High maths anxious individuals, though, did exhibit higher error rates on mathematical tasks, particularly those involving working memory resources. The authors discussed these findings with reference to processing efficiency theory. Specifically, that task-irrelevant information, such as worrisome thoughts, may have produced interference effects resulting in fewer available working memory resources and an increased likelihood of making errors.

General support for the processing efficiency explanation of the maths anxiety-performance relationship was provided by Miller and Bichsel (2004). They tested the assumption that, should the processing efficiency explanation be accurate, high maths anxious individuals with greater working memory spans would demonstrate better maths performance than those high math anxious individuals with lower working memory spans. Indeed, their results showed that, in individuals with high maths anxiety, those with high working memory capacity (both verbal and visual) performed better than those with low working memory capacity on basic maths problems. Interestingly, though, zero-order correlations showed that maths anxiety was not significantly correlated with verbal working memory span. Instead, visual working memory was found to be significantly negatively correlated with maths anxiety, even though visual working memory span was assessed using a paper-folding task and did not involve numerical stimuli. However, it should be noted that the verbal working memory span task that Miller and Bischel used was actually a test of reading span and did not involve computation. Ashcraft and Kirk (2001), on the other hand, included separate measures of listening span and computation span in a study of maths anxiety and performance. After partialling out variance in listening span computation span remained significantly negatively correlated with maths anxiety; listening span, however, was not related to maths anxiety once computation span was partialled out. Ashcraft and Kirk suggest that such relationships are indicative of an online maths anxiety effect. That is, computation span is negatively affected because of the anxiety-inducing reaction that computation produces; something that does not occur with non-computational stimuli, such as in a listening or word-reading task. Whilst a general maths anxiety to performance effect has been noted (Hembree, 1990), others have also found that imposing additional working memory load can differentially affect performance of maths anxious compared to non-maths anxious individuals (Ashcraft & Kirk, 2001). According to Ashcraft and Kirk, those that have high maths anxiety, adding a task that increases working memory load reduces performance on maths tasks in which an anxious reaction is already limiting the amount of working memory resources that are available. Accordingly, in low maths anxious individuals, increasing working memory load with a secondary task does not produce the same "affective drop" in performance. Such findings in relation to maths anxiety actually mirror those observed when studying general anxiety effects on performance and restrictions in working memory resources (e.g. MacLeod & Donnellan, 1993).

Recently, Hayes et al. (2009) investigated the dissociation of the influence of working memory capacity and increased investment in effort. They presented high and low trait anxious individuals with category learning tasks (pairing faces with previously associated pleasant or unpleasant sounds) in incidental and intentional learning conditions. In addition, these were either capacity or not capacity dependent. Consistent with Eysenck et al.'s (2007) attentional control theory, performance on a capacity-dependent task was disproportionately poor amongst those who were high in trait anxiety relative to those low in anxiety. Confirming their second hypothesis, they found this effect to only be present under incidental learning conditions. Under intentional learning conditions performance was the same across low and high anxious groups. Hayes et al. suggest that the intentional learning condition invoked effortful learning in which high anxious individuals were able to manipulate the effort invested to successfully achieve the task goal(s). According to Hayes et al., this can be explained by attentional control theory in that increased effort can result in partial recovery of the working memory resources required for successful task completion. However, in their study it was assumed that an intentional learning condition induced an increase in effort towards the task specifically. Given that self-reported effort was not explicitly measured it is difficult to determine the way in which participants increased effort and attentional control. For example, it is possible that effort was initially focused towards dealing with intrusive thoughts or worries which then consequently influenced task effort at a more general level. Further research is clearly needed in order to test this.

Whilst previous research has made reference to worrisome or irrelevant thoughts in explaining the impact that maths anxiety may have on reducing available working memory resources, surprisingly little research has attempted to examine the influence of worrisome thoughts on arithmetic performance. Hunsley (1987), however, measured maths anxiety, test anxiety, performance appraisals, internal dialogue and performance attributions amongst students before and after five of their midterm examinations in statistics. He found that maths and test anxiety together accounted for 25% of the variance in participants' negative internal dialogue, as measured using the Cognitive Interference Questionnaire (CIQ, Sarason, 1978). This required participants to rate (on a five-point scale) the frequency with which they experienced ten negative thoughts during the exam. Results showed that maths anxiety alone accounted for 15% of the variance. Unfortunately specific results pertaining to individual items on the Cognitive Interference Questionnaire are not provided, so it is difficult to assess the impact of particular aspects of negative internal dialogue that may be associated with maths anxiety and performance. Test anxiety was the only variable to significantly predict actual exam performance (grade). However, the course on which students were enrolled was a statistics course and, without being informed of the exact content of it, may not bear the same relevance to maths anxiety, as performance on a maths course might. This study is, however, still useful in that it provides some evidence to support the argument that there is a relationship between maths anxiety and negative internal dialogue (or intrusive thoughts). Clearly, examination of specific forms of mathematical testing is still required in order to develop better understanding of performance in relation to arithmetic and also maths as oppose to statistics.

More recently, Beilock, Kulp, Holt and Carr (2004) investigated the nature of 'choking under pressure'. That is, high-pressured situations may result in sub-optimal skill execution. They created high and low pressured conditions, where the high pressure condition involved multiple sources of pressure, including monetary incentives, peer pressure and social evaluation. Consistent with distraction theories of task performance, for example Lewis and Linder (1997), Beilock et al. observed that modular maths involving high working memory demands (with the inclusion of borrowing) was performed at a significantly lower level of accuracy in the high pressure condition, compared to the low pressure condition. More importantly here, they also found that those in the high pressure condition had significantly increased perceptions of performance pressure. This was assessed using a retrospective verbal thought questionnaire in which participants were required to write down any thoughts that occurred during the preceding maths task. The reduction of responses into categories revealed that over half related to thoughts and worries about the high pressure situation and its consequences. Therefore, Beilock et al.'s findings give support to the idea that poor performance may, in part, be due to inefficient processing of worrisome or distracting thoughts. However, maths anxiety was not included as a measure, so its relationship with intrusive thoughts and actual performance is still not clear.

A later study does provide some further support for the argument that worry during maths performance may in fact be a predictor of performance. Beilock, Rydell and McConnell (2007) investigated maths performance amongst two groups of women at University. One group was informed of the stereotype that men are better than women at maths, whereas the other group did not receive the information. Beilock et al. hypothesised that women who received the stereotype information would perform worse than the women who did not receive it, proposing that such information would elicit a stereotype threat and induced worry about performance. Based on the proposition that maths problems presented in horizontal format, compared to those presented in vertical format, rely more heavily on verbal or phonological working memory resources (Trbovich & LeFevre, 2003), Beilock et al. also predicted that the stereotype threat effect would only be present in response to those problems presented horizontally. This is indeed what they found. In addition, they also describe how women in the stereotype threat condition reported a greater degree of worry relating to the experimental situation and its consequences than controls did. They suggest that worry, in this case relating to stereotype threat and performance, depletes the working memory resources required for effective performance on maths problems and because horizonatally presented maths problems rely heavily on those same, verbal, resources, such depletion in resources has a detrimental influence on performance.

6.3 Introduction to study three

In order to provide support for the processing efficiency, deficient inhibition and attentional control explanations of the maths anxiety-performance relationship, the exact nature of the negative internal dialogue that participants may experience during maths performance, as well as its actual impact, need to be further explored. The current study aimed to do this by using a modified version of the Cognitive Intrusions Questionnaire (CIQ, Freeston et al., 1991) to examine the types and level of severity of thoughts experienced during a maths task, allowing detailed examination of the relationships between specific thoughts, maths anxiety and maths performance. There were several hypotheses and these are listed below:-

i) In line with previous findings (e.g. Faust et al., 1996), it was hypothesised that there would be a negative relationship between maths anxiety and performance (increased errors and longer response times) on complex addition problems involving a carry operation, but no relationship when a carry operation is not required.

ii) Further, it was hypothesised that there would be a positive relationship between self-reported impact of intrusive thoughts and performance. There were no expectations regarding specific maths/task related thoughts apart from the expectation that non-maths/task related thoughts would not be related to maths anxiety or performance.

iii) Furthermore, in line with the integration of processing efficiency theory (Eysenck & Calvo, 1992) (and the later attentional control theory, Eysenck et al., 2007) and inhibition theory (Hasher & Zacks, 1988; Connelly, et al., 1991) suggested by Hopko et al. (1998), it was expected that a joint relationship will exist between maths anxiety and intrusive thoughts regarding performance on problems involving a carry operation, such that as maths anxiety and impact of intrusive thoughts increase, performance will decrease.

iv) Self-reported effort (to reduce cognitive intrusions) was also assessed to test the hypothesis that maths anxiety would be related to increased effort, to which performance efficiency (response time) would be adversely affected.

v) Consistent with Hayes et al.'s (2009) finding that a performance (effectiveness) decrement was not apparent in high anxious individuals when increased task effort was assumed, it was further hypothesised that maths anxiety would interact with self-reported effort in reducing the impact of intrusive thoughts when predicting performance effectiveness.

The study also included a measure of trait anxiety, taken from the State-Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg & Jacobs, 1984) due to the moderate correlation previously found between trait anxiety and maths anxiety (Hembree, 1990; Zettle & Raines, 2000), and the obvious potential relationship between trait anxiety and cognitive intrusions.

6.4 Method

6.4.1 Participants

Participants were 122 (31 men, 91 women) undergraduate Psychology students from Staffordshire University and the University of Derby, U.K. Ages ranged from 18 to 51 years (mean = 24.95; SD = 8.76). Participants took part in exchange for undergraduate research scheme vouchers and came from an opportunity sample gained via advertising at the Universities.

6.4.2 Questionnaire measures

The newly developed Mathematics Anxiety Scale-U.K (MAS-U.K, Hunt et al., in press) was used. This is a 23-item scale that uses a five-point Likert-type scale and asks participants to respond how anxious they would feel in a variety of specific situations involving maths (please refer to Chapter Five for further details, including tests of reliability and validity).

In order to measure intrusive thoughts that may occur during arithmetical problem solving items from the Cognitive Intrusions Questionnaire (Freeston et al., 1991, English translation by Freeston, 1994) were selected and modified. The first part of the original questionnaire involves a list of thoughts that participants are required to tick if they experienced them during a preceding task. This was modified so that the list only contained thoughts related specifically to the maths task undertaken: "making mistakes", "time pressure", "method of problem solving", "what people would think", "panicking", "previous maths experiences", and "physical changes". As with the original scale, this was followed by the option for participants to write down additional thoughts or expand on those that were ticked. This was followed by a series of items, using a five-point Likert-type scale, relating to different aspects of the "most worrisome or troubling" thoughts. Wording of the original items was modified so that each one specifically related to the maths task and pertained to the following: frequency of the thoughts, difficulty in removing the thoughts, extent to which the thoughts impeded calculation, and the amount of effort used to stop/reduce the thoughts.

A final question asked participants to indicate whether they had experienced intrusive thoughts that were non-maths-task related, for example relationship problems or health problems, by placing a tick next to possible thoughts in list format. Again, there was the option for participants to write down additional thoughts or expand on those that were ticked.

Using the experiment-building software E-prime, eighty two-digit addition problems were presented via a verification task, for example '37 + 18 = 52'. Sixty of these problems had a solution that was true, with the remaining twenty having a solution that was false. Of the sixty true problems, thirty required a carry operation to achieve the correct solution, for example "17 + 18 = 35", and thirty involved no carry, for example "17 + 12 = 29". Addends were randomly taken from a range of 10-89. Problem-size was counterbalanced across addends and carry/no-carry conditions so that performance could be attributed to factors other than the size of the problems. Problems where both addends ending in zero decades, for example '20 + 30', or fives, for example '25 + 35', were not included. The false problems were divided equally with splits of +/- 1, +/- 3, and +/- 5. There were an equal number of positive and negative splits.

Participants gave informed consent to take part in a study involving maths and, prior to the arithmetic task, participants were required to complete the mathematics anxiety scale. Stimuli were presented in the centre of a VDU, in Times New Roman size 40 bold font. Following the on-screen instructions and five practice trials, participants were asked to respond 'true' or 'false' to the proposed answers. This was achieved by pressing the 'z' and 'm' keys on a keyboard, for 'true' and 'false', respectively. There was no time limit for participants to respond. After responding, a pause screen, consisting of '+++++', appeared, and this remained until participants pressed one of the keys to proceed to the next trial.

Immediately after completion of the arithmetic task, participants completed the cognitive intrusions questionnaire. Following this, participants were debriefed and thanked.

6.5 Results

6.5.1 General data screening and diagnostic checks

Visual inspection of histograms of the data showed the data to be sufficiently univariately normally distributed. For each regression, normality of standardised residuals was tested by visual inspection of histograms; these were found to be normal. Standardised residuals and standardised predicted values were also plotted against each and no obvious curvilinear relationships were apparent, with the display also indicating the presence of homoscedasticity. Checks for bivariate outliers were also made using scattergraphs and no outliers were identified. In order to test for multivariate outliers Cook's distance and leverage values were plotted against each and no cases appeared to obviously deviate from the main cluster of cases. In addition, checks of tolerance values and variance proportions indicated that there were no problems with multicollinearity among the data (see Appendix for examples of each of the above).

6.5.2 Problem type analysis

A within-subjects t-test was used to compare the difference in percent of errors between problems with (mean = 5.13; SD = 5.72) and problems without (mean = 2.39; SD = 3.32) a carry term. Significantly more errors were made in response to problems that included a carry term, $t(121) = 5.24$, $p < .001$, two-tailed test. The effect size (d) was 0.58, indicating a medium effect (Cohen, 1988). A within-subjects t-test was also used to compare response time (ms) to respond correctly to the two types of problem.

Participants took significantly longer to respond to problems including a carry term (mean = 5730.97; SD = 1696.32) than to problems not including a carry term (mean = 3845.15; SD = 1052.82), $t(121) = 20.60$, $p < .001$, two-tailed test. The effect size (d) was 1.34, indicating a very large effect (Cohen, 1988).

6.5.3 Zero-order correlations

The zero-order correlations between all variables can be seen in Table 10. Total maths anxiety, maths evaluation anxiety and maths observation anxiety were all significantly positively correlated with percentage of errors to problems involving a carry operation but were not correlated with percentage of errors to no-carry problems. Total maths anxiety, maths evaluation anxiety, and social/everyday maths anxiety were significantly positively correlated with response time to both problems involving a carry operation and problems that did not involve a carry operation, with maths evaluation anxiety demonstrating the strongest correlations. However, no significant correlations were observed between maths observation anxiety and response times.

Gender was significantly positively correlated with maths anxiety, such that females were more anxious than males. Experience of intrusive thought(s) related to making mistakes was highly significantly positively related to percentage of errors made in response to carry-problems. Intrusive thought(s) related to time pressure was also significantly positively related to percentage of errors to carry-problems, albeit only moderately. With the exception of thoughts relating to physical changes, there were no significant correlations between the variables and percentage of errors to no-carry problems. Frequency of the most troublesome/worrisome thought, difficulty removing the thought, effort to reduce the thought, and perceived impedance on calculation were significantly positively related to percentage of errors to carry-problems. There were no such significant relationships with percentage of errors to no-carry problems. Thoughts about time pressure were highly significantly positively correlated with response time to both carry-problems and no-carry problems. Thoughts about previous maths experiences, perceived frequency of the most troublesome/worrisome thought, effort to reduce thoughts and perceived impedance of thoughts on calculation were significantly positively correlated with response time to both carry-problems and no-carry problems. Maths anxiety total score was significantly positively correlated with several specific intrusive thoughts, including making mistakes, time pressure, what people will think, panicking, previous maths experiences, physical changes, and other non-task related problems. Maths anxiety was also very strongly and highly significantly positively correlated with perceived frequency of the most troublesome/worrisome thought, effort to reduce thoughts and perceived impedance of thoughts on calculation. A similar pattern was observed for the maths anxiety sub-scales, with some non-significant relationships with specific intrusions. Perceived frequency of the most troublesome/worrisome thought was strongly and highly significantly correlated with perceived difficulty in removing thoughts, effort to reduce the impact of thoughts and perceived impedance on calculation. In addition, there was a very strong and highly significant correlation between perceived difficulty in removing unwanted thoughts and effort to reduce thoughts. Strong and significant correlations were also found between difficulty in removing thoughts, effort to reduce thoughts and perceived impedance on calculations.

6.5.4 Regression models

6.5.4.1 Excluded variables

In the study presented in Chapter Five trait anxiety was found to not be related to performance, but, given the nature of the current study, that is, focusing on cognitive intrusions, it was felt that it would be appropriate to include a general measure of trait anxiety. However, the zero-order correlations showed no relationship between trait anxiety and error rates and response time. In addition, the regression models demonstrated trait anxiety to be a suppressor variable. That is, trait anxiety explained a sufficient amount of error variance in maths anxiety for the maths anxiety Beta value to increase when controlling for trait anxiety. Also, the sum of the squared semi-partial correlation between trait anxiety and response time to carry problems (.03) was greater than the squared zero-order correlation between the two variables (< .001), providing further support for a suppressor effect according to Velicer's (1978) definition of suppression. In addition, trait anxiety was identified as the suppressor because, having noted the zero-order correlation between trait anxiety and response being very close to zero, the standardised beta coefficient between trait anxiety and response time was opposite to that of its zero-order correlation with maths anxiety, which is consistent with Cohen and Cohen's (1975) description of a suppressor effect. Therefore, the resultant suppressor effect on maths anxiety gave appropriate justification to exclude trait anxiety from the regression analyses.

In the current study initial regression models included specific intrusive thoughts of making mistakes and time pressure as predictors. However, due to the fact that time pressure was very highly significantly correlated with response time and making mistakes was very highly significantly correlated with percentage of errors made, the decision was made to exclude both variables from the final regression models. This decision was based on the difficulty in separating the extent to which those thoughts occurred during actual task performance and the extent to which the self-reported thoughts represent a post hoc reflection about the preceding behavioural responses. More specifically, thoughts about time pressure are assumed to be related to the actual time taken; similarly thoughts about making mistakes are assumed to be related to the actual number of errors made. Exclusion of these variables provides a clearer picture of the predictive nature of the remaining variables.

Age was found to be positively skewed, with the majority of ages being in the range of 18 to 22 years. However, age was not considered to be greatly theoretically important in the current study, and, taking into consideration the impact of including a skewed variable in the regression models, age was also excluded.

Initially participants were asked to select from a list which non-task related intrusive thoughts they had experienced. However, the results demonstrated a bi-modal distribution. Therefore the decision was made to dichotomise the variable into the levels "yes" (at least one non-task related thought) and "no" (no non-task related thoughts), to represent experience of non-task related thoughts.

6.5.4.2 Hierarchical sequence of predictors

A series of hierarchical multiple regressions were conducted. In all models tested, prior to inclusion of product terms, gender was included in the first step. Maths anxiety was included in the second step, followed by all specific self-reported intrusive thoughts at step three. Step four included variables related to the self-reporting impact of the most troublesome/worrisome thought, including frequency of the thought, difficulty in removing the thought, and impact of the thought on the calculation process. Finally, step five included self-reported effort in reducing the impact of the thought. The four main regression models included the regression of response time and percentage of errors to carry-problems and no-carry problems onto the above variables.

6.5.4.3 Percentage of errors on carry problems

The final model was not significant, $F(12, 109) = 1.571$, $p = .11$, accounting for 14.7% (Adj $R^2 = 5.4$) of the variance in percentage of errors to carry problems. As shown in Table 11, whilst maths anxiety was a significant predictor at step 2, it became non-significant at step 3, remaining non-significant. All other predictor variables were non-significant, with the exception of the variable impeding calculation, representing the level of which the most troublesome/worrisome thought impeded the participant's calculation of the maths problems. Impeding calculation was significantly positively related to percentage of errors to carry problems and remained so in the final step.

6.5.4.4 Percentage of errors on no-carry problems

The final model was not significant, $F(12, 109) = 1.04$, $p = .42$, accounting for 10.3% (Adj $R^2 = .004$) of the variance in percentage of errors to carry problems. As shown in Table 12, the only variable that is significant upon entering the regression, and remains significant in the final step, is the physical changes variable; that is, thoughts about physical changes during task performance was significantly negatively correlated with percentage of errors to no-carry problems.

6.5.4.5 Response time to carry problems

The final model was significant, $F(12, 109) = 2.19$, $p = .017$, accounting for 19.4% (Adj $R^2 = 10.6$) of the variance in response time to problems involving a carry operation. As shown in Table 13, gender did not add significantly to the model, although maths anxiety had a high level of predictive power, being significantly positively related to response time to carry problems and explaining an additional 9.6% of the variance. Inclusion of self-reported intrusive thoughts, as a whole, did not add significantly to the model despite explaining an additional 6.9% of the variance. However, upon closer inspection of step three, thoughts about previous maths experiences was significantly positively related to response time. Maths anxiety and thoughts about previous maths experiences remain significant through steps four and five, although no other variables added significantly to the model. Interestingly, whilst thoughts about panicking remained non-significant throughout the hierarchical steps, it was significantly and negatively related to response time to carry-problems in the final step once self-reported effort to reduce the impact of the thoughts had been entered.

6.5.4.6 Response time to no-carry problems

The final model was significant, $F(12, 109) = 2.04$, $p = .027$, accounting for 18.3% (Adj $R^2 = 9.3$) of the variance in response time to problems that did not involve a carry operation. As shown in Table 14, with the exception of thoughts about previous maths experiences significantly predicting response time at step three, in the final model the only significant predictor was maths anxiety.

6.5.4.7 Split-half analysis

In order to analyse possible changes across time during task performance, an exploratory analysis with response time as the outcome measure was performed by running the same regression models for the first half of the trials and again for the second half of the trials. First half and second half error analyses were not performed due to the low numbers of possible errors as a result of dividing the trials in two.

With response time to carry problems as the outcome measure and only including the first half of the trials, the final model was significant, $F(12, 109) = 1.87$, $p = .05$, accounting for 17.1% (Adj $R^2 = .08$) of the variance in response time. As with analysis across all trials, maths anxiety remained a significant predictor of response time. However, unlike analysis across all trials, thoughts about previous maths experiences was not a significant predictor of response time. Perceived difficulty in removing thoughts, however, was significantly negatively related to response time (see Table 15).

With response time to no-carry problems as the outcome measure and only including the first half of the trials, the final model was not significant, $F(12, 109) = 1.66$, $p = .09$, accounting for 15.4% (Adj $R^2 = .06$) of the variance in response time. The only variable significantly related to response time in the final step was impeding calculation; that is, the self-reported level at which the most troublesome/worrisome thought impeded the participant's ability to calculation the maths problems was significantly positively related to response time (see Table 16).

With response time to carry problems as the outcome measure and only including the second half of the trials, the final model was significant, F(12, 109) = 2.45, p = .007, accounting for 21.3% (Adj R^2 = .13) of the variance in response time. Maths anxiety remained a highly significant predictor of response time throughout the steps of the regression. Thoughts about panicking and thoughts about previous maths experiences were also significantly negatively related to response time in the final model (see Table 17).

With response time to no-carry problems as the outcome measure and only including the second half of the trials, the final model was significant, F(12, 109) = 2.19, p = .02, accounting for 19.4% (Adj R^2 = 10.6) of the variance in response time. Maths anxiety remained a highly significant predictor of response time throughout the steps of the regression (see Table 18).

6.5.4.8 Tests of moderation

To directly test the hypotheses that impact of intrusive thoughts moderates the relationship between maths anxiety and performance, continuous variables were centred in order to avoid multicollinearity and product terms were created for maths anxiety and self-reported thought frequency, maths anxiety and self-reported impact of thoughts on calculation, and maths anxiety and self-reported difficulty in removing thoughts. A further product term was created to test the hypothesis that increased effort moderated the relationship between maths anxiety and performance. Also, in order to test possible moderating effects of maths anxiety and the specific intrusive thoughts shown to be significant predictors of performance, product terms were created for maths anxiety and thoughts about panicking and maths anxiety and thoughts about previous maths experiences. These were included separately as a final step in each of the regressions noted above. Using a Bonferroni correction alpha was adjusted to .008 to reduce the risk of making a type I error. None of the product terms were found to be significant (or even approaching significant) predictors of performance.

<u>6.5.4.9 Maths anxiety sub-scale analyses</u>

Full regression analyses, initially excluding product terms, were carried out in which the three maths anxiety sub-scales were entered, separately, in the second step of the regression, replacing total maths anxiety. When percentage of errors on true carry problems was included as the outcome measure, the regression models varied little from when total maths anxiety was included. Similarly, when percentage of errors on true no-carry problems was included as the outcome measure, the regression models varied little from those that included total maths anxiety. However, some differences were noted when the outcome measures were based on response time. When the maths evaluation anxiety sub-scale was entered into the regression model predicting response time to carry problems, thoughts about previous maths experiences remained a significant predictor in the final step, demonstrating a significant positive relationship with response time. Also, when the social/everyday maths anxiety sub-scale was included in place of total maths anxiety, social/everyday maths anxiety failed to be a significant predictor of response time to carry problems in the final step of the regression. However, as when maths evaluation anxiety was included, thoughts about previous maths experiences remained a significant predictor of response time in the final step. When the maths observation anxiety sub-scale was included in place of total maths anxiety, no significant predictors of response time to carry or no-carry problems were observed in the final step of the regression models. In predicting response time to no-carry problems, maths evaluation anxiety remained a significant predictor in the final step, although thoughts about panicking was no longer a significant predictor of response time, and, in addition, thoughts about method of problem solving was now found to be a significant predictor of response time, demonstrating a significant negative relationship. When the social/everyday maths anxiety sub-scale was included in place of total maths anxiety, no significant predictors of response time to no-carry problems were observed in the final step of the regression model.

As with the analysis including total maths anxiety, product terms were added to the regression models where maths anxiety (sub-scale) and another predictor were found to be significant in the final step of a regression. Therefore, based on centred data, product terms were created for maths evaluation anxiety and thoughts about panicking, previous maths experiences, and method of problem solving, respectively. Separate moderation analyses were conducted, firstly when response time to carry problems was included as the outcome measure and product terms for maths evaluation anxiety and thoughts about panicking and thoughts about previous maths experiences were added to the models. A bonferonni correction was applied to adjust alpha to .025. However, neither of the product terms added significantly to the models. Finally, the product term of maths evaluation anxiety and thoughts about method of problem solving also failed to add significantly to the model in which response time to no-carry problems was predicted. See Appendix for full details of regressions including sub-scales.

6.5.5 Additional Information

The section of the modified Cognitive Intrusions Questionnaire that enabled participants to report further on any intrusive thoughts noted or to describe ones not listed provided little in the way of additional information. A handful of participants elaborated on the intrusive thoughts they had previously ticked by noting comments such as “I didn’t want to look stupid” or similar. Such comments were considered to be part of the “what others would think” intrusive thought that was given as a self-reported tick option and appeared to offer no insight into alternative intrusive thoughts to the ones already given as self-report options.

Variable	Age	Gender	Carry errors %	No-carry errors %	Carry RT	No-carry RT	Maths anxiety total	Maths evaluation anxiety	Everyday/Social maths anxiety	Maths observation anxiety	Trait anxiety	Making mistakes	Time pressure	Method	People	Panicking	Previous experiences	Physical changes	Other problems	Freq. Most troublesome/	Difficulty removing thought	Effort to reduce thought	Impeding calculation
Age	1																						
Gender[5]	.10	1																					
Carry errors %	-.17	.12	1																				
No-carry errors %	-.01	.09	.28	1																			
			**																				
Carry RT	.03	-.01	.06	.02	1																		
No-carry RT	-.04	-.05	.25	.17	.83	1																	
			**		***																		
Maths anxiety total	.11	.22	.25	-.00	.30	.30	1																
		*	**		***	***																	

[5] Gender coding: Males = 0, Females = 1

Variable	Age	Gender	Carry errors %	No-carry errors %	Carry RT	No-carry RT	Maths anxiety total	Maths evaluation anxiety	Everyday/Social maths anxiety	Maths observation anxiety	Trait anxiety	Making mistakes	Time pressure	Method	People	Panicking	Previous experiences	Physical changes	Other problems	Freq. Most troublesome/	Difficulty removing thought	Effort to reduce thought	Impeding calculation
Maths evaluation anxiety	.03	.26	.29	-.02	.34	.35	.94	1															
		**	**		***	**	***																
Everyday/social maths anxiety	-.05	.08	.09	-.02	.25	.24	.77	.62	1														
					**	**	***	***															
Maths observation anxiety	.32	.18	.21	.04	.15	.14	.84	.69	.48	1													
	***	*	*				***	***	***														
Trait anxiety	.06	.23	.07	-.10	-.02	-.01	.46	.43	.39	.38	1												
		*					***	***	***	***													
Making mistakes	-.17	-.02	.25	.08	-.01	.08	.19	.22	.12	.11	.00	1											
			**				*	*															

Variable	Age	Gender	Carry errors %	No-carry errors %	Carry RT	No-carry RT	Maths anxiety total	Maths evaluation anxiety	Everyday/Social maths anxiety	Maths observation anxiety	Trait anxiety	Making mistakes	Time pressure	Method	People	Panicking	Previous experiences	Physical changes	Other problems	Freq. Most troublesome/	Difficulty removing thought	Effort to reduce thought	Impeding calculation
Time pressure	.02	.09	.19	-.01	.30	.33	.26	.30	.09	.23	.11	-.09	1										
			*		***	**	**	***		**													
Method	.05	.03	.04	-.02	-.01	-07	.10	.08	.07	.10	-.00	.06	-.02	1									
People	.02	.12	.14	-.02	.16	.13	.40	.41	.22	.34	.26	.12	.22	-.03	1								
							***	***	*	***	**		*										
Panicking	.04	.17	.15	-.10	.00	.07	.43	.40	.26	.43	.43	.12	.29	-.06	.20	1							
							***	***	**	***	***		**		*								
Previous experiences	-.06	-.14	.14	.06	.26	.22	.20	.18	.14	.21	.21	.01	.13	.22	.13	.15	1						
					**	*	*	*		*	*			*									
Physical changes	-.04	.01	.07	-.22	.09	.15	.37	.36	.34	.26	.08	.12	.15	.10	.14	.41	.20	1					
				*			***	***	***	**						**	*						

Variable	Age	Gender	Carry errors %	No-carry errors %	Carry RT	No-carry RT	Maths anxiety total	Maths evaluation anxiety	Everyday/Social maths anxiety	Maths observation anxiety	Trait anxiety	Making mistakes	Time pressure	Method	People	Panicking	Previous experiences	Physical changes	Other problems	Freq. Most troublesome/	Difficulty removing thought	Effort to reduce thought	Impeding calculation
Other problems	-.13	-.12	.11	.02	.14	.10	.25**	.23*	.20*	.22*	.22*	.08	.06	-.14	.10	.01	.26**	.04	1				
Freq. of most troublesome / worrisome thought	-.08	.08	.19*	.03	.23*	.26**	.59***	.55***	.50***	.45***	.43***	.20*	.21*	.08	.35***	.30***	.28**	.32***	.23*	1			
Difficulty removing	.03	.14	.20*	.10	.11	.16	.56***	.51***	.50***	.44***	.41***	.25**	.15	-.04	.32***	.32***	.13	.26**	.19*	.62***	1		
Effort to reduce thought	.04	.16	.21*	.05	.22*	.24**	.61***	.57***	.53***	.47***	.53***	.21*	.19*	.05	.42***	.42***	.23**	.38***	.15	.69***	.74***	1	
Impeding calculation	-.01	.07	.35***	.04	.25**	.28**	.52***	.53***	.36***	.40***	.37***	.23*	.25**	.07	.42***	.35***	.32***	.33***	.25**	.57***	.55***	.65***	1

Table 10. Zero-order correlations between demographic variables, performance variables, maths anxiety and sub-scales, intrusive thoughts, and perceived impact of intrusive thoughts

Step	Variables Entered	Beta	R^2 change	Model R^2
1	Gender[6]	.118		.014
2	Gender	.066	**.053***	**.067***
	Maths anxiety	**.236***		
3	Gender	.084	.018	.085
	Maths anxiety	.177		
	Method of problem solving	.010		
	People	.035		
	Panicking	.061		
	Previous maths experiences	.099		
	Physical changes	-.051		
	Other thoughts	.051		
4	Gender	.086	.061	.146
	Maths anxiety	.125		
	Method of problem solving	.000		
	People	-.039		
	Panicking	.022		
	Previous maths experiences	.053		
	Physical changes	-.087		
	Other thoughts	.017		
	Frequency	-.063		
	Difficulty in removing	-.019		
	Impeding calculation	**.338****		
5	Gender	.087	.001	.147
	Maths anxiety	.130		
	Method of problem solving	.002		
	People	-.033		
	Panicking	.028		
	Previous maths experiences	.055		
	Physical changes	-.076		
	Other thoughts	.014		
	Frequency	-.048		
	Difficulty in removing	.008		
	Impeding calculation	**.350****		
	Effort to reduce thoughts	-.068		

*$p \leq .05$

Table 11. Results of hierarchical regression with percentage of errors on carry problems as the outcome variable

[6] Gender coding: Males = 0, Females = 1

Step	Variables Entered	Beta	R^2 change	Model R^2
1	Gender	.086		.007
2	Gender	.092	.001	.008
	Maths anxiety	-.025		
3	Gender	.101	.070	.079
	Maths anxiety	.092		
	Method of problem solving	-.041		
	People	-.034		
	Panicking	-.074		
	Previous maths experiences	.132		
	Physical changes	**-.243***		
	Other thoughts	-.023		
4	Gender	.097	.022	.101
	Maths anxiety	.010		
	Method of problem solving	-.032		
	People	-.067		
	Panicking	-.094		
	Previous maths experiences	.122		
	Physical changes	**-.258***		
	Other thoughts	-.039		
	Frequency	-.012		
	Difficulty in removing	.154		
	Impeding calculation	.071		
5	Gender	.094	.002	.103
	Maths anxiety	.004		
	Method of problem solving	-.034		
	People	-.075		
	Panicking	-.101		
	Previous maths experiences	.120		
	Physical changes	**-.264***		
	Other thoughts	-.036		
	Frequency	-.030		
	Difficulty in removing	.120		
	Impeding calculation	.056		
	Effort to reduce thoughts	.084		

*$p \leq .05$

Table 12. Results of hierarchical regression with percentage of errors to no-carry problems as the outcome variable

Step	Variables Entered	Beta	R^2 change	Model R^2
1	Gender	-.014		.000
2	Gender	-.084	**.096****	**.096****
	Maths anxiety	**.318*****		
3	Gender	-.029	.126	**.166****
	Maths anxiety	**.338****		
	Method of problem solving	-.101		
	People	.036		
	Panicking	-.189		
	Previous maths experiences	.234		
	Physical changes	.005		
	Other thoughts	-.020		
4	Gender	-.020	.017	**.188***
	Maths anxiety	**.344****		
	Method of problem solving	-.118		
	People	.007		
	Panicking	-.199		
	Previous maths experiences	**.202***		
	Physical changes	-.008		
	Other thoughts	-.031		
	Frequency	.069		
	Difficulty in removing	-.172		
	Impeding calculation	.152		
5	Gender	-.026	.005	**.194***
	Maths anxiety	**.334***		
	Method of problem solving	-.121		
	People	-.006		
	Panicking	**-.212***		
	Previous maths experiences	**.199***		
	Physical changes	-.018		
	Other thoughts	-.025		
	Frequency	.036		
	Difficulty in removing	-.232		
	Impeding calculation	.125		
	Effort to reduce thoughts	.151		

*$p \leq .05$ **$p \leq .01$

Table 13. Results of hierarchical regression with response time to carry problems as the outcome variable

Step	Variables Entered	Beta	R^2 change	Model R^2
1	Gender	-.049		.002
2	Gender	-.121	**.103***	**.105***
	Maths anxiety	**.328***		
3	Gender	-.081	.050	**.155**
	Maths anxiety	**.350**		
	Method of problem solving	-.166		
	People	.002		
	Panicking	-.128		
	Previous maths experiences	**.198**		
	Physical changes	-.049		
	Other thoughts	-.068		
4	Gender	-.075	.026	**.181**
	Maths anxiety	**.312**		
	Method of problem solving	-.180		
	People	-.048		
	Panicking	-.147		
	Previous maths experiences	.156		
	Physical changes	.027		
	Other thoughts	-.088		
	Frequency	.092		
	Difficulty in removing	-.188		
	Impeding calculation	.187		
5	Gender	-.078	.002	**.183**
	Maths anxiety	**.305**		
	Method of problem solving	-.182		
	People	-.056		
	Panicking	-.154		
	Previous maths experiences	.154		
	Physical changes	.021		
	Other thoughts	-.084		
	Frequency	.073		
	Difficulty in removing	-.153		
	Impeding calculation	.171		
	Effort to reduce thoughts	.089		

*p ≤.05 **p ≤.01 ***p ≤.001

Table 14. Results of hierarchical regression with response time to no-carry problems as the outcome variable

Step	Variables Entered	Beta	R^2 change	Model R^2
1	Gender	-.012		.000
2	Gender	-.076	**.080****	.080
	Maths anxiety	**.290****		
3	Gender	-.039	.043	.124
	Maths anxiety	**.314****		
	Method of problem solving	-.069		
	People	.006		
	Panicking	-.097		
	Previous maths experiences	**.211***		
	Physical changes	-.053		
	Other thoughts	-.036		
4	Gender	-.029	.042	.166
	Maths anxiety	**.334****		
	Method of problem solving	-.093		
	People	-.022		
	Panicking	-.103		
	Previous maths experiences	.171		
	Physical changes	-.066		
	Other thoughts	-.046		
	Frequency	.126		
	Difficulty in removing	**-.266***		
	Impeding calculation	.160		
5	Gender	-.032	.005	.171
	Maths anxiety	**.325***		
	Making mistakes	-.096		
	People	-.033		
	Panicking	-.114		
	Previous maths experiences	.168		
	Physical changes	-.075		
	Other thoughts	-.041		
	Frequency	.099		
	Difficulty in removing	**-.317***		
	Impeding calculation	.137		
	Effort to reduce thoughts	.127		

*p ≤.05 **p ≤.01

Table 15. Results of hierarchical regression with response time to carry problems for the first half of trials as the outcome variable

Step	Variables Entered	Beta	R^2 change	Model R^2
1	Gender	-.090		.008
2	Gender	-.145	**.060****	**.068****
	Maths anxiety	**.251****		
3	Gender	-.114	.040	**.108*****
	Maths anxiety	**.284***		
	Method of problem solving	-.150		
	People	.012		
	Panicking	-.119		
	Previous maths experiences	.172		
	Physical changes	.008		
	Other thoughts	-.066		
4	Gender	-.107	.045	**.153****
	Maths anxiety	.244		
	Method of problem solving	-.168		
	People	-.049		
	Panicking	-.145		
	Previous maths experiences	.120		
	Physical changes	-.020		
	Other thoughts	-.093		
	Frequency	.082		
	Difficulty in removing	-.149		
	Impeding calculation	**.266***		
5	Gender	-.109	.002	**.154****
	Maths anxiety	.239		
	Method of problem solving	-.170		
	People	-.056		
	Panicking	-.152		
	Previous maths experiences	.118		
	Physical changes	-.025		
	Other thoughts	-.090		
	Frequency	.065		
	Difficulty in removing	-.180		
	Impeding calculation	**.252***		
	Effort to reduce thoughts	.070		

*$p \leq .05$ **$p \leq .01$

Table 16. Results of regression with response time to no-carry problems for first half trials as the outcome variable

Step	Variables Entered	Beta	R^2 change	Model R^2
1	Gender	-.020		.000
2	Gender	-.090	**.096*****	**.097****
	Maths anxiety	**.318*****		
3	Gender	-.026	**.101***	**.198*****
	Maths anxiety	**.348****		
	Method of problem solving	-.133		
	People	.072		
	Panicking	**-.285****		
	Previous maths experiences	**.222***		
	Physical changes	.056		
	Other thoughts	-.010		
4	Gender	-.024	.007	**.205****
	Maths anxiety	**.350****		
	Method of problem solving	-.140		
	People	.051		
	Panicking	**-.295****		
	Previous maths experiences	**.205***		
	Physical changes	.048		
	Other thoughts	-.019		
	Frequency	-.016		
	Difficulty in removing	-.056		
	Impeding calculation	.116		
5	Gender	-.029	.007	**.213****
	Maths anxiety	**.338****		
	Method of problem solving	-.144		
	People	.037		
	Panicking	**-.309****		
	Previous maths experiences	**.202***		
	Physical changes	.037		
	Other thoughts	-.012		
	Frequency	-.051		
	Difficulty in removing	-.120		
	Impeding calculation	.088		
	Effort to reduce thoughts	.160		

*$p \leq .05$ **$p \leq .01$ ***$p \leq .001$

Table 17. Results of regression with response time to carry problems for second half trials as the outcome variable

Step	Variables Entered	Beta	R^2 change	Model R^2
1	Gender	.001		.000
2	Gender	-.082	**.137*** **	**.137*** **
	Maths anxiety	**.380*** **		
3	Gender	-.040	.049	**.186** **
	Maths anxiety	**.370*** **		
	Method of problem solving	-.149		
	People	-.008		
	Panicking	-.111		
	Previous maths experiences	.181		
	Physical changes	.120		
	Other thoughts	-.062		
4	Gender	-.037	.005	**.192* **
	Maths anxiety	**.341** **		
	Method of problem solving	-.154		
	People	-.030		
	Panicking	-.119		
	Previous maths experiences	.162		
	Physical changes	.109		
	Other thoughts	-.072		
	Frequency	.058		
	Difficulty in removing	-.037		
	Impeding calculation	.072		
5	Gender	-.040	.002	**.194* **
	Maths anxiety	**.335** **		
	Method of problem solving	-.155		
	People	-.037		
	Panicking	-.127		
	Previous maths experiences	.160		
	Physical changes	.104		
	Other thoughts	-.068		
	Frequency	.040		
	Difficulty in removing	-.070		
	Impeding calculation	.057		
	Effort to reduce thoughts	.084		

*p ≤.05 **p ≤.01 ***p ≤.001

Table 18. Results of regression with response time to no-carry problems for second half trials as the outcome variable

6.6 Discussion

Consistent with previous findings (e.g. Ashcraft & Faust, 1994) overall response time was significantly longer in response to problems involving a carry operation. Similarly, significantly more errors were made in response to problems involving a carry operation. The zero-order correlations in the current study also support the established findings that maths anxiety is related to poor performance. However, once data pertaining to in-task intrusive thoughts were accounted for, maths anxiety did not predict percentage of errors to either carry or no-carry problems. Maths anxiety remained a significant predictor of response time for both carry and no-carry problems, though. In predicting percentage of errors to problems involving a carry operation no specific intrusive thought was found to be a significant predictor. Only one specific intrusive thought (physical changes) was found to be a significant predictor of percentage of errors to problems not involving a carry operation. This suggests that thoughts about such physical changes as sweating or changes in heartbeat were related to fewer errors. Contrary to expectations, focusing on the most worrisome or troublesome thought, self-reported frequency of the thought did not predict error rates to either carry problems or no-carry problems. Similarly, self-reported difficulty in removing the thought did not predict error rates. However, in partial support of the hypothesis that self-reported impact of intrusive thoughts would be related to performance, there was a significant positive relationship between the self-reported extent to which intrusive thoughts impeded calculation and percentage of errors only on problems involving a carry operation; no such relationship existed in response to problems not involving a carry operation. Therefore, it appears that it is the perceived impact of intrusive thoughts that is more important as a predictor of performance than frequency of the thoughts is. This is consistent with other recent findings that showed frequency of thoughts to be unrelated to working memory performance (Nixon, Menne, Kling, Steele, Barnes, et al., 2008).

In predicting response time to problems involving a carry operation, thoughts about panicking was a significant predictor of response time to both carry and no-carry problems. This suggests that those participants who experienced a thought about panicking responded faster than individuals who did not experience thoughts about panicking. Analyses including the maths anxiety sub-scales revealed thoughts about panicking to be related to response time only when the maths evaluation anxiety sub-scale was included in the regression model and not when the other sub-scales were included. Also, thoughts about previous maths experiences was a significant predictor of response time to carry problems only. That is, individuals who reported to have had thoughts about previous maths experiences took longer to respond than participants who did not have such thoughts. In addition, when the sub-scales of maths evaluation anxiety and social/everyday maths anxiety were included in the regression model, separately, thoughts about previous maths experiences was found to be a significant predictor of response time to carry problems only.

As with the prediction of errors, the inclusion of product terms to test a possible moderating effect of maths anxiety (and sub-scales) on measures relating to self-reported impact of intrusive thoughts did not add significantly to the models. The inclusion of the product term showed that maths anxiety did not moderate the relationship between self-reported impact of intrusive thoughts and response time, therefore not providing support for the hypothesis. According to the assumptions of attentional control theory (Eysenck et al., 2007) and inhibition theory (Hasher & Zacks, 1988; Connelly, et al., 1991), it was expected that the relationship between self-reported impact of intrusive thoughts and response time would increase as a function of maths anxiety. However, the evidence here does not provide any support for this. In addition, the inclusion of the product terms for maths anxiety (and sub-scales) and specific intrusive thoughts failed to add significantly to the models. In other words, despite maths anxiety being related to experiencing negative task-related thoughts, including those relating to what people will think, panicking, previous maths experiences, and physical changes, performance did not vary as a result.

Furthermore, according to attentional control theory, anxious individuals invest more effort in maintaining attentional control than their non-anxious counterparts. However, in the current study a joint relationship was not found between maths anxiety and self-reported effort in removing intrusive thoughts when predicting performance. Whilst effort in removing intrusive thoughts is not directly a measure of increased attentional control towards the primary task, it could be assumed that successful removal of unwanted intrusive thoughts leads to an increase in attentional control towards the primary task. The current finding appears to run counter to the findings of Hayes et al. (2009) that anxiety is related to increased effort. However, as suggested earlier, effort can be considered in a variety of ways; the current study included a measure of perceived effort rather than employing a paradigm that attempted to manipulate effort. Consequently, it appears that effort to remove intrusive thoughts does not moderate the relationship between maths anxiety and performance.

A split half analysis of the trials revealed an interesting picture. Maths anxiety remained a significant predictor of response time to carry problems across the first and second half of trials. However, in predicting response time to no-carry problems, maths anxiety failed to be a significant predictor for the first half of trials and only predicted response time for the second half, with the two correlations differing significantly, $t(119) = 2.27$, $p < .05$. This is difficult to explain but one suggestion is that the more demanding problems (those involving a carry operation) induce anxiety irrespective of certain other factors such as time pressure (consistent with previous findings of Kellogg et al., 1999), whereas for less demanding problems (no-carry problems) response time only varies as a function of maths anxiety towards the end of task completion. Further research is needed to investigate this latter finding. Of particular interest is the finding that self-reported difficulty in removing the most worrisome/troubling intrusive thought was significantly negatively related to response time to carry problems for the first half of trials only. For the second half of trials, only thoughts about panicking and previous maths experiences were found to be significant predictors of response time to carry problems. Specifically, thoughts about panicking were significantly negatively related to response time whereas thoughts about previous maths experiences were significantly positively related to response time. Intuitively, it makes sense that both self-reported difficulty in removing thoughts and thoughts about panicking are negatively related to response time, especially in response to more demanding (carry) problems. One explanation for the observed split-half effect could be that, for the first half of trials, individuals reporting difficulty in removing thoughts hurried through the trials, possibly as a local avoidance strategy. For the second half of trials, individuals reporting thoughts about panicking may also have hurried their responses and, again, possibly as a local avoidance strategy. Analysis of only those participants who reported experiencing thoughts about panicking showed no significant correlation ($r = -.12$) between difficulty in removing thoughts and response time to carry problems in both halves of the trials, suggesting that the relationship between difficulty in removing thoughts and response time in the first half of trials was not dependent on individuals who experienced thoughts about panicking. Further correlations between difficulty in removing thoughts and response time to carry problems performed separately for groups of participants who experienced each thought demonstrated very little relationship (all $< .2$). This is quite difficult to explain in that it is not clear what thought is the basis for the negative relationship between self-reported difficulty in removing the most worrisome/troubling thought and response time to carry problems. One possibility is that no one specific intrusive thought is responsible, but rather a combination of intrusive thoughts could be related to participants' reports of the difficulty in removing thoughts. This raises a methodological issue in that participants were asked to provide self reports on *the most* worrisome/troublesome thought they had experienced during the maths task, but whether participants did this may not be a completely reliable assumption. It is of course possible to analyse such correlations for all of the various combinations of thoughts experienced, however, a much larger sample size would be required to gain any meaningful results. The positive relationship found between having thoughts about previous maths experiences and response time to carry problems in the second half of trials is intriguing. There appears to be two main explanations for this. Firstly, from a processing efficiency perspective one could argue that such intrusive thoughts limited the working memory resources available for processing the maths problems efficiently. However, in the second half of trials self-reported difficulty in removing thoughts was not a significant predictor of response time. Alternatively, one could argue that the specific thought is related to consideration of the outcome of previous experiences. For example, if an individual has previously had a negative maths experience they may increase the amount of effort and time spent on problems in order to successfully complete the task. However, adding the product term into the regression did not add significantly to the model. Thus, further investigation is needed to determine the exact way in which thoughts about previous maths experiences impact on performance.

In the split half analysis of response time to no-carry problems self-reported intrusive thoughts were not found to predict response time in either the first half or second half. Unexpectedly, the self-reported extent to which the most worrisome or troubling thought impeded calculation was significantly positively related to response time to no-carry problems for the first half only. However, the correlations across the first and second halves were very similar ($r = .27$ and $r = .26$, respectively) and did not differ significantly, $t(119) = 0.56$, $p > .05$.

As noted earlier, there is a potential methodological issue surrounding the reliance on participants basing their self-reports on what they perceived to be their most worrisome or troubling in-task thought. That is, there may be problems with relying on the subjective nature of perceptions of such thoughts and the validity of such an approach to measuring them. In addition, there is a more general issue with the use of self-report measures based on introspection of in-task thoughts, as introspection has been viewed somewhat negatively within Psychology for some time, primarily because of the argument that it can not be consensually validated nor help generate causal laws (Locke, 2009). Future research may need to focus more on a manipulation of worry components, for example previous maths experiences and more detailed thought-specific self-reports, to avoid the reliability and validity issues associated with more general self-report measures.

A further methodological issue that arose from the current analyses relates to the predictive nature of those thoughts that relate directly to the performance measures, namely thoughts about time pressure and errors. It was clear from the initial regression models tested that the existence of thoughts about time pressure strongly predicted response time but not error rate. However, the existence of thoughts about making mistakes strongly predicted error rate but not response time. It is therefore very difficult to differentiate between the influence of those thoughts that relate directly to the behaviour being measured and the influence of the behavioural measure on related thoughts, for example were thoughts about time pressure an antecedent to response time or did they occur following acknowledgement of the individual's response time? Experimental designs may need to be adjusted to take this into account, possibly introducing self-report measures across time, for example before and after a manipulation of time pressure.

Finally, to the best of the author's knowledge, the current study represents the first occasion in which the Cognitive Intrusions Questionnaire (CIQ, Freeston et al., 1991) has been used to examine the types and level of severity of thoughts experienced during a maths task. In light of the current findings it may be necessary to consider further modifications, or at least provide further testing to address the utility of the CIQ in investigating intrusive thoughts in relation to specific cognitive processes, such as arithmetic.

In conclusion, maths anxiety was shown to be a significant predictor of response time, demonstrating a positive relationship to response time to both carry and no-carry problems. Maths anxiety did not, however, predict performance effectiveness. This is consistent with the general anxiety effects proposed by processing efficiency theory (Eysenck & Calvo, 1992), but the mechanisms behind these relationships still remains unclear. Despite maths anxiety being related to a variety of task-related intrusive thoughts regression models failed to demonstrate a moderating effect of anxiety and intrusive thoughts on performance. Overall, the self-reported extent to which intrusive thoughts impeded calculation was the only self-report measure of the impact of intrusive thoughts that was found to significantly predict performance taking into account all trials, specifically showing a positive relationship with percentage of errors on problems involving a carry operation. In addition, a limited number of specific intrusive thoughts were found to be related to performance, although these were significant even after maths anxiety was accounted for. Thus, certain cognitive intrusions and their self-reported impact may still be useful predictors of performance despite the lack of a joint relationship with maths anxiety.

6.7 Conclusion to Chapter Six

The purpose of this chapter was to report on the second empirical study that forms the current thesis and follows on from the initial EEG study that failed to provide any evidence in support of a neuropsychological basis for the observed maths anxiety to performance effects. The findings from the current study provide further support for a general maths anxiety – response time relationship, such that response time is longer the more anxious an individual is. The main focus of the study in this chapter was to address one of the most commonly reported explanations for maths anxiety effects. That is, intrusive thoughts related to a concurrent maths task impact on working memory in such a way that they limit the amount of working memory resources available to successfully complete the task. Whilst maths anxiety was shown to be related to several task-related intrusive thoughts, once maths anxiety was controlled for in regression analyses, specific intrusive thoughts were found to be good predictors of performance despite there not being a joint relationship with maths anxiety. For example, experiencing thoughts about panicking predicted faster response times and experiencing thoughts about previous maths experiences predicted longer response times, but only in response to problems that involved a carry operation. Also, self-reported impact of intrusive thoughts on impeding calculation was positively related to percentage of errors to problems involving a carry operation but not problems not involving a carry.

In summarising the findings of the current study, it is important to take into account measurement error and sample size, particularly with regard to self-reports based on introspection. However, based on the current findings it appears that self-reported cognitive intrusions may have some impact on performance but this does not seem to be related to maths anxiety. Consequently, cognitive intrusion explanations of maths anxiety effects on performance may not be as appropriate as others (e.g. Ashcraft & Kirk, 2001) have previously suggested. It is important that alternative approaches are therefore taken to investigate the mechanisms behind the effect of maths anxiety on performance. The following chapter reports on an attempt at doing this.

CHAPTER SEVEN

7. Explaining the relationship between maths anxiety and performance: An eye-tracking approach

7.1 Introduction

The experimental studies reported so far in this thesis have provided little explanation for the relationship between maths anxiety and performance. Specifically, the first experimental study (Chapter Four) failed to demonstrate any relationship between maths anxiety and neurophysiological processes involved in arithmetic processing. In addition, the second experimental study (Chapter Six) failed to explain effects of maths anxiety on performance in terms of in-task intrusive thoughts. Consequently the following chapter remains focused on the key theoretical mechanisms thought to underpin maths anxiety effects by using a novel approach. In particular, an eye-tracking methodology was employed whereby potential mechanisms underpinning the relationship between maths anxiety and performance, such as processing efficiency and attentional control, were assessed.

7.2 Background

Eye-movement data, acquired using eye-tracking technology, are thought to link directly to mental operations being currently performed (Suppes, 1990; Grant & Spivey, 2003). Some eye-movement studies have used the antisaccade task (Hallet, 1978). This involves peripheral presentation of stimuli to which participants have to intentionally suppress reflexive saccades towards the stimuli whilst focusing on a central cue. Studies using this task have demonstrated that working memory processes play an important role in the ability to intentionally suppress reflexive responses towards peripheral stimuli (Stuyven, Van der Goten, Vandierendonck, Claeys, & Crevits, 2000; Roberts, Hager, & Heron, 1994). In particular, Mitchell, Macrae and Gilchrist (2002) showed that the ability to suppress reflexive responding was reduced with the requirement to perform a concurrent task that placed notable demands on fronto-executive operations. Thus, such studies provide evidence to suggest that the use of eye-movement recordings can be a useful tool in the study of working memory.

However, there is a paucity of research that has used eye-tracking as a tool for investigating cognitive processes involved in mental arithmetic. The few studies that have been conducted, though, have provided strong evidence to support its utility. For example, some studies have measured eye movements in response to arithmetic word problems (De Corte, Verschaffel, & Pauwels, 1990; Hegarty, Mayer, & Monk, 1995) and others have studied eye movements in response to arithmetic following presentation of Arabic numeral stimuli (Suppes, Cohen, Laddaga, Anliker, & Floyd, 1983; Suppes, 1990). Suppes's work highlighted the usefulness of monitoring eye movements during mental arithmetic involving addition or subtraction, with results showing that fixation durations corresponded well with required arithmetic strategy. However, there were practical issues associated with early research such as the work carried out by Suppes and colleagues, including problems with small sample sizes and the cumbersome software used for analysing eye movement data.

More recently, though, Green et al. (2007) provide convincing evidence to support the correlation between eye movements and strategies used in solving complex addition problems. Specifically, Green et al. presented participants with two three-digit addends in a mental arithmetic task under choice or no-choice strategy conditions. Of particular relevance to the current study, Green et al. also varied the number of carries involved in the calculation of the presented problems. Further to finding a general effect of carries on performance (longer response time and more errors) they also observed that participants were significantly more likely to choose a unit strategy as the number of carries increased. That is, participants were more likely to begin with adding the units, followed by the tens, followed by the hundreds. Thus, the authors suggest that such a strategy choice may be linked to performance measures as the number of carries increase, especially as the unit strategy was found to correlate positively with response time to problems with a greater number of carries. The eye-movement data recorded by Green et al. was also consistent with behavioural data and reported strategy choice. For example, eye fixations were longer on carry than on no-carry problems and the timing of fixations on specific digits was consistent with the strategy chosen. Therefore, the research carried out by Green et al., and others (Suppes et al., 1983; Suppes, 1990), provides evidence to support the validity of using an eye-tracking methodology to study mental arithmetic processes.

It is only within the last few years that research has been conducted that has utilised eye-tracking technology to study attentional control processes in relation to anxiety. In a test of attentional bias to mood-congruent stimuli, Hermans et al. (1999) presented spider-anxious participants and control participants with a picture of a spider and a picture of a flower. Results were inconsistent with a traditional attentional bias effect, such that both groups of participants demonstrated a tendency to initially divert their gaze towards the image of the spider. However, as time progressed (over the course of 3 seconds) those in the spider-anxious group were significantly more likely to divert their gaze towards the image of the flower. One possible explanation, as Hermans et al. suggest, is that of an avoidance strategy displayed by those classified as spider-anxious, whereby a pattern of eye-movements away from the anxiety-provoking stimuli becomes apparent across time. Indeed, this may be a plausible explanation given that participants did not have to engage with an additional concurrent task, thus negating the need to orientate attention in relation to a particular goal. More recently, Rinck and Becker (2006) also studied eye movements among those classed as either spider-anxious or non-anxious. After presenting participants with images of a spider, a butterfly, a dog and a cat, eye-movement data revealed a similar pattern to the eye-movements observed by Hermans et al. (1999), that is, a pattern of quick, reflexive, attentional bias towards the spider image among those classed as spider-anxious, but then shorter gaze durations after the initial bias towards the stimuli. In contrast, others have reported an increase in dwell time on emotional relative to neutral stimuli (Fox et al., 2002), suggesting that eye-movements may be specific to the stimuli presented.

In a study of processing efficiency, Murray and Janelle (2003) used a driving simulation task and recorded visual search rate and driving performance between low and high trait-anxious groups. They also introduced a further task in which participants' reaction time to peripherally presented target lights was measured. Murray and Janelle observed little effect of anxiety on participants' performance effectiveness, but reaction times to the target lights were longer among the high anxious individuals, suggesting that dual-task performance affected processing efficiency. Analysis of visual search rate provided a method of supporting claims regarding processing efficiency, with the expectation that high anxious individuals would make more fixations during the task. Murray and Janelle's results provide some support for this, with both anxiety groups showing an increase in the number of fixations made.

In an investigation of anxiety effects on inhibition processes, Derakshan et al. (2009) presented participants with antisaccade and prosaccade tasks and showed that on the antisaccade task anxious individuals i) took significantly longer to make an eye movement in the correct direction after a cue and prior to a target (a decrease in processing efficiency), but ii) made no more errors than low anxious individuals (no effect on performance effectiveness). In a second experiment they further showed that processing efficiency was reduced when the cue was threatening rather than positive or neutral. Together, the results lend support to the argument that anxious individuals take longer to make attentional shifts, thus placing extra demands on the executive component of the working memory system. The results also provide further evidence to suggest that anxiety has a detrimental impact upon processing efficiency over performance effectiveness, therefore supporting the assumptions of processing efficiency theory (Eysenck & Calvo, 1992) and attentional control theory (Eysenck et al., 2007).

More recently, in a specific test of attentional control theory (Eysenck et al., 2007), Derakshan and Koster (in press) measured eye-movements during visual search as way of assessing processing efficiency in anxiety. Attentional control theory is an extension of processing efficiency theory (Eysenck & Calvo, 1992) and represents a theoretical model for explaining anxiety effects on performance. In particular it assumes that anxiety is more likely to negatively impact upon processing efficiency over performance effectiveness. Specifically, it assumes that anxiety is more likely to detrimentally affect performance when tasks involve the inhibition and shifting functions of the central executive. According to attentional control theory, such an impact on executive processes disrupts the balance between goal-directed and stimulus-driven systems, influencing the stimulus-driven system over the goal-directed system, thus reducing attentional control (see Chapter Two for further details). Derakshan and Koster presented participants with a series of trials in which eight faces were displayed, with one face (the target) varying from the remaining (crowd) faces. These included a range of target/crowd pairings of emotional expressions of angry, happy and neutral. Participants were instructed to undertake a visual search task in which they were required to press a button whenever one of the faces differed from the rest. After splitting participants into two groups based on low or high trait anxiety, eye-movement data indicated that anxiety disrupted processing efficiency, defined as the time elapsed between fixation on the target stimuli and actual behavioural response, that is, button press. Specifically, participants took longer to respond to target faces when crowd faces were angry or happy, compared to neutral. According to Derakshan and Koster, these findings are partially consistent with attentional control theory in so far as the anxious group was associated with reduced processing efficiency, but this was not dependent on a threat-specific situation. Rather, anxiety was related to an overall disruption in goal-directed processing of the target stimuli. One possible explanation for the reduced processing, the researchers suggest, is that a greater number of eye fixations on the crowd, that is, non-target stimuli, faces were observed among the high anxious group after the target stimuli had been detected. Furthermore, Derakshan and Koster suggest that emotional information embedded in both the target and the crowd, that is, happy/angry or angry/happy, may result in processing inefficiency due to increased demands on attentional processes in comparison to those trials involving neutral stimuli. Alternatively, as the authors suggest, "it could be that emotional information disrupts processing efficiency mainly under conditions of some uncertainty" (p.5). Either way, Derakshan and Koster's findings suggest that emotional information reduces processing efficiency, and further highlights the usefulness of an eye-tracking methodology in the study of anxiety and attentional control. In partial support of this, Calvo and Avero (2002) provided evidence that high anxious individuals made more regressive eye movements on trials involving threatening (word) events in comparison to neutral events. Indeed, it is one of the assumptions of attentional control theory (Eysenck et al., 2007) that anxiety is related to an increase in regressive eye movements as a compensatory strategy for reduced processing efficiency. However, it remains to be seen whether such effects generalise to different forms of emotional stimuli, such as numerical stimuli, and other forms of anxiety, such as maths anxiety.

Therefore, in order to study the relationship between maths anxiety and performance, the current study attempts to integrate eye-movement studies that have investigated i) mental arithmetic processes, and ii) attentional control processes in relation to anxiety. The aim, then, is to report on a further technique for investigating the mechanisms that underpin this relationship. It is assumed that maths anxiety is not related to a prepotent reflexive saccade response towards numerical stimuli in the same way that general anxiety may be related to threatening stimuli, such as a picture of an angry face (e.g. Derakshan et al., 2009) or spider (e.g. Rinck and Becker, 2006). That is, it is not assumed that maths anxiety results in an automatic shift of attention towards any of the particular digits presented. However, it is assumed that maths anxiety has a general negative effect on attentional control leading to reduced processing efficiency. Further to this, it is expected that eye movement data may provide insight into these effects. There are several hypotheses and these are listed below.

i) It is hypothesised that maths anxiety will be more strongly related to processing efficiency than performance effectiveness. This will be in the form of a positive relationship between maths anxiety and response time to arithmetic problems, with the expectation that this relationship is greater in response to problems involving a carry operation compared to those that do not. The focus of the current study is not on responses to false problems, so no specific predictions about responses to such problems are made, although, from an exploratory perspective responses to false problems will be assessed separately.

   Consequently, to explain the above, the following hypotheses are proposed.

ii) It is predicted that maths anxiety will be related to a greater time spent fixated on those components of an arithmetic problem that are not indicative of a goal-directed approach to arithmetic problem solving. Specifically, in a two-digit addend verification task, increased dwell time on tens digits, as opposed to the unit digits, is likely to represent inefficient processing. That is, an efficient strategy would be to compare the sum of the units to the proposed solution and then terminating the calculation process if the sum fails to match the unit value in the proposed solution. Thus, based on a stimulus-driven response, maths anxiety will be related to greater dwell time on the tens digits of a proposed problem as a result of reduced attentional control needed to proceed with an efficient calculation process. Thus, a joint relationship will exist between maths anxiety and dwell time in explaining response time.

iii) Based on the same rationale as for (ii), it is expected that maths anxiety will be related to a greater number of fixations on the tens digits of a proposed problem. Thus, a joint relationship will exist between maths anxiety and fixations in explaining response time.

iv) As a further contribution to reduced processing efficiency, it is predicted that maths anxiety will be positively related to the number of saccades made across arithmetic problems. Thus, a joint relationship will exist between maths anxiety and saccades in explaining response time.

v) Consistent with Eysenck et al.'s (2007) reports that high anxious individuals expend greater effort on reading tasks, using the compensatory strategy of regression (looking back over text), it is predicted that maths anxious individuals will display similar behaviour. In the form of eye-movements it is expected that, amongst those who are highly anxious, this will be evident in a larger number of movements between the proposed solution and the digits that form the proposed problem. Thus, a joint relationship will exist between maths anxiety and regressions in explaining response time.

vi) Finally, because of the increased working memory demands associated with problems involving a carry operation, it is expected that the above effects are likely to be most prominent in response to problems involving a carry operation.

7.3 Method

7.3.1 Participants

Participants were 82 undergraduate Psychology students from Staffordshire University, U.K. However, due to technical problems with data files, data for four participants were lost, resulting in a total sample size of 78. Ages ranged from 18 to 52 years (mean = 23.82; SD = 8.02). Participants took part in exchange for undergraduate research scheme vouchers and were recruited via advertising at the University.

7.3.2 Questionnaire measures

The newly developed 23-item Mathematics Anxiety Scale-U.K (MAS-U.K, Hunt et al., in press) was used to measure self-reported maths anxiety; details of the scale can be found in Chapter Five.

7.3.3 Experimental design and stimuli

Using Experiment Builder software, eighty two-digit addition problems, for example '23 + 29 = 52', were presented via a verification task. 40 of these problems had a solution that was true, with the remaining 40 having a solution that was false. In addition, half of all problems involved a carry operation and half did not. Addends were randomly taken from a range of 10-89 and problem-size was counterbalanced across all trials so that performance could be attributed to factors other than the size of the problems. Problems where both addends ended in zero decades, for example '20 + 30', or fives, for example '25 + 35', were not included. The false problems were divided equally with splits of +/- 1, +/- 3, and +/- 5 and there were an equal number of positive and negative splits.

7.3.4 Eye-tracking device

An Eyelink II eye-tracking device (SR Research Ltd., Mississauga, Ont., Canada) was used. The sampling rate was 500-Hz, with spatial accuracy under 0.5° and a 0.01° resolution in the pupil tracking mode. The Eyelink II device is a head-mounted eye-tracker and has ±/- 30° display allowable head movement.

7.3.5 Procedure

Participants gave informed consent to take part in a study involving maths and, prior to the arithmetic task, participants were required to complete the Mathematics Anxiety Scale-U.K. Following this, calibration and validation set-up of the eye-tracking device took place. A series of on-screen targets were used for calibration. The participant's dominant eye was selected for recording.

Stimuli were presented in the centre of a VDU, in Courier New size 30 bold font at an approximate viewing distance of 60cm. Following the on-screen instructions and two practice trials, participants were asked to respond 'true' or 'false' to the proposed answers to the remaining experimental trials. This was achieved by pressing the corresponding buttons on a Microsoft SideWinder Game Pad. There was no time limit for participants to respond. After responding, a pause screen, consisting of '+++++', appeared, and this remained until participants pressed one of the keys to proceed to the next trial. A central fixation point was presented prior to the onset of each trial.

Following completion of the task, participants were debriefed and thanked.

7.3.6 Eye-movement data

Interest areas (predefined co-ordinates in which eye-movement data can be obtained) of 150 pixels/3.97cm high and 50 pixels/1.32cm wide were manually created around each of the digits in each trial. Interest area reports were generated to obtain data on dwell time, fixations, and regressions from the solution. A separate trial and saccade report generated data pertaining to number of saccades produced on each trial, along with response time and error data. Manual group drift correction of fixations was conducted where obvious drift remained unadjusted per trial.

7.4 Results

7.4.1 Data screening

Visual inspection of histograms of the data showed the data to be sufficiently univariately normally distributed. For each regression, normality of standardised residuals was tested by visual inspection of histograms; these were found to be normal. Standardised residuals and standardised predicted values were also plotted against each and no obvious curvilinear relationships were apparent, with the display also indicating the presence of homoscedasticity. Checks for bivariate outliers were also made using scattergraphs and no outliers were identified. In order to test for multivariate outliers

Cook's distance and leverage values were plotted against each and no cases appeared to obviously deviate from the main cluster of cases. In addition, checks of tolerance values and variance proportions indicated that there were no problems with multicollinearity among the data (see Appendix for examples of each of the above).

7.4.2 Problem type analysis

7.4.2.1 Percentage of errors

Within-subjects t-tests were used to compare percentage of errors between problem types (see Table 19 for means and standard deviations). Percentage of errors was significantly greater for carry problems compared to no-carry problems, $t(77) = 2.76$, $p = .007$, two-tailed test, $d = 0.37$. Also, percentage of errors was significantly greater for true problems compared to false problems, $t(77) = 2.77$, $p = .007$, two-tailed test, $d = 0.40$. In addition, percentage of errors was significantly greater in response to true carry problems compared to true no-carry problems, $t(77) = 3.25$, $p = .002$, two-tailed test, $d = 0.42$. However, there was no significant difference in percentage of errors made in response to false carry problems compared to false no-carry problems, $t(77) = 0.66$, $p = .51$, two-tailed test, $d = 0.08$.

	Carry	No-Carry	Total
True	7.11 (8.08)	4.30 (5.08)	5.71 (4.55)
False	3.91 (5.26)	3.46 (5.66)	3.69 (5.55)
Total	5.12 (5.41)	3.38 (3.90)	

Table 19. Mean (standard deviations) of percentage of errors between problem types

7.4.2.2 Response times

Means and standard deviations of response times are displayed in Table 20. Analysis showed that participants took significantly longer to respond to carry problems compared to no-carry problems, $t(77) = 10.95$, $p < .001$, two-tailed test, $d = 0.70$. However, there was no significant difference in the response times to true problems compared to false problems, $t(77) = 1.68$, $p = .097$, two-tailed test, $d = 0.10$. Participants took significantly longer to respond to true carry problems compared to true no-carry problems, $t(77) = 11.94$, $p < .001$, two-tailed test, $d = 0.94$. Also, response time to false carry problems was significantly greater than for false no-carry problems, $t(77) = 7.91$, $p < .001$, two-tailed test, $d = 0.45$.

	Carry	No-Carry	Total
True	5493.02 (2034.64)	3921.56 (1196.20)	4689.91 (1552.59)
False	4959.03 (2235.42)	4083.82 (1632.58)	4519.30 (1890.71)
Total	5217.07 (2067.39)	3999.56 (1359.55)	

Table 20. Mean (standard deviations) of response times (ms) between problem types

7.4.3 Maths anxiety and problem type analysis

As shown in Table 21, no significant correlations were found between maths anxiety and percentage of errors on any of the problem types, with the maximum correlation (r) being -0.12, which is a small effect according to Cohen’s (1988) guidelines. On the other hand, maths anxiety was found to be related to response time, with significant positive correlations between anxiety and response time across all problem types. As shown in Table 22, effect sizes for the maths anxiety and response time correlations varied little across problem types, ranging from $r = 0.35$ to $r = 0.45$, which represents medium to large effects, according to Cohen's (1988) guidelines.

Correlations between maths anxiety sub-scales and performance measures were tested. A significant negative correlation was observed between maths observation anxiety and percentage of errors on false carry problems ($r = -.25$). No other correlations between sub-scales and error rates were significant. Correlations between maths evaluation anxiety and response time showed a similar pattern to those observed for total maths anxiety, with correlations ranging from $r = .39$ to $r = .47$ (all $p < .001$). No significant correlations were found between social/everyday maths anxiety and response time to false problems, but significant positive correlations were observed in response to true problems, with little difference in the size of the correlations between true carry ($r = .24$) and true no-carry ($r = .25$) problems. Finally, maths observation anxiety was found to be significantly positively correlated with response time across all problem types. See tables 21 and 22 for details.

	Maths Anxiety Total	Maths Evaluation Anxiety	Social/Everyday Maths Anxiety	Maths Observation Anxiety
Carry	-0.05	-.01	.05	-.12
No-Carry	-0.02	-.02	-.02	-.03
True	-0.05	-.07	.08	-.09
False	-0.01	.07	-.05	-.12
True Carry	0.01	.01	.11	-.08
True No-Carry	-0.12	-.16	-.002	-.08
False Carry	-0.10	-.02	-.07	-.25*
False No-Carry	0.08	.12	-.02	.03

* $p \leq .05$

Table 21. Pearson's r correlations (df = 76) between maths anxiety (and sub-scales) and percentage of errors across problem types

	Maths Anxiety Total	Maths Evaluation Anxiety	Social/Everyday Maths Anxiety	Maths Observation Anxiety
Carry	.38***	.43***	.18	.27*
No-Carry	.45***	.47***	.24*	.36***
True	.43***	.47***	.25*	.31**
False	.40***	.43***	.17	.31**
True Carry	.42***	.46***	.24*	.27*
True No-Carry	.43***	.45***	.25*	.34**
False Carry	.35**	.40***	.13	.26*
False No-Carry	.44***	.46***	.22	.35***

* $p \leq .05$ ** $p \leq .01$ *** $p \leq .001$

Table 22. Pearson's r correlations (df = 76) between maths anxiety (and sub-scales) and response time (ms) across problem types

Eye-movement measure	Digit	Maths anxiety total	Maths evaluation anxiety	Social/Everyday maths anxiety	Maths observation anxiety
Fixations	First	.41***	.48***	.14	.30**
	Second	.22*	.28*	.07	.15
	Third	.23*	.27*	.14	.12
	Fourth	.15	.24*	.00	.04
Dwell time	First	.34**	.43***	.07	.23*
	Second	.24*	.31**	.01	.19
	Third	.21	.23*	.14	.12
	Fourth	.25*	.33**	.05	.13
Regressions	Solution	-.05	.06	-.13	-.13
Saccades	N/A	.34**	.40***	.21	.19

* $p \leq .05$ ** $p \leq .01$ *** $p \leq .001$

Table 23. Pearson's r correlations (df = 76) between maths anxiety (and sub-scales) and eye-movement on carry problems

Eye-movement measure	Digit	Maths anxiety total	Maths evaluation anxiety	Social/Everyday maths anxiety	Maths observation anxiety
Fixations	First	.37***	.41***	.09	.33**
	Second	.20	.23*	.07	.15
	Third	.19	.22*	.10	.12
	Fourth	.23*	.24*	.13	.17
Dwell time	First	.32**	.38***	.04	.29**
	Second	.21	.25*	.05	.17
	Third	.25*	.24*	.17	.20
	Fourth	.32**	.33**	.16	.23*
Regressions	Solution	-.10	-.06	-.06	-.13
Saccades	N/A	.34**	.39***	.16	.24*

* $p \leq .05$ ** $p \leq .01$ *** $p \leq .001$

Table 24. Pearson's r correlations (df = 76) between maths anxiety (and sub-scales) and eye-movement on no-carry problems

7.4.4 Eye-movement and performance

Based on the finding that there was very little correlation between maths anxiety and error rates across all problem types (maximum $r = -0.1$), the subsequent analyses were based on a prediction of response times only. Also, t-tests demonstrated no significant difference between correlations across true and false carry, $t(75) = 1.31$, $p > .05$, and no-carry, $t(75) = 0.18$, $p > .05$, problems so the following analyses are based on responses to true problems only. In order to test the extent to which eye-movements and maths anxiety predict response times, a series of hierarchical multiple linear regression analyses were conducted in which arithmetic response times were regressed onto specific eye-movement measures in the first step, maths anxiety in the second step. The product term of specific eye-movement measures and maths anxiety was included in the final step to test for possible moderation effects (see below for further details). This was done separately for each digit presented. The first step, in tables 23 to 26, then, shows the simple linear regression of response time on eye-movements. Starting with an analysis of fixations, fixations across all digits significantly and strongly predicted response time to both carry and no-carry problems (see Table 23), with response time increasing with number of fixations. The same pattern is observed in predicting response time from dwell time on each digit: dwell time significantly and strongly predicted response time to both carry and no-carry problems (see Table 24), with response time increasing with dwell time. As shown in Table 25, number of times eye movements regressed from the proposed solution to the remainder of the problem was a significant predictor of response time to both carry and no-carry problem, with response time increasing with the number of regressions. Similarly, as shown in Tables 25, response times to both carry and no-carry problems were significantly and strongly predicted by number of saccades, with response time increasing with the number of saccades.

7.4.5 Eye-movement and maths anxiety moderation analyses

In order to counteract problems with multicollinearity, maths anxiety and eye-movement variables were centred and, as noted above, the product terms were entered into the final stage of the regressions (see table 23 to 25). A Bonferroni correction was applied according to the number of moderation analyses conducted per outcome measure, resulting in an adjusted alpha level of .005. Beginning with the analysis of maths anxiety and fixations, entering the product term into the final stage of the model failed to lead to a significant increase in R^2 for all digits. However, had an adjustment to alpha not been made, the inclusion of the product term for first-digit fixations and maths anxiety would have resulted in a significant ($p < .05$) increase in variance explained in response time to carry problems. A similar result was demonstrated when including the product term of maths anxiety and dwell time for all digits, with the inclusion of the product term failing to lead to a significant increase in R^2. However, again, had an adjustment to alpha not been made, the inclusion of the product term for first-digit dwell-time and maths anxiety would have resulted in a significant ($p < .05$) increase in variance explained in response time to carry problems. Also, no significant increases in R^2 were observed when including the product terms of maths anxiety and saccades or regressions from the proposed solution, resulting in an extremely small amount of additional variance explained in response times.

7.4.6 Eye-movement and maths anxiety sub-scale moderation analyses

Full moderation analyses were carried out, as above, for each maths anxiety sub-scale separately. Again, a Bonferroni correction was applied to alpha, resulting in an adjusted alpha of .005. The product term for maths evaluation anxiety and first digit fixations was the only one to lead to a significant increase in R^2 at the adjusted alpha level, specifically for the model in which response time to carry problems was the outcome measure, explaining an additional 8.0% of the variance (see Table 26). However, close inspection of the regression model suggests a partial mediation of the first-digit fixation and performance relationship by maths anxiety, with a reduction in the standardised beta coefficient for first digit fixations in step two. The only product term that reached significance at the adjusted alpha level was that which appears in the same model in which earlier partial mediation occurs. This renders the joint relationship between maths evaluation anxiety and first digit fixations as largely uninterpretable.

Digit	Step	Variables Entered	Carry problems Beta	R^2 change	Model R^2	No-carry problems Beta	R^2 change	Model R^2
First	1	Fixations	.328**		.107**	.424***		.179***
	2	Fixations	.188	.096**	.204***	.306**	.088**	.268***
		Maths anxiety	.340**			.320**		
	3	Fixations	.293*	.062*	.266***	.384***	.069**	.337***
		Maths anxiety	.314**			.303**		
		Fixations*Maths anxiety	-.268*			-.273**		
Second	1	Fixations	.714***		.511***	.658***		.433***
	2	Fixations	.654***	.070***	.580***	.596***	.095***	.528***
		Maths anxiety	.271***			..314***		
	3	Fixations	.651***	.001	.582***	.594***	.004	.532***
		Maths anxiety	.264***			.302***		
		Fixations*Maths anxiety	-.038			-.064		
Third	1	Fixations	.769***		.591***	.697***		.486***
	2	Fixations	.710***	.062***	.653***	.638***	.093***	.579***
		Maths anxiety	.256***			.311***		
	3	Fixations	.721***	.016	.669***	.635***	.008	.587***
		Maths anxiety	.229**			.293***		
		Fixations*Maths anxiety	-.131			-.092		
Fourth	1	Fixations	.654***		.427***	.509***		.259***
	2	Fixations	.604***	.103***	.530***	.433***	.106***	.604***
		Maths anxiety	.324***			.334***		
	3	Fixations	.605***	<.001	.530***	.429***	.002	.606***
		Maths anxiety	.324***			.341***		
		Fixations*Maths anxiety	.005			-.049		

* $p \leq .05$ ** $p \leq .01$ *** $p \leq .001$

Table 25. Regression of response time to true carry and no-carry problems on maths anxiety and first-digit fixations.

Digit	Step	Variables Entered	Carry problems Beta	R^2 change	Model R^2	No-carry problems Beta	R^2 change	Model R^2
First	1	Dwell time	.405***		.164***	.500***		.250***
	2	Dwell time Maths anxiety	.298** .317**	.089**	.253***	.402*** .302**	.082**	.332***
	3	Dwell time Maths anxiety Dwell time*Maths anxiety	.346** .296** -.202**	.039*	.292***	.438*** .292** -.196*	.037*	.369***
Second	1	Dwell time	.703***		.494***	.714***		.510***
	2	Dwell time Maths anxiety	.640*** .265***	.066***	.561***	.651*** .293***	.082***	.592***
	3	Dwell time Maths anxiety Dwell time*Maths anxiety	.636*** .252** -.071	.005	.565***	.667*** .271*** -.087	.007	.599***
Third	1	Dwell time	.736***		.542***	.723***		.523***
	2	Dwell time Maths anxiety	.679*** .276***	.073***	.615***	.656*** .270***	.069***	.591***
	3	Dwell time Maths anxiety Dwell time*Maths anxiety	.680*** .261*** -.068	.004	.620***	.662*** .254*** -.105	.011	.602***
Fourth	1	Dwell time	.723***		.523***	.646***		.418***
	2	Dwell time Maths anxiety	.660*** .251**	.059**	.582***	.566*** .253*	.057**	.475***
	3	Dwell time Maths anxiety Dwell time*Maths anxiety	.656*** .252** -.023	.001	.583***	.577*** .241** -.088	.008	.483***

* $p \leq .05$ ** $p \leq .01$ *** $p \leq .001$

Table 26. Regression of response time to true carry and no-carry problems on maths anxiety and first-digit dwell time.

Eye-movement	Step	Variables Entered	Carry problems Beta	R^2 change	Model R^2	No-carry problems Beta	R^2 change	Model R^2
Regressions	1	Regressions	.450***		.202***	.225*		.051*
	2	Regressions	.433***	.159***	.362***	.221*	.185***	.236***
		Maths anxiety	.400***			.430***		
	3	Regressions	.433***	.004	.365***	.229*	.004	.240***
		Maths anxiety	.410***			.434***		
		Regressions*Maths anxiety	.063			-.067		
Saccades	1	Saccades	.911***		.830***	.879***		.773***
	2	Saccades	.870***	.013*	.842***	.827***	.021**	.793***
		Maths anxiety	.119*			.153**		
	3	Saccades	.872***	.005	.847***	.825***	<.001	.794***
		Maths anxiety	.121*			.153**		
		Saccades*Maths anxiety	-.068			-.015		

* $p \leq .05$ ** $p \leq .01$ *** $p \leq .001$

Table 27. Regression of response time to true carry and no-carry problems on maths anxiety and i) regressions from the solution, and ii) saccades.

Digit	Step	Variables Entered	Carry problems Beta	R^2 change	Model R^2	No-carry problems Beta	R^2 change	Model R^2
First	1	Fixations	.328**		.107**	.424***		.179***
	2	Fixations	.138	.122**	.229***	.288**	.091**	.270***
		MEA	.397***			.330**		
	3	Fixations	.241*	**.080****	.281***	.379***	.071**	.341***
		MEA	.408***			.335**		
		Fixations*MEA	**-.302****			-.283**		
Second	1	Fixations	.714***		.511***	.658***		.433***
	2	Fixations	.635***	.078***	.588***	.587***	.095***	.528***
		MEA	.289***			.316***		
	3	Fixations	.637***	.000	.588***	.584***	.001	.529***
		MEA	.293***			.311***		
		Fixations*MEA	.017			-.027		
Third	1	Fixations	.769***		.591***	.697***		.486***
	2	Fixations	.695***	.072***	.663***	.628***	.090***	.576***
		MEA	.279***			.308***		
	3	Fixations	.706***	.013	.676***	.621***	.007	.583***
		MEA	.254***			.291***		
		Fixations*MEA	-.116			-.088		
Fourth	1	Fixations	.654***		.427***	.509***		.259***
	2	Fixations	.577***	.101***	.529***	.426***	.114***	.373***
		MEA	.327***			.347***		
	3	Fixations	.576***	.001	.529***	.422***	.002	.374***
		MEA	.327***			.345***		
		Fixations*MEA	-.002			-.040		

* $p \leq .05$ ** $p \leq .01$ *** $p \leq .001$

Table 28. Regression of response time to true carry and no-carry problems on maths evaluation anxiety (MEA) and first-digit fixations.

7.5 Discussion

Consistent with previous findings (Suppes et al., 1983; Suppes et al., 1990; Green et al., 2007) in which eye-movements have been shown to be related to task performance, the current study found response time to arithmetic problems to be strongly positively correlated with several eye-movement measures, including number of saccades, dwell time and number of fixations on individual digits in a proposed on-screen problem. This further supports the validity of using an eye-tracking methodology in investigating arithmetic performance. The main focus of the current study, though, was the extent to which eye-movement data may help explain the relationship between maths anxiety and performance. Performance data indicated that maths anxiety was not correlated with error rates on two-digit addition problems, but it was significantly positively correlated with response time. This supports the hypothesis that maths anxiety is related to processing efficiency over performance effectiveness and therefore supports the corresponding assumption proposed by processing efficiency theory (Eysenck & Calvo, 1992) and attentional control theory (Eysenck et al., 2007). However, in contrast to the prediction that the relationship between response time and maths anxiety would be strongest in relation to problems involving a carry operation, there was very little difference in this relationship between carry and no-carry problems, particularly for true carry ($r = .42$) and true no-carry ($r = .43$) problems.

According to attentional control theory (Eysenck et al., 2007), anxiety may lead to stimulus-driven task performance. Such a strategy can be inefficient, leading to poor performance. In the context of a two-digit addend verification task, an inefficient strategy would involve attending to those components of the problem that are not required for an immediate termination of the calculation process, that is, it is possible to focus attention on the unit digits in order to verify the accuracy of the unit presented in the proposed solution, so attending to the tens digits would lead to greater processed time and consequently greater response time, thus representing an inefficient strategy. In contrast, a goal-directed approach is more likely to lead to more efficient task processing and consequently better task performance. The current results provide some evidence to suggest that these assumptions can be extended to maths anxiety effects on arithmetic performance. Consistent with a stimulus-driven approach to processing, bivariate correlations indicated that the relationship between maths anxiety and fixations and dwell time on first digits was stronger than for all other digits. However, a series of moderation analyses provided little evidence to suggest a joint relationship between maths anxiety and eye-movements in predicting performance. Observation of the regression models indicated that maths anxiety may partially mediate the relationship between first digit fixations and response time to problems that involved a carry operation. This possibility is based on the relationship between first digit fixations and response time being reduced from significant to non-significant once maths anxiety was added into the model. The standardised beta coefficient for the first digit fixations predictor, whilst lower, was not reduced to zero, suggesting partial mediation. To explore this further and to investigate other potential partial mediation effects within the regression models, full mediation analyses were carried out using Sobel tests to test the significance of the indirect paths between eye-movements, maths anxiety and response time, with maths anxiety acting as the mediator. Whilst some indirect paths were shown to be significant these were all at the .05 level and failed to reach significance once alpha was adjusted to account for the risk of making a type I error. Thus, with only a partial reduction in the standardised beta values of eye-movement variables with the addition of maths anxiety it is tentatively suggested that maths anxiety partially mediates the relationship between eye movements and response time, but more research is needed, with a much narrower focus, to explore this further.

Another specific eye-movement measure recorded in the current study was the number of regressions made in which participants looked at the proposed solution and then to the problem itself. According to attentional control theory (Eysenck et al., 2007) such behaviour represents a compensatory strategy based on the greater expenditure in effort seen among those who are highly anxious and research has demonstrated an effect of anxiety on regressive eye movements to threat-related stimuli (Calvo & Avero, 2002). Here it was hypothesised that the relationship between maths anxiety and response time may be explained by an increase in the number of regressions made. However, the findings did not support this. Whilst number of regressions was positively related to response time, the product term created from maths anxiety and regressions was not significant. Similarly, it was further expected that inefficient processing of the arithmetic problems may be partially explained by an increase in the number of saccades made generally, thus explaining the relationship between maths anxiety and performance. However, again, whilst number of saccades was a strong predictor of response time, the product term created from maths anxiety and saccades was not significant. Taken as a whole, the results reported here do not provide support for an attentional control account of maths anxiety effects on arithmetic task performance. In particular, to explain the longer response times that were observed as a function of maths anxiety, there was little evidence from eye movement measures to suggest increased effort among individuals high in maths anxiety. However, it may be that the current methodology is not the most appropriate way to test such variation in motivation towards a more goal-directed approach to task completion and the possibility of an increase in effort among those high in maths anxiety should not be ruled out; this will be discussed more in Chapter Eight. Furthermore, according to Eysenck et al. (2007), high anxious individuals have a low level of motivation and make minimal use of attentional control processes when there is no clear task goal or a task is undemanding.

Thus, explanatory factors behind maths anxiety effects on processing efficiency may appear in scenarios where an attempt is made to manipulate maths anxiety itself by increasing task demands or emphasising motivational influences, such as social pressure. However, this does not negate the fact that maths anxiety was significantly and moderately positively correlated with response time within the current study.

Typically, previous eye-tracking studies investigating anxiety and attentional control processes have measured saccades via pro-saccade or anti-saccade tasks. However, one of the problems faced with using an eye-tracking methodology for the study of maths anxiety is that such tasks may not be as appropriate as they are for other forms of anxiety. For example, previous studies have presented stimuli that have immediate relevance to anxious individuals, such as images of spiders (Hermans et al., 1999) or angry faces (Derakshan & Koster, in press). Numerical stimuli, on the other hand, may not produce the same prepotent reflexive saccades. Therefore, other, more anxiety-specific, tasks may be needed to assess inhibition and attention control processes in relation to maths anxiety.

Despite the lack of evidence to explain the relationship between maths anxiety and response time to arithmetic problems, the current findings still provide strong support for the utility of an eye-tracking methodology in the study of mental arithmetic. In particular, several eye-movement measures, including saccades, fixations, dwell time, and regressions, were all significantly positively correlated with response time. This suggests that such measures may, at least in part, provide explanations for reduced efficiency in processing.

As noted earlier, this appears to be the first study in which eye-tracking has been used to investigate maths anxiety effects on arithmetic performance and may provide a useful starting point for future research. There are several routes such research may take. Firstly, as a variation on previous studies, for example Rinck & Becker (2006) and Hermans et al. (1999), possible inhibitory (or disinhibitory) processes could be studied by presenting task relevant and irrelevant stimuli and measuring participants' attentional control of such processes. Previously, Hopko et al. (1998) demonstrated that maths anxious individuals took longer to read paragraphs of text that contained distractor words, providing some support for the concept of a deficient inhibition mechanism associated with higher levels of maths anxiety. The methodology employed did not allow for the testing of subtle behavioural differences according to levels of maths anxiety. Thus, an eye-tracking methodology may allow for this, taking into account a range of eye-movements that could potentially impact on performance, for example saccades, fixations, dwell time, and regressions.

Secondly, further study needs to be undertaken into calculation strategies chosen by individuals performing mental arithmetic and how maths anxiety may be related to this. Research into the use of eye-tracking for investigating arithmetic calculation strategies has shown the technique to be extremely valuable (Green et al., 2007), suggesting that this could be extended to the study of maths anxiety effects. In particular, one approach would be to compare performance across self-reported calculation strategies and measure the relationship with maths anxiety, validated using eye-movement recordings.

Finally, whilst several studies have reported a strong correlation between maths anxiety and maths self-efficacy, for example Pajares and Miller (1995), there appears to be no research that has investigated this in relation to the specifics of task processing. An eye-tracking methodology might therefore be a suitable approach to this. In particular, it could be that the relationship between maths anxiety and response time to solving arithmetic problems is more complex than first assumed. Using eye-tracking, with the inclusion of additional measures, such as maths self-efficacy, may help to identify more subtle relationships. For example, the current study assumed that, based on the regression assumption of attentional control theory (Eysenck et al., 2007), the relationship between maths anxiety and performance could be explained by the number of regressions made from the proposed solution back to the problem itself, whereas it may be the case that measures such as maths self-efficacy may contribute to a predictive model by, for example, explaining further behaviours such as double-checking prior to responding.

In conclusion, the findings presented here provide support for the usefulness of tracking eye movements during mental arithmetic processing, with measures of fixations, dwell time, saccades and regressions all found to be related to response times. In particular, increases in each of these measures were related to longer response times. This occurred irrespective of whether problems required a carry operation and therefore may indicate a general effect of eye movements on processing efficiency. Whilst analyses revealed a moderating effect of maths anxiety on the relationships between first-digit dwell time and response time and fixations and response time, follow-up analyses demonstrated that the relationships reduced in positivity across low, medium and high maths anxious groups, respectively, with no significant relationships based on a high level of maths anxiety.

7.6 Conclusion to Chapter Seven

The present chapter represents the final empirical study that forms the current thesis. The study built on those investigations reported earlier in the thesis and provides the details of a further methodological approach to the study of maths anxiety effect on arithmetic performance. Specifically, the initial research, described in Chapter Four, demonstrated no neurophysiological correlates of maths anxiety when predicting arithmetic performance. The next experimental investigation, reported in Chapter Six, developed as a result of the need to test the predictive nature of self-reported cognitive intrusions on arithmetic task performance and how this may interact with maths anxiety. This was based on the positive maths anxiety-to-performance relationship observed in the first experiment, despite finding that maths anxiety failed to predict event-related potential measures. Having demonstrated no moderating effect between maths anxiety and intrusive thoughts on performance, the present study focused on the utility of an eye-tracking methodology in predicting arithmetic performance based on a potential moderating effect of maths anxiety and a range of eye-movement measures. One important effect that is consistent with that reported in Chapter Six, is that maths anxiety is related to longer response times, but not an increase in number of errors. This therefore supports the assumption that maths anxiety is related to reduced processing efficiency over performance effectiveness and is consistent with the general assumption of processing efficiency theory (Eysenck & Calvo, 1992).

The findings of the present chapter confirm the usefulness of an eye-tracking approach in the study of arithmetic generally, and may even provide some insight into potential reasons behind reduced performance efficiency. However, when testing moderation effects between maths anxiety (including sub-scales) and specific forms of eye-movement in predicting performance, results showed that no moderation effects were present. There was some evidence to suggest a potential indirect path between the variables, with maths anxiety partially mediating the relationship between eye-movement and response time, but the evidence was not sufficient to draw firm conclusions. In sum, the findings reported in the current chapter provide a useful addition to those already reported in this thesis and also provide a further starting point for more research using an eye-tracking methodology in the study of maths anxiety effects on performance, particularly processing efficiency.

CHAPTER EIGHT

8. General discussion

The primary focus of this thesis has been on investigating possible mechanisms underpinning the relationship between maths anxiety and performance. Previous studies have demonstrated that maths anxiety is related to poor performance and that this relationship is complex. For example, poor performance can consist of longer response times (reduced efficiency) and greater error rates (reduced effectiveness), and, whilst studies have reported a positive relationship between maths anxiety and both longer response times and increased error rates, the more consistent finding has been the relationship between maths anxiety and longer response times. Also, such maths anxiety effects appear in response to performing mental arithmetic, that is, without pencil and paper, and particularly on maths problems that place greater demands on working memory resources, for example those that require a carry operation.

The three experimental studies reported in chapters four, six and seven investigated potential mechanisms behind the effects noted above. In study one (Chapter Four) event-related potentials were measured and used as a tool for assessing whether there are any neuropsychological correlates of maths anxiety, in a bid to explain the effects of maths anxiety on performance. The next experimental study (study three; Chapter Six) measured self-reported in-task intrusive thoughts in order to test their relationship with maths anxiety and performance. This also introduced a methodology for assessing some of the current theoretical assumptions regarding maths anxiety and performance: namely the presence of a deficient inhibition mechanism, and the role of cognitive intrusions and maths anxiety in reducing processing efficiency and attentional control. The final experimental study (study four; Chapter Seven) introduced a further methodological approach that has not previously been used to investigate the relationship between maths anxiety and performance: eye-tracking was used to measure various forms of eye-movement to address whether maths anxiety may be related to such eye-movements and in turn whether this could be used to explain maths performance. As a further study (Chapter Five) borne out of the acknowledgement of validity issues with existing self-report measures of maths anxiety, a new maths anxiety scale was developed and utilised in the second and third experimental studies noted above. This chapter will focus on the findings from these studies and their implications.

8.1 Problem type and performance

Previous research has confirmed the inclusion of carry operations as an appropriate method for assessing demands placed on working memory (e.g. Furst & Hitch, 2000; Imbo et al., 2005) and the findings presented in chapters six and seven, are consistent with this. Across all three experimental studies presented in this thesis the stimuli used were two-digit addition problems. In the first experimental study, reported in Chapter Four, a slightly higher percentage of errors were made in response to problems involving a carry operation compared to those involving no carry. This difference was not significant and only produced a small effect ($d = 0.1$), but the direction of means was nevertheless in the expected direction. In the next experimental studies, reported in chapters six and seven, again percentage of errors was greater in response to carry problems, but the difference was significant, producing medium effect sizes of $d = 0.58$ and $d = 0.42$ in the second and third experimental studies, respectively. It is difficult to explain why the first study failed to produce an effect, although it was particularly low in statistical power because of the comparatively small sample size ($N = 27$).

Regarding response times to problems with and without a carry, these were not recorded in the first experimental study due to the ceiling effect as a result of the imposed time limit. However, across the next two experimental studies participants performed consistently significantly more slowly on problems that required a carry operation, demonstrating large effect sizes of $d = 1.34$ and $d = 0.94$, respectively. Thus, there is strong support for the use of such problems as a method for differentiating between problems in terms of processing demands and is consistent with previous findings (Furst & Hitch, 2000; Imbo et al., 2005). It is important to note, however, that these are findings from responses to problems i) presented in the form of a verification task, and ii) in which the proposed solution was true. The implications of this will be discussed later.

8.2 Maths anxiety and performance

As discussed in Chapter One, several studies have reported that maths anxiety is related to poor arithmetic performance, particularly on those problems that place greater demands on working memory by requiring a carry operation (e.g. Faust et al., 1996; Ashcraft & Kirk, 2001). One of the overall aims of this thesis was to test for the consistency of these findings. Analysis of error rates in study one showed a significant positive correlation between maths anxiety and percentage of errors to problems involving a carry operation. Also, in study three, there was a significant positive correlation between maths anxiety and percentage of errors to carry problems. However, study four revealed no significant correlation between maths anxiety and percentage of errors to carry problems. When considering the strength of the correlations across studies, these varied too. In study one and three correlations were $r = .43$ and $r = .25$, respectively, whereas in study four the correlation was $r = .01$, indicating a change from moderate sized correlations in studies one and three to virtually no correlation in study four. This discrepancy cannot be attributed to the problems used because two-digit addition problems, with problem size controlled, were consistent across each of the studies. However, one potential explanation for the inconsistency in the relationship between math anxiety and number of errors on problems involving a carry operation could relate to the fact that participants performed the task alone in studies one and three, but, due to the need to operate the eye-tracking software, the researcher was present in the final study. In support of this possibility, observation of the zero-order correlations between response time to carry and no-carry problems and scores on the maths evaluation anxiety sub-scale of the Mathematics Anxiety Scale U.K reveals smaller correlations where participants performed the task alone ($r = .34$ and $r = .35$ for carry and no-carry problems, respectively) but larger correlations between maths evaluation anxiety and response times to both carry ($r = .43$) and no-carry problems ($r = .47$) when the researcher was present during task performance. Therefore, maths evaluation anxiety was found to be more strongly related to response time in the condition that may result in a feeling of being evaluated, that is, when the researcher is present. However, post hoc analysis shows that the correlations do not differ significantly according to whether the researcher was present ($p > .05$). Further research is needed to explore the potential influence of researcher presence on performance, possibly emphasising performance evaluation or observation and perhaps taking into account physiological measures associated with increased arousal, such as heart rate. The discrepancy in correlations between maths anxiety and error rates on carry problems is consistent with the discrepancy across previous studies (see Chapter One for more details), suggesting that other factors, possibly subtle ones such as the presence of the researcher, may contribute to this relationship. On the other hand, across all three experimental studies, small and non-significant correlations were found between maths anxiety and percentage of errors on problems that did not involve a carry operation, providing support for the general assumption that maths anxiety is unlikely to be related to performance on problems that do not place many demands on working memory.

A further aim of the current thesis was to test the assumption that maths anxiety is related to processing efficiency more than performance effectiveness. As described in more detail in Chapter Two, processing efficiency theory (Eysenck & Calvo, 1992) and attentional control theory (Eysenck et al., 2007) propose that anxiety is more likely to affect processing efficiency over performance effectiveness on anxiety-related tasks, particularly on tasks that require greater working memory resources. That is, anxiety is likely to be related to longer response times but not necessarily an increase in number of errors made. Others (e.g. Ashcraft & Kirk, 2001) have argued that this phenomenon can be applied to the study of maths anxiety effects on performance. In the two experimental studies reported in this thesis that analysed response times, both found moderate to strong positive correlations between maths anxiety and response time. The consistency in this relationship, compared to the variation in relationship between maths anxiety and percentage of errors, provides support for the general assumption that anxiety is likely to affect processing efficiency more than performance effectiveness. However, across both studies, the relationship between maths anxiety and response time was virtually the same regardless of whether response times to carry problems or no-carry problems were analysed. This runs counter to the assumption that processing efficiency will be poorer in response to problems that place greater demands on working memory, that is, those that involve a carry operation. Thus, a general effect of maths anxiety on processing efficiency was observed, but this was not influenced by existence of a carry operation. There are some points to consider in relation to this. It is possible that, whilst response times to carry problems were longer than response times to no-carry problems when collapsed across anxiety levels, the difficulty level of the problems may not have been set at a level high enough for maths anxiety to influence performance. For example, whilst previous research has shown that the relationship between maths anxiety and response time is stronger in response to mental addition involving a carry operation compared to no carry operation, research has shown this relationship to be particularly strong on complex mental arithmetic problems, such as mixed fractions or algebra (Ashcraft et al., 1998). It is also important to bear in mind the maths abilities of the participants in the sample used, that is, all participants were Psychology undergraduates and a certain level of maths ability can be assumed, although, this sample is highly typical of samples used in maths anxiety research. As noted previously, however, controlling for maths ability is not straightforward because maths performance has been shown to be confounded by maths anxiety (see Hembree, 1990). In sum, the studies presented in this thesis provide mixed findings in terms of the relationship between maths anxiety and accuracy on two-digit addition problems. A consistent finding, however, is that higher maths anxiety is related to poorer processing efficiency, although this appears to be more of a general deficit in processing efficiency that is not differentiated by the existence of a carry operation.

8.3 Neuropsychological correlates of maths anxiety

Ashcraft (2002) requested that "We need research on the origins of math anxiety and on its 'signature' in brain activity, to examine both its emotional and its cognitive components" (p. 181). The first experimental study reported in this thesis attempted to address this request using an electroencephalogram methodology. Specifically, the study measured event-related potentials to focus on cortical activation within the frontal brain region. There is widespread evidence to suggest that the frontal region is integral to working memory processes (Miyake & Shah, 1999), and based on the argument that maths anxiety interferes with the efficiency of working memory processes (Ashcraft & Kirk, 2001), it was expected that, in response to two-digit addition problems, any maths anxiety effects would be observed in the frontal area. Maths anxiety was not expected to be related to amplitude of ERPs at the parietal site as it was assumed that maths anxiety has no influence on the neurophysiological processing of arithmetic in terms of the brain's response to the implementation of fact retrieval or of the calculation process. Rather, it is the ability to maintain sufficient levels of attention and to hold transient numerical information in the form of a carry term that was considered to be of most importance. It was hypothesised that, as Chwilla and Brunia (1992) and Jost et al. (2004) found, slow wave negativity would increase as a function of problem difficulty. Further to this, it was expected that maths anxiety would be positively related to ERP amplitude in response to problems involving a carry operation. Analysis involved three time windows succeeding the presentation of the second addend: 0-500ms immediately after presentation of the second addend, 500 – 3000ms after presentation of the second addend but prior to presentation of the proposed solution, and 4000 – 5000ms which relates to the time window succeeding presentation of the proposed solution. As expected, no relationship between ERP amplitude and maths anxiety or problem type was found in the very early (0 – 500ms) time window following presentation of the second addend. Also, ERP amplitude was not related to anxiety or problem type in the late time window following presentation of the proposed solution. A consistent finding across all three time windows was that amplitude positivity was greater at the parietal site (PZ). This is in line with the established finding that the parietal lobe is integral to arithmetic processing (e.g. Cohen et al., 2000; Delazer, et al., 2003). According to Prieto-Corona et al. (2010), other studies have demonstrated the late positive component to have a centro-parietal maximum: a finding supported by the current study. Therefore, these findings validate the methodology used in the study of mental arithmetic. Contrary to expectations, however, in the 500-3000ms time window, the results showed the opposite pattern to what was expected. Rather than maths anxiety being positively related to amplitude in response to problems involving a carry, a positive relationship was observed in response to problems not involving a carry operation. Somewhat consistent with the hypothesis, though, this relationship was confined to the left frontal sites FZ, F3 and F7 and explained 10.4%, 18.2% and 15.4% of the variance in amplitude, respectively. The location of this effect is consistent with the location of the negative slow wave found elsewhere (Chwilla & Brunia, 1992); however, it is still not clear why the effect appeared to be almost entirely specific to no-carry problems. As discussed in Chapter Four, one explanation could stem from the finding that pre-stimulus negativity has been related to preparation for a motor response (e.g. Brunia & Damen, 1988; Brunia, 2004; van Boxtel & Bocker, 2004) and it is possible that maths anxious individuals showed a greater willingness to respond when a problem requires little in the way of cognitive demands, as is the case with maths problems that do not involve a carry operation. For maths anxious individuals, this could be tentatively likened to a form of "cognitive relief" where online processing demands are immediately relaxed and the participant is keen to respond to a problem to which they have greater perceived self-efficacy in their ability to respond correctly. However, it is unclear why the reverse was not true for problems involving a carry operation.

Study one provides little support for the idea that event-related potentials actually vary as a function of problem difficulty per se. Rather, once problem size is controlled for, inclusion of a carry operation has little effect on the amplitude of the resultant ERPs. Study one therefore provides some useful evidence that contributes to general ERP research into mental arithmetic.

In study one maths anxiety was found to be positively related to slow wave negativity in response to problems that did not involve a carry operation, suggesting that maths anxiety may be related to an increased preparedness to respond to less cognitively demanding arithmetic, although further research is clearly needed to substantiate this suggestion. Returning to Ashcraft's earlier request that the "signature" of maths anxiety needs to be investigated in the brain, the current findings provide little support for the suggestion that maths anxiety is related to ERPs to arithmetic problems recorded from areas known to subserve working memory processes.

Methodologically, study one may have been partly limited by the number of electrode sites that were recorded from. A greater number of sites would enable greater insight into the relationship between maths anxiety and arithmetic processing across a wider range of brain regions. For example, research investigating the processing of emotional stimuli has found that anxiety is related to increased attention towards those stimuli and is also related to greater activation in the anterior cingulate cortex (Bush, Luu & Posner, 2000). Also studying the influence of anxiety on the allocation of attentional resources, van Hoof et al. (2008) used an emotional Stroop task and found ERPs to be related to response times. Such a paradigm may be useful in addressing the paucity of research into neuropsychological correlates of maths anxiety. Other related approaches such as fMRI may shed greater light on possible neural correlates of maths anxiety, particularly as fMRI can provide cerebral activity data in almost continuous, real-time (Cohen, Noll, & Schneider, 1993), highlighting activation in a range of sub-cortical regions.

In sum, study one found a significant correlation between maths anxiety and percentage of error rates on problems that involved a carry operation, but a relationship was not observed in response to problems that did not involve a carry operation. Despite these behavioural findings, there was little evidence for a relationship between maths anxiety and cortical activation in the form of ERPs. Findings did, however, provide some evidence for increased activation in centro-frontal regions in response to less demanding, no-carry, problems. On the whole, in response to Ashcraft's (2002) request, the findings provide little evidence for a brain signature relating to maths anxiety, suggesting alternative methodologies may need to be adopted.

8.4 The role of cognitive intrusions in explaining the relationship between maths anxiety and performance

As discussed in more detail in the previous chapters, many researchers have attempted to explain the relationship between maths anxiety and performance in terms of the influence of intrusive thoughts. For example, Hopko et al. (1998) suggested an integration of processing efficiency theory (Eysenck & Calvo, 1992) with inhibition theory (Hasher & Zacks, 1988; Connelly et al., 1991), proposing that maths anxiety may be related to a reduction in the ability to inhibit intrusive thoughts and that it may also pre-empt task-related working memory processes, particularly relating to the central executive component of working memory. Furthermore, it is argued that, in line with processing efficiency theory and the later attentional control theory (Eysenck et al., 2007), processing efficiency more than effectiveness, is characteristically impaired by maths anxiety.

Until now there has been very little research that has attempted to address these theoretical assumptions in relation to intrusive thoughts and maths anxiety specifically. Study three used a modified version of the Cognitive Intrusions Questionnaire (Freeston et al., 1991) to measure self-reported in-task intrusive thoughts, including participants' perception of those thoughts in relation to their performance. Results revealed that certain in-task intrusive thoughts significantly predicted performance. The existence of thoughts about panicking was related to faster response times, although it is difficult to identify whether such thoughts were related to actual panic or simply thoughts about it.

Therefore more research is needed to explore this; in particular, physiological measures, such as heart rate, could be used in conjunction with self-reports of thoughts about panic. Also, participants could be asked to differentiate between aspects of panic, for example, retrospective accounts of feelings of actual panic, and also worry about the potential to panic. Furthermore, the existence of thoughts about previous maths experience was related to longer response times; as discussed later. Overall, reports based on participants' most worrisome or troubling thoughts showed that perceived difficulty in removing those thoughts was related to longer response times in the first half of trials, providing support for the assumption that intrusive thoughts are related to poorer processing efficiency. Further support came from participants' self-reported impact of intrusive thoughts on their ability to calculate effectively, which was found to be positively related to percentage of errors. Consistent with a processing efficiency approach, these effects existed in response to carry problems only, suggesting intrusive thoughts only impacted on performance in response to mental arithmetic that placed greater demands on working memory. Interestingly, these effects were also present once maths anxiety had been controlled for, suggesting independent effects on performance. In order to address the possibility that maths anxiety may have a mediating effect on the relationship between intrusive thoughts and performance, all regression models were performed again with maths anxiety added after all intrusive thought measures. However, adding maths anxiety into the models at a later stage had very little effect on the beta coefficients and significance levels of individual intrusive thought predictors, therefore providing little evidence to suggest a mediating path exists between intrusive thoughts, maths anxiety and performance.

Consistent with the general anxiety effects proposed by processing efficiency theory (Eysenck & Calvo, 1992), study three showed that maths anxiety was related to longer response times irrespective of problem type. However, in attempting to explain the relationship between maths anxiety and performance, there was no evidence for a joint relationship between maths anxiety and experience of any specific intrusive thought or perceived impact of the thought. Consequently, the results provide little support for an intrusive thoughts account of maths anxiety effects, despite this being a frequently used explanation in the literature (e.g. Hunsley, 1987; Hopko et al., 1998; Hopko et al., 2005).

As discussed in Chapter Six (study three), one methodological issue relates to the problem of self-reported intrusive thoughts being directly related to the outcome measures being taken, for example thoughts about time pressure and the measurement of response times. The regression models in study three showed that the existence of thoughts about time pressure was strongly related to actual response times, but not error rates. Similarly, the existence of thoughts about making mistakes was related to the actual percentage of errors made, but not response time. This highlights the difficulty in differentiating between intrusive thoughts as antecedents to behavioural responses and intrusive thoughts as a response to behaviour. As noted in Chapter Six, one possible way to gain clarity could be to measure self-reported intrusive thoughts before and after a manipulation relating to the performance measures, for example increasing time pressure, or introducing an evaluation of accuracy.

8.5 Eye-movement, maths anxiety and performance

As discussed previously, explanations for the general effect of maths anxiety on performance have tended to focus on the role of worry in interfering with working memory processes and reducing the resources needed for efficient and effective mental arithmetic performance. This has generally been discussed in relation to processing efficiency theory (Eysenck & Calvo, 1992). For example, Ashcraft and Kirk (2001) discuss their observed maths anxiety effects in terms of “inappropriate (and self-defeating) attention to the cognitive components of the math-anxiety reaction and to intrusive thoughts, worry, preoccupation with performance evaluation, and the like” (p. 236). In particular, they explain their findings in relation to the assumption of processing efficiency theory that anxiety reduces the availability of resources needed for task-relevant processing. It is this latter point that Eysenck et al.’s (2007) attentional control theory builds on and, as outlined in more detail in Chapter Two, emphasises the increase in a stimulus-driven approach to task processing as a result of anxiety, compared to a goal-orientated approach. Study four, reported in Chapter Seven, aimed i) to test some of the assumptions of processing efficiency theory and attentional control theory with regard to the relationship between maths anxiety and performance, but also ii) to use a methodology that has not previously been used in the study of maths anxiety: eye-tracking.

The results from study four provided support for the usefulness of tracking eye movements during mental arithmetic processing, with measures of fixations, dwell time, saccades and regressions all found to be related to response times. In particular, increases in each of these measures were related to longer response times. This occurred irrespective of whether problems required a carry operation and therefore may indicate a general effect of eye movements on processing efficiency.

By using a verification task it was possible to measure the extent to which participants focused attention on specific digits in a proposed mental arithmetic problem, possibly giving some insight into the attentional control processes discussed by Eysenck et al.’s attentional control theory. For example, an inefficient processing strategy would involve focusing on those aspects of a proposed problem that are not necessary in verifying the proposed solution, for example the tens digits compared to the unit digits. Also, according to attentional control theory, anxiety is related to increased effort towards effective task performance, resulting in a greater occurrence of regressions over the task stimuli. Accordingly, it could be assumed that maths anxiety moderates the relationships between task performance and a range of eye-movement measures. However, results showed that maths anxiety was related to longer response times but not to the percentage of errors made. Moderation analyses failed to provide sufficient evidence to suggest that a joint relationship exists between maths anxiety and eye movements in explaining arithmetic performance. There was some evidence, however, to suggest that maths anxiety is more strongly related to fixations and dwell time to first digits compared to other digits. Mediation analyses showed some reduction in standardised beta values of those eye-movement measures after maths anxiety was added to the regression models. Also, there was some evidence to suggest an indirect path exists between eye-movement, maths anxiety and response time, but such paths did not remain significant once alpha was adjusted to control for the possibility of a type I error. As such, it is tentatively suggested that maths anxiety partially mediates the relationship between eye-movement and arithmetic response time, particularly in relation to eye movements towards the first digit of a proposed problem but further research is needed to investigate this.

A major methodological issue to consider when using an eye-tracking approach to test for maths anxiety effects on the processing of on-screen maths problems relates to the assumptions behind the eye movements themselves. In study four, assumptions focused on attentional control processes, but a further consideration could relate to decisions around strategy choice more generally. In solving a two-digit verification problem there are several calculation strategies that can be employed, including, for example, direct retrieval of a solution, comparison of units only, counting on, summing one pair of tens and units and then the other. Therefore, it is possible that eye movements reflect this to a greater degree than other processes related to attentional control. Future research would need to take into account self-reported calculation strategies in order to test the validity of eye movements as an index of calculation strategy, but, in particular, whether this is moderated by anxiety.

8.6 Integrating approaches

It is possible that a processing efficiency or attentional control approach may not be effective in explaining the relationship between anxiety and task performance. However, as discussed in Chapter Two, there is much support for the validity of these approaches. A further consideration is that maths anxiety effects on performance are simply unrelated to processing efficiency and attentional control, including the concept of in-task intrusive thoughts and inhibition processes. The findings of the current studies do de-emphasise the role of these approaches, but there also seems to be justification for exploring the role of processing efficiency and attentional control further. In particular, the findings regarding the consistency of the relationship between maths anxiety and response times, and also the relationship between maths anxiety and experience of in-task intrusive thoughts, may provide a foundation for further research, including the possibility of integrating approaches.

Studies three and four take somewhat different approaches to the study of maths anxiety effects, despite having the same underlying assumptions regarding processing efficiency and attentional control, including disinhibition of intrusive thoughts. An effective approach in studying the mechanisms behind the consistently observed positive relationship between maths anxiety and response time could be to combine an eye-tracking methodology with an experimental paradigm involving the inhibition of distractor stimuli. As discussed in more detail in Chapter Two, Hopko et al. (1998) presented participants with paragraphs of text including maths-related and non-maths-related distractors. Whilst the type of distractor appeared to have little effect on reading time, maths anxiety was related to a general failure to inhibit irrelevant information, consequently leading to longer reading times. Using eye-tracking measures it would be possible to introduce two further experimental designs not previously implemented in the study of maths anxiety. Firstly, a version of the anti-saccade task could be utilised. For example, this could involve a combination of the general anti-saccade paradigm adopted in the study of anxiety (see Chapter Seven for further details, e.g. Hermans et al., 1999), in which maths and non-maths related stimuli could be presented as distractors during mental arithmetic. This could extend the work of Hopko et al. and measure the influence of distractors during actual arithmetic processing, but also measure eye-movement towards task-based and non-task based (distractor) stimuli. Secondly, to help counteract methodological issues surrounding certain intrusive thoughts as antecedents or consequences of maths anxiety, as seen in study three, an experimental design could involve the presentation of on-screen maths problems and also include the visual presentation of, for example, an on-screen timer. Again, eye-movement measures could be a useful indicator of participants' level of attentional control towards the maths problem or the timer. Attentional focus on the maths problem could be seen as indicative of a goal-directed approach, whereas attentional focus on the timer could be seen as evidence for reduced attentional control, particularly if this behaviour is related to self-reports of time-related intrusive thoughts.

8.7 Gender differences in maths anxiety

A final aim of this thesis was to report on the difference in maths anxiety between males and females. As discussed in Chapter One, several studies have reported maths anxiety scores for males and females, with some studies finding no difference (e.g. Dambrot et al., 1985), but studies generally finding that females report slightly higher maths anxiety than males, with Hembree's (1990) meta-analysis, for example, finding an effect size (d) of 0.31 when comparing maths anxiety between males and females at University. No research to date has reported on maths anxiety levels in British undergraduates, so the findings reported in study two (Chapter Five) provide a useful comparison against gender differences observed elsewhere. Based on a large sample (544 males, 609 females), results showed that females reported significantly higher maths anxiety than males, but, based on the effect size measure eta-squared, gender accounted for only 0.8% of the variance in maths anxiety scores, suggesting that gender may not be a useful variable for consideration in future maths anxiety research in a British undergraduate population. However, on closer inspection, females did score higher (d = 0.45) than males on the maths evaluation sub-scale of the MAS-U.K, suggesting that gender should not be ignored completely.

8.8 Self-reporting maths anxiety

As with any self-report measures, there are issues surrounding the use of maths anxiety scales as a valid tool for measuring the level of maths anxiety an individual experiences. Therefore, it is important that an appropriate scale is chosen. Anecdotal evidence from the use of the Mathematics Anxiety Rating Scale (MARS, Richardson & Suinn, 1972) in study one indicated that some students misunderstood some of the terminology used on certain items. As a second study the new Mathematics Anxiety Scale U.K. was developed to address this issue and also to provide some much needed normative data on maths anxiety levels in a British undergraduate population. The final scale, including 23 items, was found to have excellent psychometric properties (see Chapter Five for details) and was subsequently used in studies three and four. The consistent relationship between maths anxiety and performance further validated the scale and highlights the usefulness of it as a self-report measure.

8.9 Maths anxiety and issues of specificity

One of the main obstacles involved in maths anxiety research concerns who and what it is applied to. As already described, the experimental studies reported in this thesis all used verification problems involving two-digit addition. This was for two main reasons. Firstly, to avoid conflating maths anxiety effects with maths ability, two-digit addition has been a popular choice of problem (e.g. Faust et al., 1996). Secondly, in order to make valid judgements regarding mechanisms underpinning the relationship between maths and performance, problem type needed to be consistent across studies. It should be noted, however, that it is possible to include a wider range of problem types within maths anxiety research and it may be the case that more demanding problems need to be used to identify the influence of certain factors, particularly where such factors could be seen as interfering with cognitive resources needed for effect task performance, for example experience of intrusive thoughts.

The experimental studies reported in this thesis made no attempt to manipulate the context in which participants were being tested. However, as discussed in Chapter Two, previous attempts to manipulate components of maths anxiety, for example time pressure (Kellogg et al., 1999) and physically induced anxiety (Hopko et al., 2003) have failed to explain maths anxiety effects on performance. As discussed earlier, taking time pressure as an example, it could be that it is not necessarily the case that time pressure per se is important, but it may be that it is the focusing of attention towards thoughts about time that is important in relation to performance. Whilst there were interpretation issues in study three of this thesis surrounding the role of experiencing thoughts related to time pressure, there was a significant moderate positive correlation between maths anxiety and experiencing thoughts about time pressure (r = .26), and an even stronger correlation (r = .30) when the maths evaluation anxiety sub-scale was used. Consequently, despite previous research failing to demonstrate an effect of time pressure on performance that was differentially affected by level of maths anxiety (Kellogg et al., 1999), it would be interesting to readdress such a design but also including measures of attentional control towards the time and thoughts related to time.

A further consideration relates to the sample that is used. In the studies presented in this thesis the focus was on studying maths anxiety in a British undergraduate population. The findings present a useful insight into the relationship between maths anxiety and performance in this population. However, two factors need to be addressed. Firstly, the studies in this thesis are based on samples of students who volunteered to participate. Consequently, it is possible that individuals who experience the highest levels of maths anxiety were unlikely to volunteer to participate in a study involving maths. There have been many studies that have reported a negative relationship between maths anxiety and desire to avoid maths (Hembree, 1990). Indeed, an observation of the mean maths anxiety scores across studies three (mean = 51.56; SD = 16.27) and four (mean = 48.42; SD = 13.97) of this thesis reveal them to be considerably lower than the overall mean of Science students (84% studying Psychology) reported in study two, in which the mean was 82.12 (SD = 27.12). This finding highlights the problem with generalising to the population of students when the samples may not contain representative levels of maths anxiety. Secondly, it should not be assumed that self-reported maths anxiety is homogeneous across academic subject areas. Normative data in study two revealed significant differences in self-reported maths anxiety across Faculties, whereby maths anxiety was greatest in the Arts, Media and Design Faculty, and lowest in the Business Faculty. Consequently, future research needs to take this variation into account when making generalisations to the population of undergraduate students.

The vast majority of published studies on maths anxiety fail to report on effects according to the sub-scales of the self-report maths anxiety scales adopted. However, as discussed in detail in Chapter Five, maths anxiety can be viewed as a multidimensional construct. Therefore, consideration of these dimensions may provide greater insight into maths anxiety effects. Indeed, the findings in studies three and four emphasise this point. The Mathematics Anxiety Scale U.K. (Hunt et al., in press) was found to contain three sub-scales: maths evaluation anxiety, everyday/social maths anxiety, and maths observation anxiety (see Chapter Five for details). On the whole, maths evaluation anxiety was the strongest predictor of performance. This is not surprising given the test-type conditions under which participants performed. Similarly, everyday/social maths anxiety was generally a poor predictor of performance. Again, this is to be expected given that the experimental conditions adopted were not typical of everyday or social maths situations. These results may provide a useful starting point for further research in which the context that individuals experience maths in is taken into account, along with the specific form of maths anxiety that is being measured. As noted earlier, some studies have attempted to manipulate certain variables as a way of investigating specific aspects of maths anxiety, for example, time pressure (Kellogg et al., 1999) and physically-induced anxiety (Hopko et al., 2003), but have failed to demonstrate how such manipulations affect performance differentially across levels of maths anxiety. Therefore, future research may need to consider experimental manipulations more directly related to maths anxiety dimensions. For example, based on the finding reported in the current thesis that maths evaluation anxiety is a good predictor of performance, experimental manipulations could focus on evaluation, such as peer evaluation, or being observed (something that, anecdotally, many self-confessed maths anxious individuals in the current studies reported would heighten their anxiety). Furthermore, as discussed in Chapter Five, there may be other maths anxiety dimensions to consider, such as a numerical or calculation anxiety (e.g., Rounds & Hendel, 1980; Alexander & Martray, 1989).

8.10 Processing efficiency and the role of motivation

As discussed in more detail in Chapter Two, attentional control theory (Eysenck et al., 2007) extended the earlier processing efficiency theory (Eysenck & Calvo, 1992) and as part of their theory Eysenck et al. emphasise the role of effort in relation to attentional control. Eysenck and Derakshan (in press) discuss this further, specifically in terms of a two-stage process of enhanced effort. Eysenck and Derakshan propose that, in tasks that are undemanding, high anxious individuals have a low level of motivation and make minimal use of attentional control mechanisms. Conversely, when a task is demanding or where there are clear task goals, this produces a high level of motivation amongst individuals high in anxiety. Consequently, in overriding the influence of the stimulus-driven attentional system as a result of anxiety, individuals are likely to employ compensatory strategies to achieve task goals. According to Eysenck and Derakshan, high anxious individuals are more likely to employ compensatory strategies, such as more effortful processing, in response to tasks where motivation is high. In support of this they highlight studies such as those conducted by Hayes et al. (2009) in which high trait anxiety had a negative impact on performance in a low motivation condition, but this effect was eliminated in a high motivation condition. Therefore, future research into maths anxiety effects on performance may wish to consider these developments, perhaps manipulating experimental conditions according to the level of motivation they are likely to induce. The findings from the studies in this thesis provide some support for this proposition; for example, as discussed earlier, there was no correlation between maths anxiety and percentage of errors in the final study in which the researcher was present during task performance, but maths anxiety was found to be significantly correlated with percentage of errors in studies one and three in which participants performed the maths task alone. Consistent with a compensatory strategy approach, in the presence of the researcher, the relationship between maths anxiety and response time was stronger than in the experiments in which participants performed alone. It is possible that the presence of the researcher resulted in increased motivation, as evidenced from a lack of correlation between maths anxiety and error rate, suggesting greater investment of effort to achieve the task goal. However, expenditure of effort was not explicitly tested and future studies would need to attempt to measure this in order to validate claims that maths anxiety, motivation and effort are related in the context of task performance. Nonetheless, the findings from the current studies provide partial support for this later addition to attentional control theory.

8.11 Further factors for consideration

One of the main findings of study three was that existence of in-task intrusive thoughts relating to previous maths experiences was positively related to response times in the solving of two-digit arithmetic problems. Whilst a joint relationship between maths anxiety and experience of such thoughts did not exist, both maths anxiety and thoughts about previous maths experiences remained significant predictors in the final stage of the regression models tested. Linked to previous maths experiences, there have been many studies that have demonstrated the influence of parental or teacher attitudes towards maths in relation to the development of maths anxiety (e.g. Hembree, 1990; Haynes, et al., 2004, Trujillo & Hadfield, 1999). The findings from study three therefore suggest it is worth exploring the role of previous maths experiences further. For example, it would be interesting to investigate exactly which aspects of previous maths experiences intrusive thoughts relate to. A closer examination of this may improve understanding of the relationship between maths anxiety and performance, and perhaps give further insight into other factors that have previously been shown to be related to maths anxiety, such as maths self-efficacy (e.g. Pajares & Miller, 1995).

8.12 Concluding comments

In sum, this thesis reported on three experimental studies designed to investigate the relationship between maths anxiety and arithmetic performance. In particular, the aim of the thesis was to empirically test some possible mechanisms considered to underpin this relationship. The findings provide no evidence to suggest that intrusive thoughts or eye-movements help in explaining why performance decreases as maths anxiety increases. Also, event-related potentials recorded during mental arithmetic presented no evidence to suggest there are neuropsychological correlates of maths anxiety. Together, the findings from the studies de-emphasise the role of processing efficiency theory and attentional control theory in explaining maths anxiety effects on performance, although results did demonstrate that maths anxiety detrimentally affects processing efficiency more than performance effectiveness. Despite lacking explanatory power with regard to maths anxiety effects, findings demonstrated the utility of measuring in-task cognitive intrusions and recording eye-movements in studying mental arithmetic performance since both were related to performance. Finally, as a direct result of validity issues that arose during the current investigations, this thesis reports on the newly developed Mathematics Anxiety Scale U.K. as a self-report measure of maths anxiety suitable for measuring maths anxiety in a British and potentially European undergraduate population and highlights the multidimensional nature of maths anxiety. Overall, the findings presented in this thesis provide a valuable contribution to the field of maths anxiety research and have helped to identify a wide range of further research that could be conducted to investigate the mechanisms underpinning the relationship between maths anxiety and performance.

References

Acherman-Chor, D., Aladro, G., & Dutta Gupta, S. (2003). Looking at both sides of the equation: Do student background variables explain math performance? *Journal of Hispanic Higher Education*, 2, 129-145.

Alexander, L., & Martray, C. (1989). The development of an abbreviated version of the mathematics anxiety rating scale. *Measurement and Evaluation in Counseling and Development*, 38, 485-490.

Alkhateeb, H. M., & Taha, N. (2002). Mathematics self-concept and mathematics anxiety of undergraduate majors in education. *Psychological Reports*, 9, 11273-1275.

American Psychiatric Association. (1994). *Diagnostic and statistical manual of mental health disorders* (4th edn.). Washington DC: Author.

Anderson, S. W., Domasio, A. R., & Domasio, H. (1990). Troubled letters but not numbers: Domain specific cognitive impairments following focal damage in frontal cortex. *Brain*, 113, 749-766.

Ansari, T. L., Derakshan, N., & Richards, A. (2008). Effects of anxiety on task switching: Evidence from the mixed antisaccade task. *Cognitive Affective and Behavioral Neuroscience*, 8, 229-238.

Ashcraft, M. H. (1995). Cognitive psychology and simple arithmetic: A review and summary of new directions. *Mathematical Cognition*, 1, 3-34.

Ashcraft, M. H. (2002). Math Anxiety: Personal, Educational, and Cognitive Consequences. *Current Directions in Psychological Science*, 11, 181–185.

Ashcraft, M. H., & Battaglia, J. (1978). Cognitive arithmetic: Evidence for retrieval and decision processes in mental addition. *Journal of Experimental Psychology: Human Learning and Cognition*, 4, 527-538.

Ashcraft, M. H., & Faust, M. W. (1994). Mathematics anxiety and mental arithmetic performance: An exploratory investigation. *Cognition and Emotion*, 8, 97–125.

Ashcraft, M. H., & Kirk, E. P. (1998). The relationships among working memory, math anxiety, math competence, and attitudes toward math. Unpublished manuscript.

Ashcraft, M. H., & Kirk, E. P. (2001). The relationships among working memory, math anxiety, and performance. Journal of Experimental Psychology – General, 130, 224–237.

Ashcraft, M. H., & Ridley, K. S. (2005). Math anxiety and its cognitive consequences: A tutorial review. In J. I. D. Campbell (Ed.), *Handbook of mathematical cognition* (pp. 315-327). New York: Psychology Press.

Ashcraft, M. H., Kirk, E. P., & Hopko, D. (1998). On the cognitive consequences of mathematics anxiety. In C. Donlan (Ed.), *The development of mathematical skills* (pp. 175-196). Hove, England: Psychology Press.

Ashcraft. H., & Krause, J. A. (2007). Working memory, maths performance, and maths anxiety. *Psychonomic Bulletin & Review*, 14, 243-248.

Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, 4, 417-423.

Baddeley, A. D. (1986). *Working Memory*. New York : Oxford University Press.

Baddeley, A. D., & Hitch, G. J. (1974). Working Memory. In G.A. Bower (Ed.), *Recent Advances in Learning and Motivation* (vol 8, 47-90). New York: Academic Press.

Baloglu, M., & Kocak, R. (2006). A multivariate investigation of the differences in mathematics anxiety. *Personality and Individual Differences*, 40, 1325-1335.

Bandalos, D. L., Yates, K., & Thorndike-Christ, T. (1995). Effects of math self-concept, perceived self-efficacy, and attributions for failure and success on test anxiety. *Journal of Educational Psychology*, 87, 611-623.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Englewood Cliffs, NJ: Prentice Hall.

Bandura. A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review*, 84, 191-215.

Bandura. A. (1982). Self-efficacy mechanism in human agency. *American Psychologist*, 37, 122-147.

Beilock, S. L., Kulp, C. A., Holt, L. E., & Carr, T. H. (2004). More on the fragility of performance: Choking under pressure in mathematical problem solving. *Journal of Experimental Psychology: General*, 133, 584-600.

Beilock, S. L., Rydell, R. J., & McConnell, A. R. (2007). Stereotype threat and working memory: Mechanisms, alleviation, and spillover. *Journal of Experimental Psychology: General*, 136, 256-276.

Benson, J. (1989). Structural components of statistical test anxiety in adults: An exploratory model. *Journal of Experimental Education*, 57, 247-261.

Bessant, K. (1995). Factors associated with types of mathematics anxiety in college students. *Journal for Research in Mathematics Education*, 26, 327-345.

Betz, N. E. (1978). Prevalence, distribution, and correlates of maths anxiety in college students. *Journal of Counseling Psychology*, 25, 441-448.

Birenbaum, M., & Eylath, S. (1994). Who is afraid of statistics? Correlates of statistics anxiety among students in educational sciences. *Educational Research*, 36, 93-98.

Bishop, S., Duncan, J., Brett, M., & Lawrence, A. D. (2004). Prefrontal cortical function and anxiety: Controlling attention to threat-related stimuli. *Nature Neuroscience*, 7, 184–188.

Brewin, C. R., & Beaton, A. (2002). Thought suppression, intelligence, and working memory capacity. *Behaviour Research and Therapy*, 40, 923-930.

Browne, M. W., & Cudeck, R. (1993). Alternative ways of assessing model fit. In K. A. Bollen, & J. S. Long (Eds.), *Testing structural equation models* (pp. 445–455). Newbury Park, CA: Sage.

Brunia, C. H. M. (2004). Slow potentials in anticipatory behaviour. *Journal of Psychophysiology*, 18, 59-60.

Brunia, C. H. M., & Damen, E. J. P. (1988). Distribution of slow brain potentials related to motor preparation and stimulus anticipation in a time estimation task. *Electroencephalography and Clinical Neurophysiology*, 69, 234-243.

Burns, M. (1998). *Math: Facing an American Phobia*. Sausalito, CA: Math Solutions Publications.

Bush, G., Luu, P., & Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences*, 4, 215-222.

Butterworth, B. (1999). *The mathematical brain*. London: Macmillian.

Byrne, A., & Eysenck, M. W. (1995). Trait anxiety, anxious mood, and threat detection. *Cognition and Emotion*, 9, 549-562.

Calvo, M. G. (1985). Effort, aversive representations and performance in test anxiety. *Personality and Individual Differences*, 6, 563-571.

Calvo, M. G., & Avero, P. (2002). Eye movement assessment of emotional processing in anxiety. *Emotion*, 2, 105-117.

Calvo, M. G., & Castillo, M. D. (1995). Phonological coding in reading comprehension: The importance of individual differences. *European Journal of Cognitive Psychology*, 7, 365–382.

Calvo, M. G., & Eysenck, M. W. (1996). Phonological working memory and reading in test anxiety. *Memory*, 4, 289–305.

Capraro, M. M., Capraro, R. M., & Henson, R. K. (2001). Measurement error of scores on the mathematics anxiety rating scale across studies. *Educational and Psychological Measurement*, 61, 373-386.

Caramazza, A., & McCloskey, M. (1987). Dissociations of calculation processes. In G. Deloch & X. Seron (Eds.), *Mathematical disabilities: A cognitive neuropsychological perspective* (pp. 221-234). Hillsdale, NJ: Erlbaum.

Carretie, L., Mercado, F., Hinojosa, J. A., Martin-Loeches, M., & Sotillo, M. (2004). Valence-related vigilance biases in anxiety studied through event-related potentials. *Journal of Affective Disorders*, 78, 119-130.

Carroll, D., Ring., & Winzer, A. (2000). Stress and muscosal immunity. In G. Fink (Ed.). *Encyclopedia of stress* (vol. 2, pp. 781-786). San Diego: Academic Press.

Carroll, D., Turner, J. R., & Prasad, R. (1986). The effects of level of difficulty of mental arithmetic challenge on heart-rate and oxygen consumption. *International Journal of Psychophysiology*, 4, 167-173.

Cates, G. L., & Rhymer, K. N. (2003). Examining the relationship between mathematics anxiety and mathematics performance: A learning hierarchy perspective. *Journal of Behavioral Education,* 12, 23-34.

Cherkasova, M. V., Manoach, D. S., Intriligator, J. M., & Barton, J. J. S. (2002). Antisaccades and task-switching: Interactions in controlled processing. *Experimental Brain Research*, 144, 528-537.

Chipman, S. F, Krantz, D.H., & Silver, R. (1992). Mathematics anxiety and science careers among able college women. *Psychological Science*, 3, 292-295.

Chiu, L., & Henry, L. (1990). The development and validation of the Mathematics Anxiety Rating Scale for Children. *Measurement and Evaluation in Counseling and Development*, 23, 121-127.

Chwilla, D. J., & Brunia, C. H. M. (1992). Effects of emotion on event-related potentials in an arithmetic task. *Journal of Psychophysiology*, 6, 321-332.

Cipolotti, L. (1995). Multiple routes for reading words, why not numbers – evidence from a case of Arabic numeral dyslexia. *Cognitive Neuropsychology*, 12, 313-342.

Cipolotti, L., Butterworth, B., & Denes, G. (1991). A specific deficit for numbers in a case of dense acalculia. *Brain*, 114, 2619-2637.

Cipolotti, L., Warrington, E. K., & Butterworth, B. (1995). Selective impairment in manipulating Arabic numerals. *Cortex*, 31, 73-86.

Cockburn, J., & Smith, P. T. (1994). Anxiety and errors of prospective memory among elderly people. *British Journal of Psychology*, 85, 273–282.

Cohen, J. (1983). The cost of dichotomization. *Applied Psychological Measurement*, 7, 249-253.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences* (2nd Edn.). Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Cohen, J. D., Noll, D. C., & Schneider, W. (1993). Functional magnetic resonance imaging: Overview and methods for psychological research. *Behavior Research Methods, Instruments, and Computers*, 25, 101-113.

Cohen, J., & Cohen, P. (1975). *Applied multiple regression/correlation for the behavioural sciences*. New York: Wiley.

Cohen, L., Dehaene, S., Chochon, F., Lehericy, S., & Naccache, L. (2000). Language and calculation within the parietal lobe: A combined cognitive, anatomical and fMRI study. *Neuropsychologia*, 38, 1426-1440.

Comrey, A. L., & Lee, H. B. (1992). *A first course in factor analysis*. (2nd ed). Hillsdale, NJ: Lawrence Erlbaum Associates.

Connelly, S. L., Hasher, L., & Zacks, R. T. (1991). Age and reading: The impact of distraction. *Psychology and Aging*, 6, 533–541.

Crowe, S. F., Matthews, C., & Walkenhorst, E. (2007). Relationship between worry, anxiety and thought suppression and the components of working memory in a non-clinical sample. *Australian Psychologist*, 42, 170-177.

Curtin, P. A., & Maier, S. R. (2001). Numbers in the newsroom: A qualitative examination of a quantitative challenge. *Journalism and Mass Communication Quarterly*, 78, 720-738.

D'Esposito, M., Postle, B. R., Ballard, D., & Lease, J. (1999). Maintenance versus manipulation of information held in working memory: An event-related fMRI study. *Brain and Cognition*, 66-86.

Dambrot, F. (1985). Correlates of sex differences in attitudes toward and involvement with computers. *Journal of Vocational Behavior*, 27, 71-86

Dambrot, F. H., Watkins-Malek, M. A., Silling, S. M., Marshall, R. S., & Garver, J. A. (1985). Correlates of sex differences in attitudes toward and involvement with computers. *Journal of Vocational Behavior*, 27, 71-86.

Darke, S. (1988a). Anxiety and working memory capacity. *Cognition and Emotion*, 2, 145–154.

De Corte, E., Verschaffel, L., & Pauwels, A. (1990). Influence of the semantic structure of word problems on second graders' eye movements. *Journal of Educational Psychology*, 82, 359-365.

Dehaene, S., Naccache, L., Le Clec'H, G., Koechlin, E., Mueller, M., Dehaene-Lambertz, G., van de Moortele, P. F., & Le Bihan, D. (1998b). Imaging unconscious semantic priming. *Nature*, 395, 597-600.

Dehaene, S., Piazza, M., Pinel, P., & Cohen, L. (2003). Three parietal circuits for number processing. *Cognitive Neuropsychology*, 20, 487-506.

Dehaene, S., Piazza, M., Pinel, P., & Cohen, L. (2005). Three parietal circuits for number processing. In J. I. D. Campbell (Ed.). *Handbook of mathematical cognition* (pp. 433-454). Hove: Taylor and Francis.

Delazer, M., & Benke, T. (1997). Arithmetic facts without meaning. *Cortex*, 4, 697-710.

Delazer, M., Domahs, F., Bartha, L., Brenneis, C., Lochy, A., Trieb, T., & Benke, T. (2003). Learning complex arithmetic – an fMRI study. *Cognitive Brain Research*, 18, 76-88.

Derakshan, N., & Koster, E. H. W. (in press). Processing efficiency in anxiety: Evidence from eye-movements during visual search. *Behaviour Research and Therapy*, 1-6.

Derakshan, N., Ansari, T. L., Hansard, M., Shoker, L., & Eysenck, M. W. (2009). Anxiety, inhibition, efficiency, and effectiveness: An investigation using the antisaccade task. *Experimental Psychology*, 56, 48-55.

Dew, K. M. H., Galassi, J. P., & Galassi, M. D. (1983). Mathematics anxiety: Some basic issues. *Journal of Counseling Psychology*, 30, 443-446.

Dornic, S. (1977). *Mental load, effort, and individual differences*. Reports from the Department of Psychology, University of Stockholm, No. 509.

Dornic, S. (1980). *Efficiency vs. effectiveness in mental work: The differential effect of stress*. Reports from the Department of Psychology, University of Stockholm, No. 568.

Dreger, R. M., & Aiken, L. R. (1957). The identification of number anxiety in a college population. *Journal of Educational Psychology*, 48, 344-351.

Dugas, M. J., Letarte, H., Rheaume, J., Freeston, M. H., & Ladouceur, R. (1995). Worry and problem solving: Evidence of a specific relationship. *Cognitive Therapy and Research*, 19, 109-120.

Dusek, J. B., Kermis, M. D., & Mergler, N. L. (1975). Information processing in low- and high-test-anxious children as a function of grade level and verbal labeling. *Developmental Psychology*, 11, 651–652.

Eccles, J. S. (1983). Sex differences in achievement patterns. In T. B. Sondregger (Ed.). *Nebraska symposium on motivation* (pp. 97-132). Lincoln: University of Nebraska Press.

Eccles, J. S., Wigfield, A., Meece, J., Kaczala, C., & Jayrante, T. (1986). *Sex differences in attitudes and performance in math*. Unpublished manuscript, University of Michigan.

Elliman, N. A., Green, M. W., Rogers, P. J., & Finch, G. M. (1997). Processing efficiency theory and the working memory system: Impairments associated with sub-clinical anxiety. *Personality and Individual Differences*, 23, 31-35.

El Yagoubi, R., Lemaire, P., & Besson, M. (2003). Different brain mechanisms mediate two strategies in arithmetic: Evidence from event-related brain potentials. *Neuropsychologia*, 40, 855-862.

Engelhard, G. (1990). Math anxiety, mothers education, and the mathematics performance of adolescent boys and girls: Evidence from the United States and Thailand. *Journal of Psychology*, 124, 289-298.

Eysenck, M. W. (1979). Anxiety, learning, and memory reconceptualization. *Journal of Research in Personality*, 13, 363-385.

Eysenck, M. W. (1985). Anxiety and cognitive task performance. *Personality and Individual Differences*, 6, 579-586.

Eysenck, M. W. (1989). Stress, anxiety and intelligent performance. In D. Vickers & P. L. Smith (Eds., *Human information processing: Measures, mechanisms and models*. Amsterdam: North-Holland.

Eysenck, M. W., & Byrne, A. (1992). Anxiety and susceptibility to distraction. *Personality and Individual Differences*, 13, 793–798.

Eysenck, M. W., & Calvo, M. G. (1992). Anxiety and performance: The processing efficiency theory. *Cognition and Emotion*, 6, 409–434.

Eysenck, M. W., & Derakshan, N. (in press). New perspectives in attentional control theory. *Personality and Individual Differences*.

Eysenck, M. W., & Payne, S. (2006). Effects of anxiety on performance effectiveness and processing efficiency. Unpublished manuscript. Royal Holloway University of London, Egham, Surrey, U.K.

Eysenck, M. E., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion*, 7, 336-353

Faust, M. W., Ashcraft, M. H., & Fleck, D. E. (1996). Mathematics anxiety effects in simple and complex addition. *Mathematical Cognition*, 2, 25–62.

Fennema, E. (1989). The study of affect and mathematics: A proposed generic model for research. In D. B. McLeod & V. M. Adams (Eds.), *Affect and mathematical problem solving: A new perspective* (pp. 205-219). New York: Springer-Verlag.

Fennema, E., & Sherman, J. (1976). Fennema-Sherman mathematics attitude scales: Instruments designed to measure attitudes towards the learning of mathematics by girls and boys. *Journal for Research in Mathematics Education*, 7, 324-326.

Fox, E., Russo, R., & Dutton, K. (2002). Attentional bias for threat: Evidence for delayed disengagement from emotional faces. *Cognition and Emotion*, 16, 355-379.

Freeston, M. H., Ladouceur, R., Letarte, H., Thibodeau, N., & Gagnon, F. (1991). Cognitive intrusions in a non-clinical population. I. Response style, subjective experience, and appraisal. *Behaviour Research and Therapy*, 29, 585-597.

Furst, A., & Hitch, G. (2000). Separate roles for executive and phonological components of working memory in mental arithmetic. *Memory and Cognition*, 28, 774-782.

Garcia-Larrea, L., Cezanne-Bert, G. (1998). P3, positive slow wave and working memory load: A study on the functional correlates of slow wave activity. *Electroencephalography and Clinical Neurophysiology*, 108, 260-273.

Gerra, G., Zaimovic, A., Giusti, F., Baroni, M. C., Delsignore, R., Raggi, M. A., & Brambilla, F. (2001). Pivagabine effects on neuroendocrine responses to experimentally induced psychological stress in humans. *Behavioural Brain Research*, 122, 93-101.

Girelli, D., & Delazer, M. (1996). Subtraction bugs in an acalculic patient. *Cortex*, 32, 547-555.

Göbel, S. M., Rushworth, M. F. S., & Walsh, V. (2006). Inferior parietal rTMS affects performance in an addition task. *Cortex,* 42, 774-781.

Golden, C. (1994). *Stroop colour and word test*. Wood Dale, IL: Stoelting.

Goodwin, A. H., & Sher, K. J. (1992). Deficits in set-shifting ability in non-clinical compulsive checkers. *Journal of Psychopathology and Behavioral Assessment*, 14, 81–92.

Gough, M. F. (1954). Mathemaphobia: Causes and treatments. *Clearing House*, 28, 290-294.

Grant, E. R., & Spivey, M. J. (2003). Eye movements and problem solving: Guiding attention guides thought. *Psychological Science*, 14, 462-466.

Green, H. J., Lemaire, P., & Dufau, S. (2007). Eye movement correlates of younger and older adults' strategies for complex addition. *Acta Psychologica*, 125, 257-278.

Gruber, O., Indefrey, P., Steinmetz, H., & Kleinschmidt, A. (2001). Dissociating neural correlates of cognitive components in mental calculation. *Cerebral Cortex*, 11, 350-359.

Hadwin, J. A., Brogan, J., & Stevenson, J. (2005). State anxiety and working memory in children: A test of processing efficiency theory. *Educational Psychology*, 25, 379-393.

Hallet, P. E. (1978). Primary and secondary saccades to goals defined by instructions. *Vision Research*, 18, 1279-1296.

Hamilton, P., Hockey, G. R. J., & Rejman, M. (1977). The place of the concept of activation in human information processing theory: An integrative approach. In S. Dornic (Ed.), *Attention and performance*, Vol VI. Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Harris, L. M., & Cumming, S. R. (2003). An examination of the relationship between anxiety and performance on prospective and retrospective memory tasks. *Australian Journal of Psychology*, 55, 51–55.

Harris, L. M., & Menzies, R. G. (1999). Mood and prospective memory. *Memory*, 7, 117–127.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. *The Psychology of Learning and Motivation*, 22, 193–225.

Hayes, S., MacLeod, C., & Hammond, G. (2009). Anxiety-linked task performance: Dissociating the influence of restricted working memory capacity and increased investment of effort. *Cognition and Emotion*, 23, 753-781.

Haynes, A. F., Mullins, A. G., & Stein, B. S. (2004). Differential models for math anxiety in male and female college students. *Sociological Spectrum*, 24, 295-318.

Hegarty, M., Mayer, R. E., & Monk, C. A. (1995). Comprehension of arithmetic word problems: A comparison of successful and unsuccessful problem solvers. *Journal of Educational Psychology*, 87, 18-32.

Hembree, R. (1990). The nature, effects, and relief of mathematics anxiety. *Journal of Research for Mathematics Education*, 21, 33-46.

Hendel, D. D. (1980). Experiential and affective correlates of math anxiety in adult women. *Psychology of Women Quarterly*, 5, 219-230.

Henly, S. J. (1993). Robustness of some estimators for the analysis of covariance structure. *British Journal of Mathematical and Statistical Psychology*, 46, 313-338.

Hermans, D., Vansteenwegen, D., & Eelen, P. (1999). Eye movement registration as a continuous index of attention deployment: Data from a group of spider anxious students. *Cognition and Emotion*, 13, 419-434.

Hitch, G. J. (1978b). The role of short-term working memory in mental arithmetic. *Cognitive Psychology*, 10, 302-323.

Hoffman, B. (2010). “I think I can fly, but I’m afraid to try”: The role of self-efficacy beliefs and mathematics anxiety in mathematics problem solving efficiency. *Learning and Individual Differences*, 20, 276-283.

Hopko, D. R. (2003). Confirmatory factor analysis of the maths anxiety rating scale-revised. *Educational and Psychological Measurement*, 63, 336-351.

Hopko, D. R., Ashcraft, M. H., Gute, R., Ruggiero, K. J., & Lewis, C. (1998). Mathematics anxiety and working memory: Support for the existence of a deficient inhibition mechanism. *Journal of Anxiety Disorders*, 12, 343–355.

Hopko, D. R., Hunt, M. K., & Armento, M. E. (2005). Attentional task aptitude and performance anxiety. *International Journal of Stress Management*, 12, 389-408.

Hopko, D. R., Mahadevan, R., Bare, R. L., & Hunt, M. K. (2003). The abbreviated maths anxiety scale (AMAS): Construction, validity, and reliability. *Assessment*, 10, 178-182.

Hopko, D. R., McNeil, D. W., Gleason, P. J., & Rabalais, A. E. (2002). The emotional Stroop paradigm: Performance as a function of stimulus properties and self-reported mathematics anxiety. *Cognitive Therapy and Research*, 26, 157-166.

Hopko, D. R., McNeil, D. W., Lejuez, C. W., Ashcraft, M. H., Eifert, G. H., & Riel, J. (2003). The effects of anxious responding on mental arithmetic and lexical decision task performance. *Journal of Anxiety Disorders*, 17, 647-665.

Hopko, D. R., McNeil, D. W., Zvolensky, M. J., & Eifert, G. H. (2001). The relation between anxiety and skill in performance-based anxiety disorders: A behavioural formulation of social phobia. *Behavior Therapy*, 32, 185-207.

Houde, O., & Tzourio-Mazoyer, N. (2003). Neural foundations of logical and mathematical cognition. *Nature Reviews Neuroscience*, 4, 507-514.

Hu, L.-T., & Bentler, P. M. (1998). Fit indices in covariance structure modelling: Sensitivity to underparameterized model misspecification. *Psychological Methods*, 3, 424-453.

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

Huang, Y. X., Bai, L., Ai, H., Li, W., Yua, C., Liu, J., & Luo, Y. J. (2009). Influence of trait anxiety on inhibition function: Evidence from ERPs study. *Neuroscience Letters*, 456, 1-5.

Hunsley, J. (1987). Cognitive processes in mathematics anxiety and test anxiety: The role of appraisals, internal dialogue, and attributions. *Journal of Educational Psychology*, 79, 388-392.

Hunt, T. E., Clark-Carter, D., & Sheffield, D. (In press). The development and part-validation of a U.K. scale for mathematics anxiety. *Journal of Psychoeducational Assessment*.

Iguchi, Y., & Hashimoto, I. (2000). Sequential information processing during mental arithmetic is reflected in the time course of event-related brain potentials. *Clinical Neurophysiology*, 111, 204–213.

Imbo, I., De Rammelaere, S., & Vandierendonck, A. (2005). New insights in the role of working memory in carry and borrow operations. *Psychologica Belgica*, 45, 101-121.

Imbo, I., Vandierendonck, A., & De Rammelaere, S. (2007). The role of working memory in the carry operation of mental arithmetic: Number and value of the carry. *Quarterly Journal of Experimental Psychology*, 60, 708-731.

Jackson, C., & Leffingwell, R. (1999). The role of instructors in creating math anxiety in students from kindergarten through college. *Mathematics Teacher*, 92, 583-587.

Jahanshahi, M., Dirnberger, G., Fuller, R., & Frith, C. D. (2000). The role of the dorsolateral prefrontal cortex in random number generation: A study with positron emission tomography. *Neuroimage*, 12, 713-725.

Janelle, C. M., Singer, R. N., & Williams, A. M. (1999). External distraction and attentional narrowing: Visual search evidence. *Journal of Sport and Exercise Psychology*, 21, 70–91.

Jastak Associates (1993): *Wide Range Achievement Test*, Revision 3. Division of Wide Range, 15 Ashley Place, Suite 1A, Wilmington, DE 19804-1314.

Jones, W. (2001). Applying psychology to the teaching of basic math: A case study. *Inquiry*, 6, 60-65.

Jose, P.E. (2008). ModGraph-I: A programme to compute cell means for the graphical display of moderational analyses: The internet version, Version 2.0. Victoria University of Wellington, Wellington, New Zealand. Retrieved 17/01/09 from http://www.victoria.ac.nz/psyc/staff/paul-jose-files/modgraph/modgraph.php

Jost, K., Beinhoff, U., Henninghausen, E., & Rosler, F. (2004). Facts, rules, and strategies in single-digit multiplication: Evidence from event-related brain potentials. *Cognitive Brain Research*, 20, 183-193.

Kazelskis, R., Reeves, C., Kersh, M. E., Bailey. G., Cole, K., Larmon, M., Hall, L., & Holiday, D. C. (2000). Mathematics anxiety and test anxiety: Separate constructs? *Journal of Experimental Education*, 68, 137-146.

Kellogg, J. S., Hopko, D. R., & Ashcraft, M. H. (1999). The effects of time pressure on arithmetic performance. *Journal of Anxiety Disorders*, 13, 591–600.

Knops, A., Nuerk, H. C., Fimm, B., Vohn, R., & Willmes, K. (2006). A special role for numbers in working memory? An fMRI study. *Neuroimage*, 29, 1-14.

Kondo, H., Morishita, M, Osaka, N., Osaka, M., FU.Kuyama, H., & Shibasaki, H. (2004). Functional roles of the cingulo-frontal network in performance on working memory. *Neuroimage*, 21, 2-14.

Kong, J., Wang, Y., Shang, H., Wang, Y., Yang, X., & Zhuang, D. (1999). Brain potentials during mental arithmetic - effects of problem difficulty on event-related brain potentials. *Neuroscience Letters*, 260, 169–172.

Lamm, M. E. (1998). Current concepts in mucosal immunity IV. How epithelial transport of IgA antibodies relates to host defense. *American Journal of Physiology Gastrointestinal and Liver Physiology*, 274, G614-G617.

Le Clec'H, G., Dehaene, S., Cohen, L., Mehler, J., Dupoux, E, Poline, J. B., Lehericy, S., Van de Moortele, P. F., & Le Bihan, D. (2000). Distinct cortical areas for names of numbers and body parts independent of language and input modality. *Neuroimage*, 12, 381-391.

Le Doux, J. (1996). *The emotional brain: The mysterious underpinnings of emotional life*. New York: Simon & Schuster.

LeFevre, J. A., Kulak, A. G., & Heymans, S. L. (1992). Factors influencing the selection of university majors varying in mathematical content. *Canadian Journal of Behavioural Science*, 24, 276-289.

Lejuez, C. W., Kahler, C. W., & Brown, R. A. (2003). A modified computer version of the Paced Auditory Serial Addition Task (PASAT) as a laboratory-based stressor: Implications for behavioral assessment. *Behavior Therapist*, 26, 290-293.

Levitt, E. E., & Hutton, L. A. (1983). Correlates and possible causes of math anxiety. In N. J. Butcher & C. D. Spielberger (Eds.), *Advances in personality assessment* (vol. 3, pp. 129-140). Hillsdale, NJ: Erlbaum.

Lewis, B. P., & Linder, D. E. (1997). Thinking about choking? Attentional processes and paradoxical performance. *Personality and Social Psychology Bulletin*, 23, 937-944.

Ley, R., & Yelich, G. (1998). Fractional end-tidal CO2 as an index of the effects of stress on math performance and verbal memory of test-anxious adolescents. *Biological Psychology*, 49, 83-94.

Li, X. B., Chan, R. C. K., & Luo, Y. J. (2010). Stage effects of negative emotion on spatial and verbal working memory. *BMC Neuroscience*, 11:60.

Locke, E. A. (2009). It's time we brought introspection out of the closet. *Perspectives on Psychological Science*, 4, 24-25.

Lussier, G. (1996). Sex and mathematical background as predictors of anxiety and self-efficacy in mathematics. *Psychological Reports*, 79, 827-833.

Ma, X. (1999). A meta-analysis of the relationship between anxiety toward mathematics and achievement in mathematics. *Journal for Research in Mathematics Education*, 30, 520-540.

Ma, X., & Xu, J. M. (2004). The causal ordering of mathematics anxiety and mathematics achievement: A longitudinal panel analysis. *Journal of Adolescence*, 27, 165-179.

MacCallum, R. C., Zhang, S., Preacher, K. J., & Rucker, D. D. (2002). On the practice of dichotomization of quantitative variables. *Psychological Methods*, 7, 19-40.

MacLeod, C., & Donnellan, A. M. (1993). Individual differences in anxiety and the restriction of working memory capacity. *Personality and Individual Differences*, 15, 163-173.

Markela-Lerenc, J., Ille, N., Kaiser, S., Fiedler, P., Mundt, C., & Weisbrod, M. (2004). Prefrontal cingulate activation during executive control: Which comes first? *Cognitive Brain Research*, 18, 278-287.

Marsh, H. W., Parker, J. W., & Smith, I. D. (1983). Preadolescent self-concept: Its relation to self-concept as inferred by teachers to academic ability. *British Journal of Educational Psychology*, 53, 60-78.

Massen, C. (2004). Parallel programming of exogenous and endogenous components in the antisaccade task. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, 57, 475-498.

Mayer, R. E. (1977). Problem solving performance with task overload: Effects of self-pacing and trait anxiety. *Bulletin of the Psychonomic Society*, 9, 282-286.

McLaughlin, M. S. (1996). Comparison of a self-report questionnaire and a Stroop color-naming task. Unpublished senior thesis. Oklahoma State University.

Meece, J. L., Wigfield, A., & Eccles, J. S. (1990). Predictors of math anxiety and its influence on young adolescents' course enrolment intentions and performance in mathematics. *Journal of Educational Psychology*, 82, 60-70.

Menon, V., Mackenzie, K., Rivera, S., & Reiss, A. (2002). Prefrontal cortex involvement in processing incorrect arithmetic equations: Evidence from event-related fMRI. *Human Brain Mapping*, 16, 119-130.

Miller, H., & Bichsel, J. (2004). Anxiety, working memory, gender, and maths performance. *Personality and Individual Differences*, 37, 591-606.

Miller, J. D., Kimmel, L., Hoffer, T. B., & Nelson, C. (2000). Longitudinal study of American youth: Users manual. Chicago, IL: International Center for the Advancement of Scientific Literacy, Northwestern University.

Mitchell, J. P., Macrae, C. N., & Gilchrist, I. D. (2002). Working memory and the suppression of reflexive saccades. *Journal of Cognitive Neuroscience*, 14, 95-103.

Miyake, A., & Shah, P. (1999). Toward unified theories of working memory: Emerging general consensus, unresolved theoretical issues, and future research directions. In A. Miyake, & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 442-481). Cambridge: Cambridge University Press.

Mogg, K., Mathews, A., Bird, C., & MacGregor-Morris, R. (1990). Effects of stress and anxiety on the processing of threat stimuli. *Journal of Personality and Social Psychology*, 59, 1230–1237.

Monfort, V., & Pouthas, V. (2003). Effects of working memory demands on frontal slow waves in time-interval reproduction tasks in humans. *Neuroscience Letters*, 343, 195-199.

Morris, L. W., Davis, M. A., & Hutchings, C. H. (1981). Cognitive and emotional components of anxiety: Literature review and a revised worry-emotionality scale. *Journal of Education Psychology*, 73, 541-555.

Murray, N. P., & Janelle, C. M. (2003). Anxiety and performance: A visual search examination of the processing efficiency theory. *Journal of Sport & Exercise Psychology*, 25, 171-187.

Naccache, L., & Dehaene, S. (2001). Unconscious semantic priming extends to novel unseen stimuli. *Cognition*, 80, 215-229.

Newstead, K. (1998). Aspects of children's mathematics anxiety. *Educational Studies in Mathematics*, 36, 53–71.

Nieuwenhuis, S., Broerse, A., Nielen, M. M. A., & de Jong, R. (2004). A goal activation approach to the study of executive function: An application to antisaccade tasks. *Brain and Cognition*, 56, 198-214.

Nixon, R., Menne, A., King, L., Steele, A., Barnes, J., Dognt, H., Ball, S. A., & Tyler, H. (2008). Metacognition, working memory, and thought suppression in acute stress disorder. *Australian Journal of Psychology*, 60, 168-174.

Núñez-Pena, M. I., Cortinas, M., & Escera, C. (2006). Problem size effect and processing strategies in mental arithmetic. *Neuroreport*, 17, 357-360.

Owen, A. M., Herrod, N. J., Menon, D. K., Clark, J. C, Downey, S. P. M. J., Carpenter, T. A., Minhas, P. S., Turkheimer, F. E., Williams, E. J., Robbins, T. W., Sahakian, B.

J., Petrides, M., & Pickard, J. D. (1999). Redefining the functional organisation of working memory processes within human lateral prefrontal cortex. *European Journal of Neuroscience*, 11, 567-574.

Pajares, F., & Miller, M. D. (1994). Role of self-efficacy and self-concept beliefs in mathematical problem solving: A path analysis. *Journal of Educational Psychology*, 86, 193-203.

Pajares, F., & Miller, M. D. (1995). Mathematics self-efficacy and mathematics performance: The need for specificity of assessment. *Journal of Counseling Psychology*, 42, 190-198.

Pallak, M. S., Pittman, T. S., Heller, J. F., & Munson, P. (1975). The effect of arousal on Stroop color-word task performance. *Bulletin of the Psychonomic Society*, 6, 248–250.

Pauli, P., Lutzenberger, W., Birbaumer, N., Rickard, T., & Bourne, L. (1996). Neurophysiological correlates of mental arithmetic. *Psychophysiology*, 33, 522-529.

Pauli, P., Lutzenberger, W., Harald, R., Birbaumer, N., Rickard, T., Yaroush, R., & Bourne, L. (1994). Brain potentials during mental arithmetic: Effects of extensive practice and problem difficulty. *Cognitive Brain Research*, 2, 21–29.

Pesenti, M., Thioux, M., Seron, X., & De Volder, A. (2000). Neuroanatomical substrates of Arabic number processing, numerical comparison, and simple addition: A PET study. *Journal of Cognitive Neuroscience*, 12, 461-179.

Phaf, R. H., Christoffels, I. K., Waldorp, L. J., & den Dulk, P. (1998). Connectionist investigations of individual differences in Stroop performance. *Perceptual and Motor Skills*, 87, 899–914.

Plake, B. S., & Parker, C. S. (1982). The development and validation of a revised version of the mathematics anxiety rating scale. *Educational and Psychological Measurement*, 42, 551-557.

Postle, B. R., Berger, J. S., Taich, A. M., & D'Esposito, M. (2000). Activity in human frontal cortex associated with spatial working memory and saccadic behaviour. *Journal of Cognitive Neuroscience*, 12, 2-14.

Prieto-Corona, B., Rodriguez-Camacho, M., Silva-Pereyra, J., Marosi, E., Fernandez, T., & Guerrero, V. (2010). Event-related potentials findings differ between children and adults during arithmetic-fact retrieval. *Neuroscience Letters*, 468, 220-224.

Resnick, J. H., Viehe, J., & Segal, S. (1982). Is maths anxiety a local phenomenon? A study of prevalence and dimensionality. *Journal of Counseling Psychology*, 29, 39-47.

Reyes, L. (1984). Affective variables and mathematics education. *The Elementary School Journal,* 5, 558-581.

Rickard, T. C., Romero, S. G., Basso, G., Wharton, C., Flitman, S., & Grafman, J. (2000). The calculating brain: An fMRI study. *Neuropsychologia*, 38, 325-335.

Richardson, F. C., and Suinn, R. M. (1972). The Mathematics Anxiety Rating Scale. *Journal of Counselling Psychology*, 19, 551-554.

Rinck, M., & Becker, E. S. (2006). Spider fearful individuals attend to threat, then quickly avoid it: Evidence from eye movements. *Journal of Abnormal Psychology*, 115, 231-238.

Ring, C., Drayson, M., Walkey, D. G., Dale, S., & Carroll, D. (2002). Secretory immunoglobulin A reactions to prolonged mental arithmetic stress: Inter-session and intra-session reliability. *Biological Psychology*, 59, 1-13.

Roberts, R. J., Hager, L. D., & Heron, C. (1994). Prefrontal cognitive processes, working memory and inhibition in the antisaccade task. *Journal of Experimental Psychology: General*, 123, 374-393.

Rosen, V. M., & Engle, R. W. (1998). Working memory capacity and suppression. *Journal of Memory and Language*, 39, 418-436.

Rosler, F., Schumacher, G., & Sojka, B. (1990). What the brain reveals when it thinks: Event-related potentials during mental rotation and mental arithmetic. *German Journal of Psychology*, 14, 185-203.

Rossor, M. N., Warrington, E. K., & Cipolotti, L. (1995). The isolation of calculation skills. *Journal of Neurology*, 242, 78-81.

Royston, P., Altman, D. G., & Sauerbrei, W. (2006). Dichotomizing continuous predictors in multiple regression: A bad idea. *Statistics in Medicine*, 25, 127-141.

Rounds, J., & Hendel, D. (1980). Measurement and dimensionality of mathematics anxiety. *Journal of Counseling Psychology*, 27, 138-149.

Rypma, B., Berger, J. S., & D'Esposito, M. (2002). The influence of working-memory demand and subject performance on prefrontal cortical activity. *Journal of Cognitive Neuroscience*, 14, 721-731.

Salame, R. F. (1984). Test anxiety: Its determinants, manifestations, and consequences. In H. M. van der Ploeg., R. Schwarzer., & C. D. Spielberger (Eds.), *Advances in test anxiety research* (pp. 83–119). Hillsdale, NJ: Erlbaum.

Sandman, R. S. (1979). Mathematics Anxiety Inventory: User's Manual. Unpublished manuscript, University of Minnesota, Minnesota Research and Evaluation Center, Minneapolis.

Santos, R., & Eysenck, M. W. (2005). Effects of anxiety on dual-task performance. Unpublished manuscript. Royal Holloway University of London, Egham, Surrey, U.K.

Santos, R., Wall, M.B., Eysenck, M. (In preparation.) Anxiety and processing efficiency: fMRI evidence.

Sarason, I. G. (1978). The test anxiety scale: Concept and research. In C. D. Spielberger & I. G. Sarason (Eds.), *Stress and anxiety* (vol. 5, pp. 193-218). Washington, DC: Hemisphere.

Sarason, I. G. (1984). Stress, anxiety, and cognitive interference: Reactions to tests. *Journal of Personality and Social Psychology*, 46, 929-938.

Sewell, T. E., Farley, F. H., & Sewell, F. B. (1983). Anxiety, coping style, and mathematics achievement. *Journal of General Psychology*, 109, 59-66.

Sheffield, D., & Hunt, T. E. (2007). How does anxiety influence performance and what can we do about it? *MSOR Connections,* 6, 1-5.

Simon, O., Mangin, J. F., Cohen, L., Le Bihan, D., & Dehaene, S. (2002). Topographical layout of hand, eye, calculation, and language-related areas in the human parietal lobe. *Neuron*, 33, 475-487.

Smith, E. E., Geva, A., Jonides, J., Miller, A., Reuter-Lorenz, P., & Koeppe, R. A. (2001). The neural basis of task-switching in working memory: Effects of performance and aging. *Proceedings of the National Academy of Sciences of the United States of America*, 98, 2095-2100.

Snaith, R. P., & Zigmond, A. S. (1994). *The Hospital Anxiety and Depression Scale manual*. Windsor: NFER-Nelson.

Spielberger, C. D. (1977). *The test anxiety inventory*. Palo Alto, CA: Consulting Psychologists Press.

Spielberger, C. D., Gorsuch, R. L., Lushene, R., Vagg, P. R., & Jacobs, G. A. (1984). *State-Trait Anxiety Inventory*. Consulting Psychological Press, Inc.

Standish, R. R., & Champion, R. A. (1960). Task difficulty and drive in verbal learning. *Journal of Experimental Psychology*, 59, 361–365.

Stanescu-Cosson, R., Pinel, P., van de Moortele, P. F., Le Bihan, D., Cohen, L., & Dehaene, S. (2000). Understanding dissociations in dyscalculia: A brain imaging study of the impact of number size on the cerebral networks for exact and approximate calculation. *Brain*, 123, 2240-2255.

Stoltzfus, E. R., Hasher, L., & Zacks, R. T. (1996). Working memory and aging: Current status of the inhibitory view. In J. T. E. Richardson, R. W. Engle, L. Hasher, R. H. Logie, E. R. Stoltzfus, & R. T. Zacks (Eds.), *Working memory and human cognition* (pp. 66–88). New York: Oxford University Press.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, 18, 643–661.

Stuyven, E., Van der Goten, K., Vandierendonck, A., Claeys, K., & Crevits, L. (2000). The effect of cognitive load on saccadic eye movements. *Acta Psychologica*, 104, 69-85.

Suinn, R. M, & Richardson, F. (1971). Anxiety management training: A nonspecific behavior therapy program for anxiety control. *Behavior Therapy*, 2, 498-510.

Suinn, R. M, Edie, C., & Spinelli, R. (1970). Accelerated massed desensitization, innovation in short-term treatment. *Behavior Therapy*, 1, 303-311.

Suinn, R. M. (1969). Changes in non-treated subjects over time: Data on a fear survey schedule and the test anxiety scale. *Behaviour Research and Therapy*, 7, 205-206.

Suinn, R. M., & Winston, E. H. (2003). The mathematics anxiety rating scale, a brief version: Psychometric data. *Psychological Reports*, 92, 167-173.

Suinn, R., & Edwards, R. (1982). The measurement of mathematics anxiety: The mathematics anxiety rating scale for adolescents: MARS – A. *Journal of Clinical Psychology*, 38, 576-580.

Suinn, R., Taylor. S., & Edwards, R. (1988). Suinn Mathematical Anxiety Rating Scale for elementary school students (MARS- E): Psychometric and normative data. *Educational and Psychological Measurement*, 48, 979-986.

Suppes, P. (1990). Eye-movement models for arithmetic and reading performance. *Reviews of Oculomotor Research*, 4, 455-457.

Suppes, P., Cohen, M., Laddagar, R., Anlikerm J., & Floyd, R. (1983). A procedural theory of eye movements in doing arithmetic. *Journal of Mathematical Psychology*, 27, 341-369.

Suri, R., & Monroe, K. B. (1998). Effects of consumers' mathematics anxiety on their processing of price information. *Advances in Consumer Research*, 25, 85.

Tabachnick, B. A., & Fidell, L. S. (2001). *Using multivariate statistics* (4th ed). Needham Heights, MA: Allyn and Bacon.

Tapia, M. & Marsh, G. E. II. (2004). An instrument to measure mathematics attitudes. *Academic Exchange Quarterly , 8*, 16-21.

Tobias, S., & Weissbrod, C. (1980). Anxiety and mathematics – an update. *Harvard Educational Review*, 50, 63-70.

Todman, J., & Lawrenson, H. (1992). Computer anxiety in primary school children and university students. *British Educational Research Journal*, 18, 63-72.

Trbovich, P. L., & LeFevre, J. A. (2003). Phonological and visual working memory in mental addition. *Memory & Cognition.* 31, 738-745.

Trujillo, K. M., & Hadfield, O. D. (1999). Tracing the roots of mathematics anxiety through in-depth interviews with preservice elementary teachers. *College Student Journal*, 33, 219-232.

Universities and Colleges Admissions Service (2009). Retrieved from http://www.ucas.ac.U.K/about_us/stat_services/stats_online/

Van Boxtel, G. J. M., & Bocker, K. B. E. (2004). Cortical measures of anticipation. *Journal of Psychophysiology*, 18, 61-76.

Van Hoof, J. C., Dietz, K. C., Sharma, D., & Bowman, H. (2008). Neural correlates of intrusion of emotion words in a modified Stroop task. *International Journal of Psychophysiology*, 67, 23-34.

Velicer, W. F. (1978). Suppressor variables and the semi-partial correlation coefficient. *Educational and Psychological Measurement*, 38, 953-958.

Warrington, E. K. (1982). The fractionation of arithmetical skills: A single case study. *Quarterly Journal of Experimental Psychology*: *Human Experimental Psychology*, 34, 31-51.

Warrington, E. K., & James, M. (1967). Tachistoscopic number estimation in patients with unilateral cerebral lesions. *Journal of Neurology Neurosurgery and Psychiatry*, 30, 468-474.

Watkins, E. (2004). Appraisals and strategies associated with rumination and worry. *Personality and Individual Differences*, 37, 679-694.

Wechsler, D. (1997). *The Wechsler Adult Intelligence Scale – Third Edition (WAIS-III)*. San Antonio, TX: Psychological Corporation.

Weinberg, R. S., & Hunt, W. (1976). Interrelationships between anxiety, motor performance and electromyography. *Journal of Motor Behavior*, 8, 219-224.

Weinstein, A. M. (1995). Visual ERPs evidence for enhanced processing of threatening information in anxious university students. *Biological Psychiatry*, 37, 847–858.

West, S. G., Finch, J. F., & Curran, P. J. (1995). Structural equation models with non-normal variables: Problems and remedies. In R. H. Hoyle (Ed.), *Structural equation modeling: Concepts, issues, and applications* (pp. 56-75). Thousand Oaks, CA: Sage.

Whalen, J., McCloskey, M., Lesser, R., & Gordon, B. (1997). Localizing arithmetic processes in the brain: Evidence from a transient deficit during cortical stimulation. *Journal of Cognitive Neuroscience*, 9, 409-417.

Wigfield, A., & Meece, J. L. (1988). Math anxiety in elementary and secondary school children. *Journal of Educational Psychology*, 80, 210-216.

Wood, J., Matthews, A., & Dalgleish, T. (2001). Anxiety and cognitive inhibition. *Emotion*, 1, 166-181.

Yee, P. L., Hsieh-Yee, I., Pierce, G. R., Grome, R., & Schantz, L. (2004). Self-evaluative intrusive thoughts impede successful searching on the Internet. *Computers in Human Behavior*, 20, 85-101.

Yoshida, T., & Iwaki, T. (2000). The study of early emotion processing in the frontal area using a two-dipole source model. *Japanese Psychological Research*, 42, 54–68.

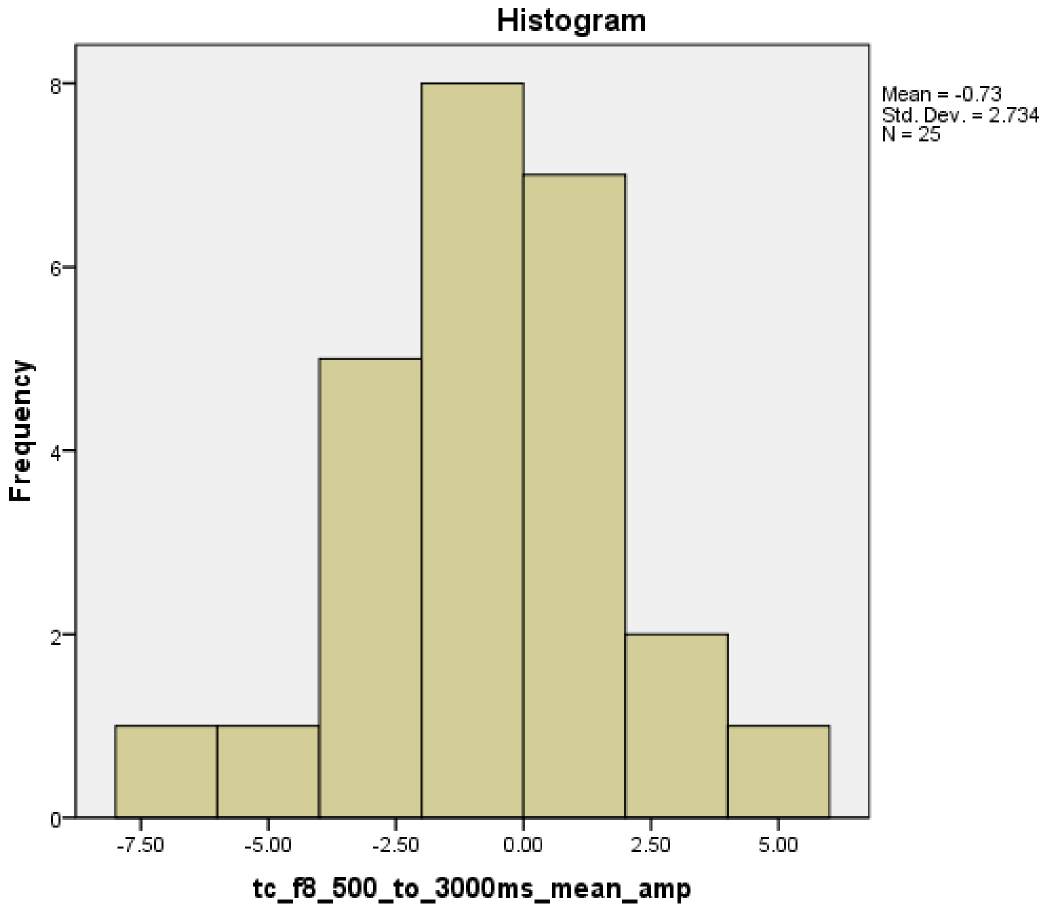
Zago, L., Pesenti, M., Mellet, E., Crivello, F., Mazoyer, B., & Tzourio-Mazoyer, N. (2001). Neural correlates of simple and complex mental calculation. *Neuroimage*, 13, 314-327.

Zeidner, M. (1992). Statistics and mathematics anxiety in social science students: Some interesting parallels. *British Journal of Educational Psychology*, 61, 319-328.

Zettle, R. & Raines, S. (2000). The relationship of trait and test anxiety with mathematics anxiety. *College Student Journal*, 34, 246-259.

Zettle, R. D., & Houghton, L. L. (1998). The relationship between mathematics anxiety and social desirability as a function of gender. *College Student Journal*, 32, 81-86.

Example of visual inspection for univariate normality: distribution of amplitude data for true carry problems, at electrode location F8, time window 500-3000ms (Chapter Four)



Example of output for Mauchly's test for violation of the sphericity assumption: prior to interpretation of a 2 (problem) x 7 (location) two way within-subjects ANOVA on ERP amplitudes in the 0-500ms time window. (Chapter Four)

Mauchly's Test of Sphericity[b]

Measure:MEASURE_1

Within Subjects Effect	Mauchly's W	Approx. Chi-Square	df	Sig.	Epsilon[a]		
					Greenhouse-Geisser	Huynh-Feldt	Lower-bound
problem	1.000	.000	0	.	1.000	1.000	1.000
location	.000	208.393	20	.000	.235	.245	.167
problem * location	.002	139.462	20	.000	.355	.390	.167

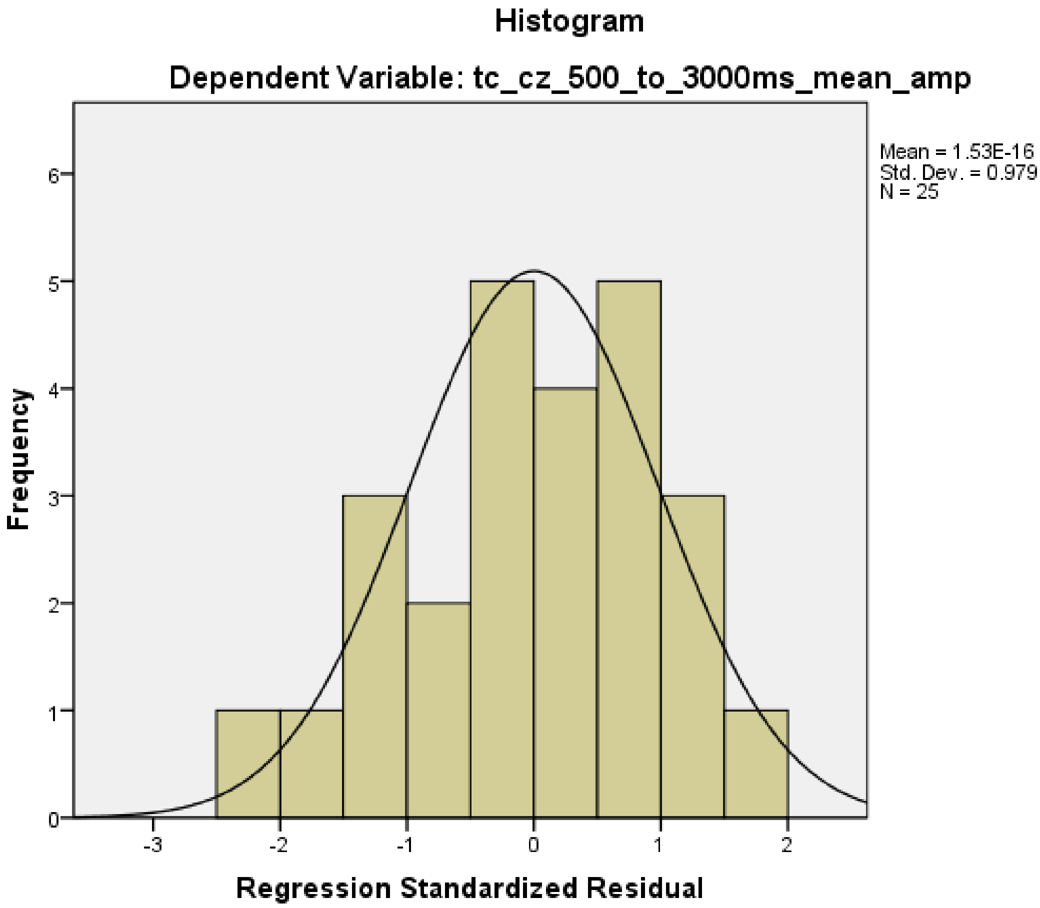
Example of effects being unaffected by adjustments due to violation of the sphericity assumption: output for a 2 (problem) x 7 (location) two way within-subjects ANOVA on ERP amplitudes in the 0-500ms time window. (Chapter Four)

Tests of Within-Subjects Effects

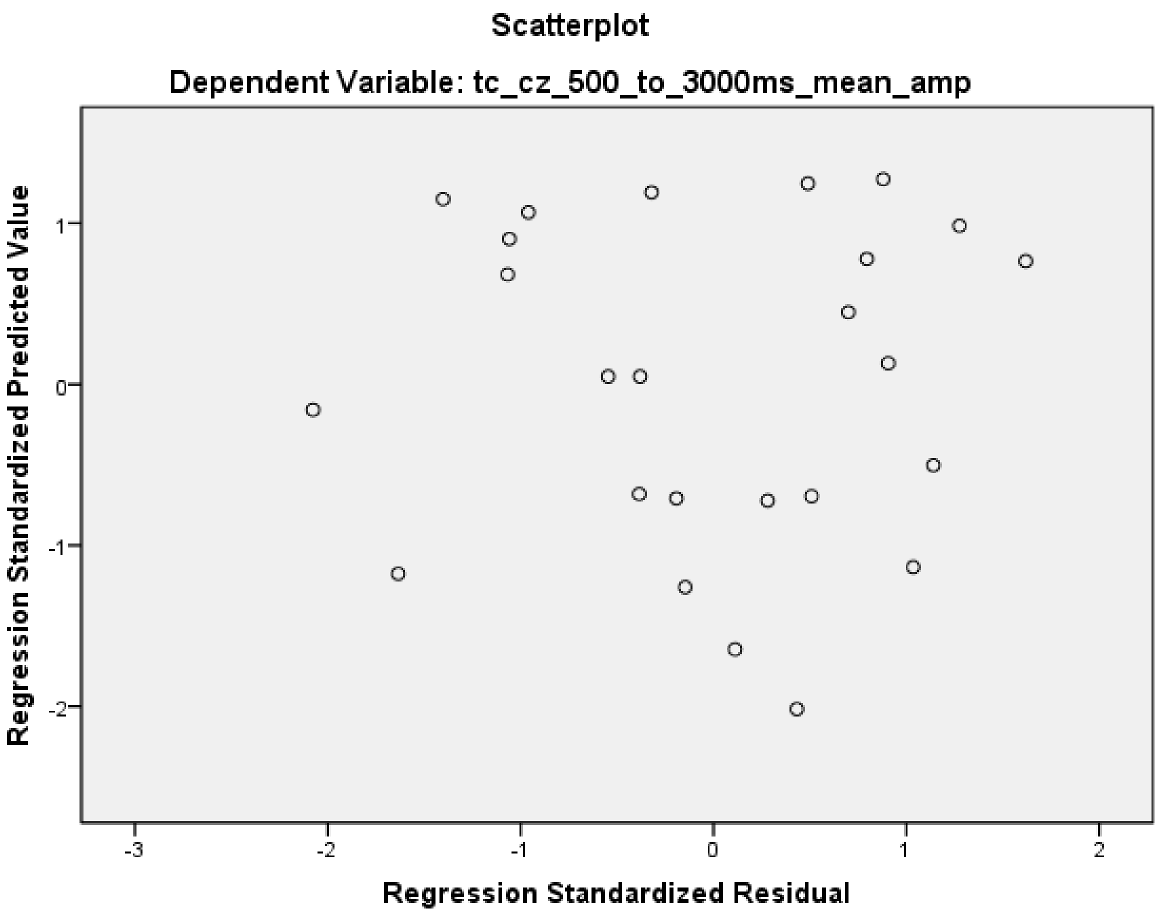
Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
problem	Sphericity Assumed	19.465	1	19.465	2.209	.150	.084
	Greenhouse-Geisser	19.465	1.000	19.465	2.209	.150	.084
	Huynh-Feldt	19.465	1.000	19.465	2.209	.150	.084
	Lower-bound	19.465	1.000	19.465	2.209	.150	.084
Error(problem)	Sphericity Assumed	211.441	24	8.810			
	Greenhouse-Geisser	211.441	24.000	8.810			
	Huynh-Feldt	211.441	24.000	8.810			
	Lower-bound	211.441	24.000	8.810			
location	Sphericity Assumed	468.742	6	78.124	7.039	.000	.227
	Greenhouse-Geisser	468.742	1.409	332.710	7.039	.006	.227
	Huynh-Feldt	468.742	1.471	318.751	7.039	.006	.227
	Lower-bound	468.742	1.000	468.742	7.039	.014	.227
Error(location)	Sphericity Assumed	1598.114	144	11.098			
	Greenhouse-Geisser	1598.114	33.813	47.264			
	Huynh-Feldt	1598.114	35.293	45.281			
	Lower-bound	1598.114	24.000	66.588			
problem * location	Sphericity Assumed	12.587	6	2.098	.893	.502	.036
	Greenhouse-Geisser	12.587	2.129	5.912	.893	.421	.036
	Huynh-Feldt	12.587	2.342	5.374	.893	.429	.036
	Lower-bound	12.587	1.000	12.587	.893	.354	.036
Error(problem*location)	Sphericity Assumed	338.349	144	2.350			
	Greenhouse-Geisser	338.349	51.094	6.622			
	Huynh-Feldt	338.349	56.209	6.019			
	Lower-bound	338.349	24.000	14.098			

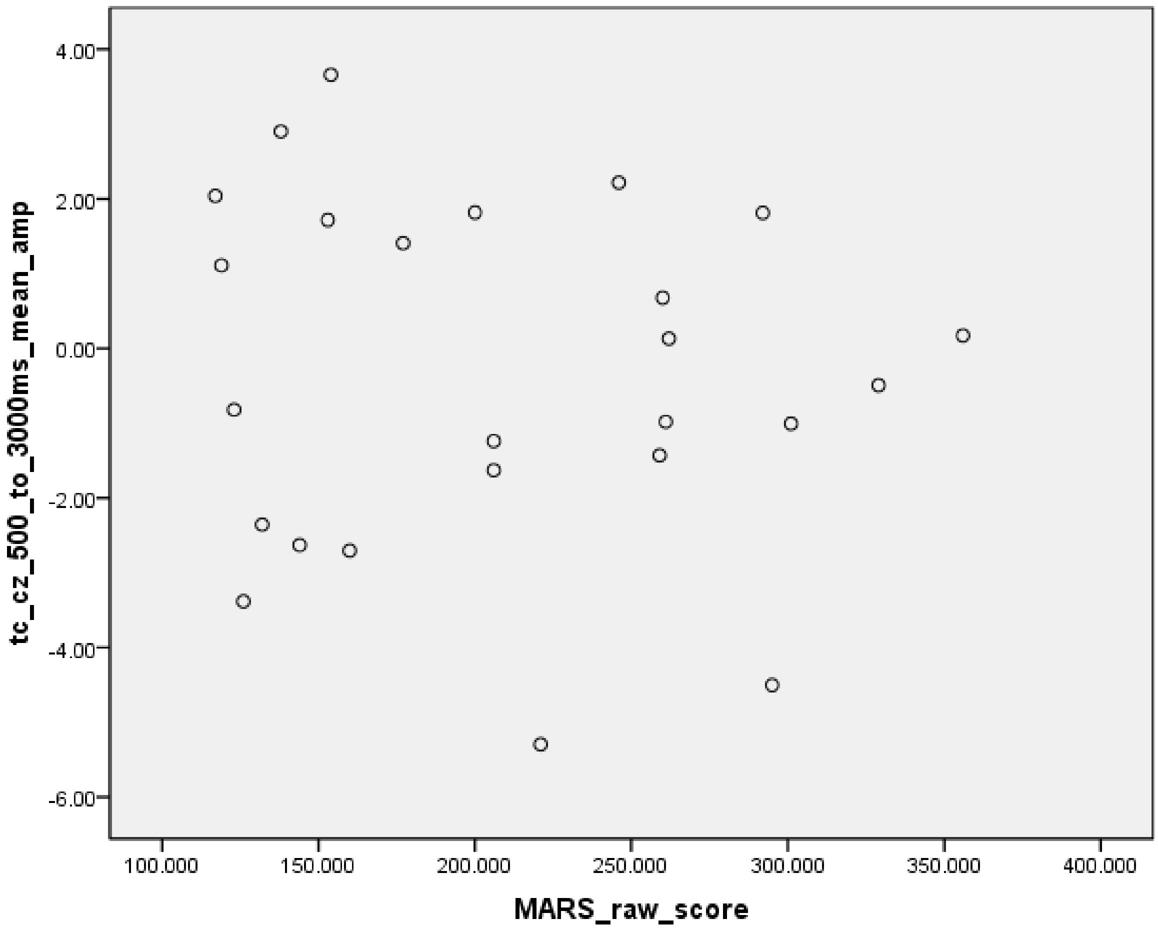
Example of a histogram of standardised residuals, demonstrating normality: in this case, residuals based on prediction of amplitude in response to true carry problems, at electrode site CZ and time window 500-3000ms. (Chapter Four)



Example of the plotting of standardised residuals against standardised predicted residuals, demonstrating no obvious problematic relationship and the presence of homoscedasticity: in this case, residuals based on prediction of amplitude in response to true carry problems, at electrode site CZ and time window 500-3000ms. (Chapter Four)



Example of the plotting of maths anxiety scores against amplitude, demonstrating no obvious curvilinear relationship or bivariate outliers: in this case, amplitude based on a response to true carry problems, at electrode site CZ and time window 500-3000ms. (Chapter Four)



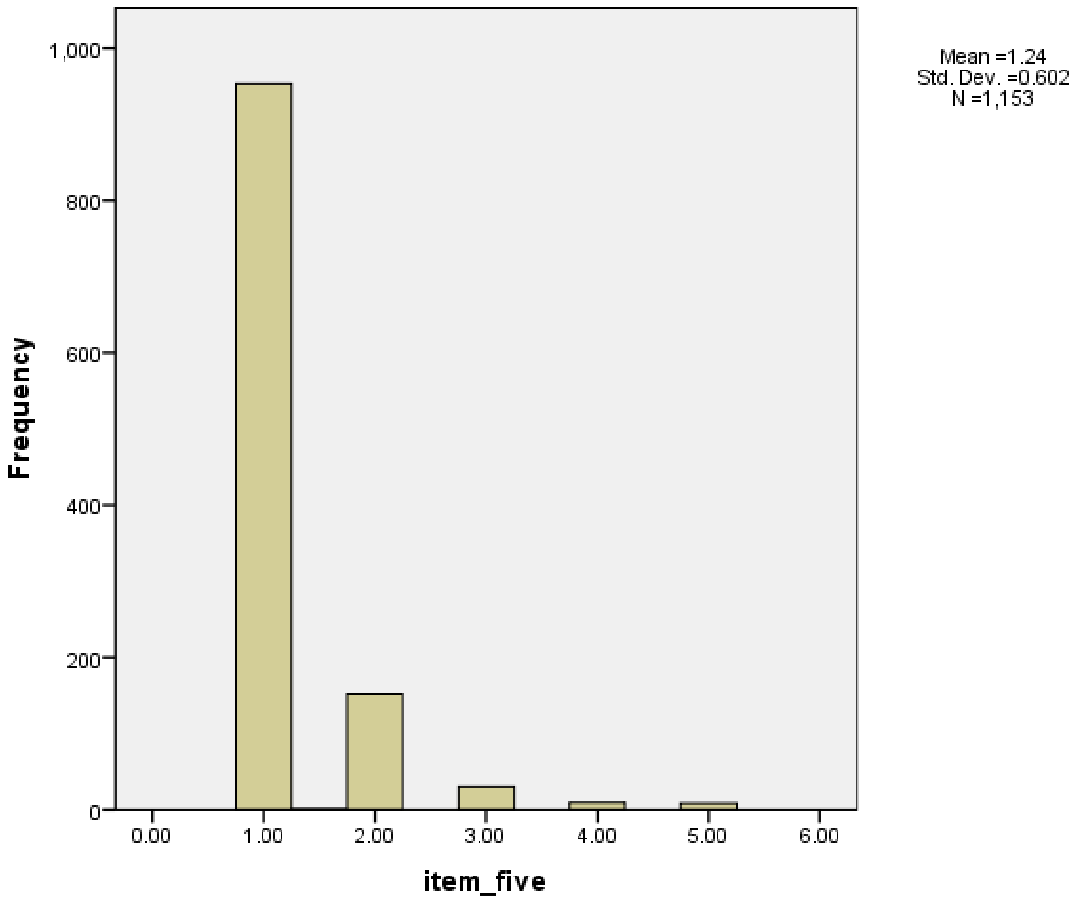
All original 38 items of the Mathematics Anxiety Scale-U.K. (retained items highlighted in bold; see Chapter Five for more details)

How anxious would you feel in the following situations?........Please circle the appropriate numbers below.

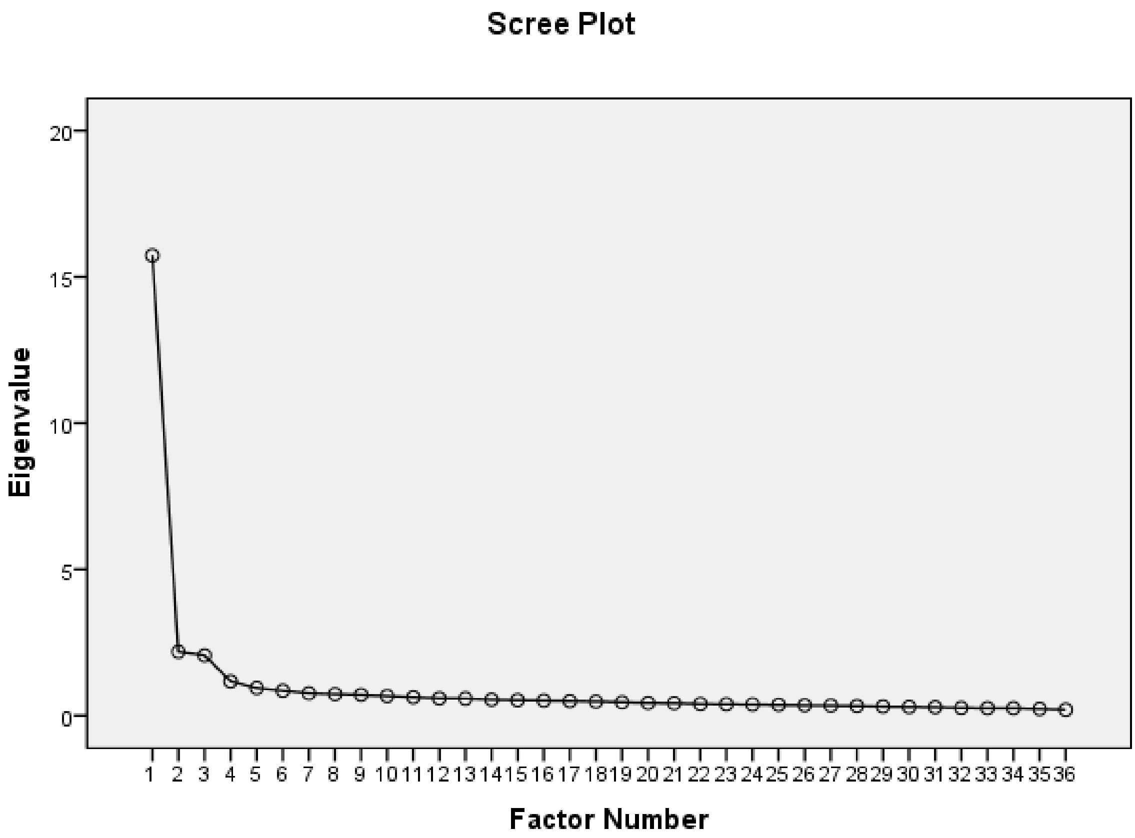
		Not at all	Slightly	A fair amount	Much	Very much
1.	**Having someone watch you multiply 12 x 23 on paper.**	1	2	3	4	5
2.	Calculating 20% off the price of an item of clothing in a shop.	1	2	3	4	5
3.	Working out how much you would get paid if you worked for 8 hours at £6.22 an hour	1	2	3	4	5
4.	**Adding up a pile of change.**	1	2	3	4	5
5.	Being asked to change a pound coin for someone.	1	2	3	4	5
6.	**Being asked to write an answer on the board at the front of a maths class.**	1	2	3	4	5
7.	**Being asked to add up the number of people in a room.**	1	2	3	4	5
8.	**Calculating how many days until a person's birthday.**	1	2	3	4	5
9.	**Taking a maths exam.**	1	2	3	4	5
10.	Reading the word "maths"	1	2	3	4	5
11.	Telling the cashier at a restaurant that you believe the bill is wrong.	1	2	3	4	5
12.	**Being asked to calculate £9.36 divided by four in front of several people.**	1	2	3	4	5
13.	**Being given a telephone number and having to remember it.**	1	2	3	4	5
14.	Calculating and recording the scores your friends get in a darts game.	1	2	3	4	5
15.	Having someone explain a maths problem and not understanding what they mean.	1	2	3	4	5
16.	**Reading the word "algebra".**	1	2	3	4	5
17.	Working out a spending budget for the month.	1	2	3	4	5
18.	**Calculating a series of multiplication problems on paper.**	1	2	3	4	5
19.	Asking someone a question about a maths problem you don't understand.	1	2	3	4	5
20.	**Working out how much time you have left before you set off to work or place of study.**	1	2	3	4	5
21.	**Listening to someone talk about maths.**	1	2	3	4	5
22.	**Working out how much change a cashier should have given you in a shop after buying several items.**	1	2	3	4	5
23.	Being asked to add up 427 + 256 in your head.	1	2	3	4	5
24.	**Deciding how much each person should give you after you buy an object that you are all sharing the cost of.**	1	2	3	4	5
25.	**Reading a maths textbook.**	1	2	3	4	5
26.	**Watching someone work out an algebra problem.**	1	2	3	4	5
27.	Being told you need to attend a maths course at work or as part of your course.	1	2	3	4	5
28.	Working out how much interest you need to pay on a bank overdraft.	1	2	3	4	5
29.	**Sitting in a maths class.**	1	2	3	4	5

30.	Being given a series of subtraction problems on paper.	1	2	3	4	5
31.	Handing in a maths homework assignment.	1	2	3	4	5
32.	**Being given a surprise maths test in a class.**	1	2	3	4	5
33.	**Being asked to memorise a multiplication table.**	1	2	3	4	5
34.	**Watching a teacher/lecturer write equations on the board.**	1	2	3	4	5
35.	Being asked to solve the problem 'if $2(x + 3) = 10$, work out the value of x'.	1	2	3	4	5
36.	**Being asked to calculate three fifths as a percentage.**	1	2	3	4	5
37.	**Working out how much your shopping bill comes to.**	1	2	3	4	5
38.	**Being asked a maths question by a teacher in front of a class.**	1	2	3	4	5

An example of visual inspection of the distribution of data per item: In this case showing extreme positive skew for item 5. (Chapter Five)



Scree plot indicating the existence of three factors prior to the point of inflexion. (Chapter Five)



Example of the calculation for Cohen's d, including pooling the standard deviations, in this case based on error rates across carry and no-carry problems reported in Chapter Four)

Cohen's d = [(mean 1 – mean 2) / pooled SD]

Pooled SD = $\sqrt{}[(SD_1^2 + SD_2^2) / 2]$

Cohen's d = $[(7.28 – 6.68) / (\sqrt{}(5.74^2 + 6.45^2) / 2)]$

= 0.1

An example of comparing the significance of the difference between two Pearson's r coefficients taken from the same sample (based on values reported in Chapter Seven)

r_{21} = maths anxiety and response time to true carry problems

r_{31} = maths anxiety and response time to false carry problems

r_{32} = response time to true carry problems and response time to false carry problems

$|R| = [(1 - (r_{21})^2 - (r_{31})^2 - (r_{32})^2] + (2 \text{ x } r_{21} \text{ x } r_{31} \text{ x } r_{32})$

$|R| = [(1 - (0.42)^2 - (0.35)^2 - (0.84)^2] + (2 \text{ x } 0.42 \text{ x } 0.35 \text{ x } 0.84)$

$|R| = -0.00045 + 0.24696$

$|R| = 0.24651$

$\bar{r} = [(r_{21} + r_{31}) / 2]$

$\bar{r} = [(0.42 + 0.35) / 2]$

$\bar{r} = 0.385$

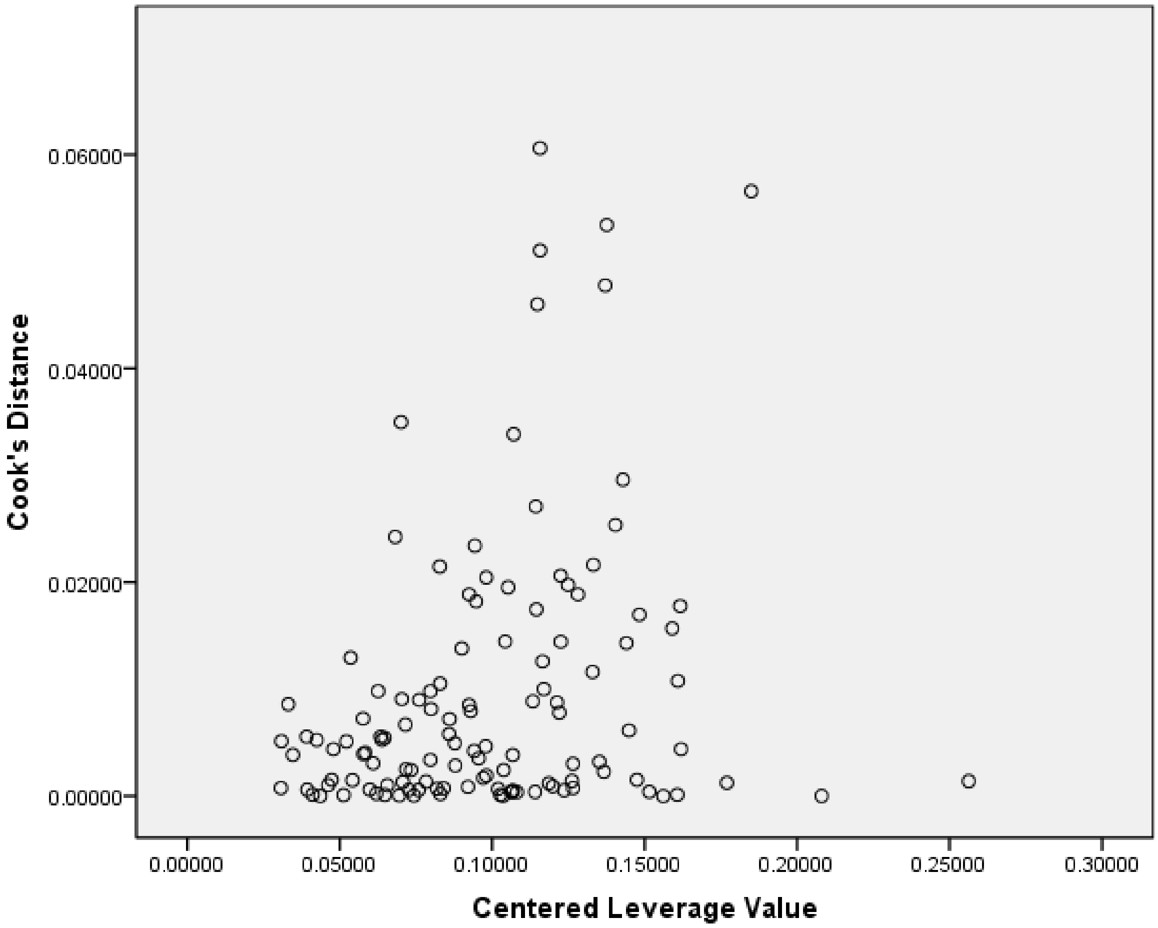
$$t\,(n-3) = (r_{21} - r_{31})\text{x}\sqrt{\frac{(n-1)\text{x}\,(1+r_{32})}{\left[2 \text{ x } \left(\frac{n-1}{n-3}\right) \text{ x } |R|\,\right] + \left[\bar{r}^2 \text{ x } (1 - r_{32})^3\right]}}$$

$$t\,(75) = 0.07 \text{ x } \sqrt{\frac{(77)\text{x}(1.84)}{[(2 \text{ x } 1.03 \text{ x } 0.25) + 0.00061]}}$$

$$t\,(75) = 0.07 \text{ x } \sqrt{141.68 \div 0.51}$$

$$t\,(75) = 1.1686$$

An example of plotting Cook's Distance values against Leverage values, demonstrating no obvious multivariate outliers (based on a regression model in which response times to carry problems was the outcome measure, from Chapter Six)



Example of checking tolerance values (at step 5 of a hierarchical regression). As the output shows, there are no problems with multicollinearity, with values ranging from .29 to .88. (Chapter Six)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	**Tolerance**	VIF
5	(Constant)	3823.092	579.716		6.595	.000		
	Gender	-102.444	356.479	-.026	-.287	.774	**.876**	1.142
	maths_anxiety	34.778	13.175	.334	2.640	.010	**.463**	2.160
	method	-409.917	315.055	-.121	-1.301	.196	**.852**	1.174
	people	-22.252	343.723	-.006	-.065	.949	**.748**	1.337
	panicking	-874.317	431.154	-.212	-2.028	.045	**.677**	1.478
	previous_maths_experiences	684.323	339.814	.199	2.014	.046	**.760**	1.316
	physical_changes	-66.583	371.179	-.018	-.179	.858	**.736**	1.359
	other_problems_dichotomised	-85.101	331.206	-.025	-.257	.798	**.790**	1.265
	how_often	59.668	213.179	.036	.280	.780	**.439**	2.280
	difficult_to_remove	-323.087	190.381	-.232	-1.697	.093	**.395**	2.533
	impeding_calculation	200.198	198.292	.125	1.010	.315	**.479**	2.086
	effort_to_reduce_thoughts	231.502	244.255	.151	.948	.345	**.291**	3.441

a. Dependent Variable: CarryRT