UNIVERISTY OF SOUTHAMPTON

FACULTY OF MEDICINE, HEALTH AND LIFE SCIENCES

SCHOOL OF PSYCHOLOGY

THE RELATIONSHIP BETWEEN ANXIETY, WORKING MEMORY AND ACADEMIC PERFORMANCE AMONG SECONDARY SCHOOL PUPILS WITH SOCIAL, EMOTIONAL AND BEHAVIOURAL DIFFICULTIES: A TEST OF PROCESSING EFFICIENCY THEORY

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ABSTRACT

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THE RELATIONSHIP BETWEEN ANXIETY, WORKING MEMORY AND ACADEMIC PERFORMANCE AMONG SECONDARY SCHOOL PUPILS WITH SOCIAL, EMOTIONAL AND BEHAVIOURAL DIFFICULTIES: A TEST OF PROCESSING EFFICIENCY THEORY

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Research has shown that negative emotions, particularly anxiety, can play a role in learning and academic performance. The Processing Efficiency Theory (PET) and the more recent Attentional Control Theory (ACT) have been put forward to explain the relationship between anxiety and performance. The theories assume that worry (the cognitive component of anxiety) is thought to have a significant impact on performance and that the affect of anxiety on performance is through working memory, and in particular the central executive. The literature review identified a number of key areas of development, including the application of the theories to younger populations and with targeted populations who underachieve in school. The empirical paper aimed to test the application of PET and ACT for pupils with social, emotional and behavioural difficulties (SEBD). It investigated whether the negative impact of anxiety on academic performance was mediated via working memory and whether this relationship was moderated by emotional regulation.

Twenty-four pupils with SEBD aged 12 to 14 completed working memory tasks and self-report anxiety measures. Academic performance was also assessed. Heart rate variability and parent-rated measures of conduct problems and hyperactivity were used as indicators of emotional regulation. The results showed that overall, there was a negative association between test anxiety and academic performance and this association was clearer for the thoughts component of test anxiety. Visuospatial, but not verbal working memory was found to mediate the relationship between test anxious thoughts and academic performance on tasks where the central executive was involved. These findings are broadly consistent with PET and ACT. The mediation relationship was stronger for pupils identified as displaying higher levels of hyperactivity; no moderating effect was found for either heart rate variability or conduct problems. The results have implications for understanding the underachievement of children with SEBD and for considering interventions to promote attainment in school.

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Declaration of Authorship

I, CHERYL ANNE CURTIS, declare that the thesis entitled 'The Relationship Between Anxiety, Working Memory and Academic Performance Among Secondary School Pupils With Social, Emotional and Behavioural Difficulties: A Test of the Processing Efficiency Theory' and the work presented in the thesis are both my own, and have been generated by me as the result of my own original research. I confirm that:

- this work was done wholly or mainly while in candidature for a research degree at this University;
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- where I have consulted the published work of others, this is always clearly attributed;
- where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
- I have acknowledged all main sources of help;
- where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
- none of this work has been published before submission

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Abbreviations

α = Chronbach's alpha
ACT = attentional control theory
ADHD = attention deficit hyperactivity disorder
AWMA = automated working memory assessment
β = standardised regression weight
CANTAB = Cambridge neuropsychological test automated battery
CAT = Cognitive abilities test
CFI = comparative fit index
CTAS = children's test anxiety scale
$\Delta\chi^2$ = chi squared difference test
GCSE = general certificate of secondary education
HRV = heart rate variability
IQ = intelligence quotient
PET = processing efficiency theory
RCADS = revised child anxiety and depression scale
RMSEA = root mean square error of approximation
SAT = national curriculum standard assessment tests
SEBD = social, emotional and behavioural difficulties
SEN = special educational needs
SPM = Raven's standard progressive matrices
STAI – state trait anxiety inventory
STAIC = state trait anxiety inventory for children
WM = working memory
WRAT = wide range achievement test

Chapter 1. Literature Review

1.1. Abstract

Research has shown that negative emotions, particularly anxiety, can play a role in learning and academic performance. The Processing Efficiency Theory (PET) and the more recent Attentional Control Theory (ACT) have been put forward to explain the relationship between anxiety and performance.

The theories rest on key assumptions: firstly, that worry (the cognitive component of anxiety) is thought to have a significant impact on performance; secondly, that the affect of anxiety on performance is through working memory and in particular the central executive; and lastly, that the negative effects of anxiety are predicted to be significantly greater on processing efficiency than on performance effectiveness.

Overall, research to date provides support for the main assumptions of PET and ACT. However, there are a number of key areas of development required in testing these assumptions including: the application of the theory to younger populations and with targeted populations who underachieve in school; and further evidence from longitudinal and multi-modal designs incorporating physiological measures of anxiety.

1.2. Introduction

Anxiety is one of the most basic human emotions – everyone has experienced anxiety to some degree. Anxiety responses can vary in their severity from mild uneasiness to extreme panic. A commonly cited definition of anxiety refers to a physiological state characterised by cognitive, physical, and behavioural components (Seligman, Walker & Rosenhan, 2001). These components combine to create the feelings that are typically recognised as fear or worry. The cognitive system relates to the actual feelings of nervousness and panic and includes thoughts such as “there is something wrong.” The physical system refers to symptoms such as sweating, breathlessness and increased heart rate. The behavioural system includes activities such as foot tapping and avoidance.

A distinction between state and trait anxiety has become commonplace (Spielberger, Gorsuch, Lushene, Vagg & Jacobs, 1983). State anxiety is typically seen as the experience we have in response to threatening demands or dangers. This is a temporary experience characterised by subjective, consciously perceived feelings of tension and apprehension, and heightened autonomic nervous system activity. On the other hand, trait anxiety refers to a general tendency to respond with anxiety to perceived threats.

In recent years, there has been increased interest in the role of anxiety in education, particularly with heightened performance and accountability pressures, league tables and target setting (Putwain, 2008a). In the UK, the interim report of the Cambridge University Review of Primary Education

(Tymms & Merrell, 2007) highlighted how pressures associated with Standardised Assessment Tests (SATs) increased test-related anxiety among children and were discouraging them from learning.

There are consistent findings in the empirical literature that childhood anxiety is associated with lower academic performance. Hembree (1988) meta-analysed 562 studies of American students from elementary school to college to address the correlates, effects and treatment of test anxiety. Hembree (1988) found a consistent negative correlation between anxiety and academic performance (r = -.29) and concluded that test anxiety leads to poor academic performance. In a further meta-analysis of the relationship between anxiety and performance, Seipp (1991) included 126 studies published from 1975 to 1988, based on a total sample of 36,626 subjects. An overall analysis with 156 effect sizes yielded a population effect size of r = -.21. Subsequent analyses suggested that variation across studies was associated with the kinds of anxiety measured, for example the more specific the anxiety measure the more closer the association.

Research with both clinical and typical populations have shown that elevated anxiety is associated with a range of negative educational outcomes. These include underperformance on ability tests, underachievement on academic grades and leaving school at an earlier age.

Davis, Ollendick and Nebel-Schwalm (2008) found that children with anxiety disorders had significantly lower Full-scale IQ scores and Performance IQ scores on the Weschler Intelligence Scales (Weschler, 1997) compared to a non-clinical control group. This corroborated earlier findings by Hodges and Plow (1990).

Gumora and Arsenio (2002) evidenced that academic affect, including anxiety, predicted academic achievement after controlling for the influence of other cognitive variables including academic self-efficacy. Consistent with this, Mazzone et al. (2007) found that high levels of anxiety were negatively associated with school grades among children aged 8 to 16 years. More recently, Putwain (2008b) reported a significant negative association between self-reported test anxiety and GCSE performance in 558 students.

Kessler, Foster, Saunders and Stang (1995) presented results of a national comorbidity survey of 8098 respondents investigating the social consequences of psychiatric disorders. The survey indicated that the probability of terminating education during high school was consistently higher for respondents with a prior psychiatric disorder, including anxiety. More recently, Duchesne, Vitaro, Larose and Tremblay (2008) evidenced that anxiety predicted high school non-completion by the age of 20 in a sample of 1817 children and young people.

The above studies are all correlational in nature and therefore are not able to establish the casual direction of the effects. For example, although it is assumed that higher levels of anxiety lead to poor academic performance, the experiences of children with lower grades and poorer academic performance may produce feelings of anxiety. Both intervention studies and longitudinal studies have attempted to address this.

Wood (2006) tested the effect of a reduction in anxiety over time in the context of participating in a cognitive-behavioural intervention. The longitudinal analyses for the 40 children aged 6 to 13 years suggested that decreased anxiety over the course of the intervention was associated with improved school performance. In a more recent intervention study, Fonseca et al. (2008) ran a similar intervention following cognitive-behavioural techniques and found that the programme led to reduced state anxiety and enhanced IQ performance for children and adolescents taking part.

A longitudinal study by Woodward and Fergusson (2001) exploring the relationship between adolescent anxiety and educational achievement found that increased levels of anxiety at time 1 predicted educational underachievement at time 2. Furthermore, Grover, Ginsberg and Ialongo (2007) examined the outcomes associated with anxiety symptoms among 149 African-Americans over a seven-year period (mean age at time 1 was 6 years). The results indicated that high levels of anxiety at time 1 were associated with significantly impaired achievements in reading and mathematics at time 2, even after the effects of earlier academic performance were statistically controlled.

Overall, these findings seem to provide clear evidence of an association between childhood anxiety and educational outcomes. Not all available research, however, is in agreement with the above findings. For example, Andrews and Wilding (2004) carried out a longitudinal study exploring the association between mental health problems and academic performance in 351 undergraduate students. They found that self-reported levels of anxiety at time 1 did not predict subsequent exam performance. More interestingly, DiLalla, Marcus and Wright-Phillips (2004) carried out a longitudinal study into parent-rated anxiety of pre-school children on subsequent academic performance in early adolescence. The results indicated that early general anxiety in fact predicted better performance at school.

There are several possible reasons for conflicting findings. The first could be related to different levels of anxiety being measured. For example, in line with the Yerkes and Dodson (1908) inverted-U hypothesis, it would be expected that if the sample is non-clinical and has low to moderate levels of anxiety then this might produce a positive relationship with performance. In line with this, the sample within the DiLalla et al. (2004) study was skewed with low numbers of high-anxious children present. A further reason for conflicting findings could be the use of different measures of anxiety. Generally, the majority of research has tended to be one dimensional where anxiety has been assessed using a single self-report measure. There is little research that incorporates multifaceted assessment methods or different types of anxiety (e.g. state-trait anxiety; test anxiety; somatic anxiety). The importance of assessing anxiety from a multidimensional perspective was highlighted in the Grover et al. (2007) study where high levels of anxiety at time 1 were associated with significantly impaired achievements in reading and mathematics at time 2 for teacher ratings of anxiety, but not for parent- or self-ratings of anxiety.

1.3. Theoretical Framework

Overall, despite inconsistent findings, the evidence suggests some association between anxiety and cognitive performance. An influential theoretical model which attempts to explain the effects of anxiety on performance was put forward by Eysenck and Calvo (1992). The Processing Efficiency Theory (PET; Eysenck & Calvo, 1992) draws on two major components to explain the anxiety-performance relationship. The first relates to the role of worry in the interference of cognitive functions and the second relates to the mechanisms of working memory affected by anxiety. It should be noted that PET has since been revised and updated within the Attentional Control Theory (Eysenck, Derakshan, Santos & Calvo, 2007), however it is important to consider the major components and assumptions of the original theory before addressing revisions. The role of worry and working memory will be explored in turn.

1.3.1. Worry and the anxiety-performance relationship.

Liebert and Morris (1967) suggested that test anxiety can be divided into two components of worry and emotionality. Worry is considered to be the cognitive component, whilst emotionality is considered to be the affective component. Worry is viewed primarily as the thoughts relating to failure; whereas emotionality is viewed as the perceived arousal component of the anxiety experience (Goetz, Preckel, Zeidner & Schleyer, 2008). PET proposes that worry rather than emotionality is responsible for the negative influence of anxiety on performance as it absorbs more cognitive resources (Eysenck & Calvo, 1992).

Recent studies have shown that the worry component is more strongly related to academic achievement than the emotionality component. Meijer and Oostdam (2007) administered the revised Worry-Emotionality Scale (Meijer, 2002), together with intelligence tests, to 135 children aged between 10 and 13 years. The Worry-Emotionality Scale consists of 14 items referring to worry and 12 items referring to emotionality. The results indicated that worry had a stronger detrimental influence on performance than emotionality. In a further study, Goetz et al. (2008) used Spielberger's (1977) Test Anxiety Inventory which consists of six items relating to worry (e.g. I worry about possible failure when studying for an exam) and six items relating to emotionality (e.g. When I'm taking an exam I feel uncomfortable and tense). The Test Anxiety Inventory was administered to 789 students aged between 10 and 14 years and measures of scholastic achievement were indexed through school grades. Analysis of the results indicated that the negative association between test anxiety and achievement outcomes was stronger for worry than emotionality. These findings were corroborated by Putwain (2008b) in a sample of 558 pupils aged 15 to 16 years.

In PET, it is assumed that worry is activated in stressful situations and is most likely to occur in individuals high in trait anxiety. Eysenck (1992) reviewed research which typically found that those high in trait anxiety are hyper-vigilant, scanning the environment for threatening or potentially threatening material. This results in selective attentional biases in favour of the location of threatening material, and also in increased susceptibility to distraction and interference.

Keogh, Bond, French, Richards and Davis (2004) explored the role that both worry about examinations and cognitive susceptibility to distraction would have on the academic performance of 106 undergraduate students. The Revised Test Anxiety Scale (Benson & El-Zahhar, 1994) was used which comprises of 20 items relating to four sub-scales of worry, tension, test-irrelevant thinking and bodily sensations. Susceptibility to distraction was measured through a computer-based task including pairs of distractor words that varied in valence and relevance to examinations. The results indicated that students high in worry found threatening words more distracting than non-threat words; whereas those low in worry were equally distracted by threatening and non-threatening words. Furthermore, they found that susceptibility to distraction significantly predicted examination performance. Therefore, available evidence utilising self-report measures appears to support the assumption of PET that worry rather than emotionality plays a key role in the relationship between anxiety and performance

1.3.2. Working memory and the anxiety-performance relationship.

PET draws attention to working memory in explaining the anxiety-performance relationship. Working memory is generally seen as a dynamic mechanism that allows individuals to store information over short periods of time while engaging in cognitively demanding activities (Baddeley, 2007). In contrast to short-term memory which is usually described in terms of temporary storage of information, working memory is assumed to be able to manipulate the information being stored; to incorporate information from long-term memory; and is also dependent upon a limited capacity attentional control system, not simply a limited storage capacity (Baddeley, 2007).

The assumptions of PET are based on the original working memory model proposed by Baddeley (1986). This original model consisted of three components: the central executive and two temporary storage systems known as the phonological loop and the visuospatial sketchpad. Baddeley (2000; 2007) has since developed the model to include a third storage system, the episodic buffer. The phonological loop is assumed to be capable of holding speech-based information and is proposed to comprise of both a temporary phonological input store and an articulatory rehearsal process. The phonological loop is thought to be subject to rapid decay which can be offset by the rehearsal process. The visuospatial sketchpad is assumed to take a similar role for the processing and storage of visual and spatial information. The central executive is seen as the attentional control system. Baddeley (2007) refers to the Supervisory Attentional System (Norman & Shallice, 1986) to conceptualise the central executive. Norman and Shallice (1986) proposed that behaviour is controlled at two levels: one which is relatively automatic based on predictable events; and the other, the Supervisory Attentional System, which executes controlled processes necessary for planning for future actions, making decisions and working with novel stimuli. The episodic buffer is assumed to form an interface between the three working memory subsystems and long-term memory. The buffer allows perceptual information, information from the subsystems and from long-term memory to be integrated into a limited number of episodes (Baddeley, 2007).

Convergent evidence for Baddeley's model of working memory has been drawn from a variety of sources including experimental studies with adult participants (e.g. Baddeley, 1966; Baddeley, Lewis & Vallar, 1984; Levy, 1971; Murray, 1968), by studying memory function in individuals with highly specific neurological and neuropsychological deficits (e.g. Baddeley, Della Sala, Papagno & Spinnler, 1997; Vallar & Baddeley, 1984; Vallar, Papagno & Baddeley, 1991; Vallar & Papagno, 2002); through developmental studies which indicate changes in memory across childhood (e.g. Gathercole, Pickering, Ambridge & Wearing, 2004) and also through neuroimaging evidence (e.g. Jonides, et al., 1997; Smith & Jonides, 1997).

Evidence suggests that working memory skills play a role in the acquisition of important abilities in childhood which are likely to have a direct impact on a child's success within school. The phonological loop has been liked with the acquisition of language and vocabulary (Baddeley, Gathercole & Papagno, 1998). The central executive has been linked with reading comprehension (Cain, Oakhill & Bryant, 2004) and both the central executive and visuospatial sketchpad may play a role in the acquisition of arithmetic skills (Bull, Johnson & Roy, 1999; Dark & Benbow, 1990). Therefore, with working memory playing a role in key aspects of learning, it seems likely that there would be a relationship between working memory abilities and success at school. A number of studies have investigated this association across various stages of education.

Alloway et al. (2005) examined the relationship between scores on working memory tasks involving the central executive and phonological loop with teacher assessments in language, literacy, numeracy and personal development for 194 children aged 4 and 5 years. Hierarchical regression analyses revealed unique associations between teacher ratings in each area and working memory measures.

Gathercole, Pickering, Knight and Stegmann (2004) explored the relationship between working memory skills and pupil attainment in national curriculum assessments for a group of 40 children at Key Stage 1 (7 and 8 years of age) and a group of 43 children at Key Stage 3 (14 and 15 years of age). Both groups were given two central executive tests and two phonological loop tests from the Working Memory Test Battery for Children (Pickering & Gathercole, 2001). At Key Stage 1, children with high abilities in both English and mathematics scored better on working memory measures than children of low or average ability. At Key Stage 3, working memory test scores significantly differed between low and average ability groups and average and high ability groups for mathematics and science with higher working memory scores associated with pupils in higher ability groups.

Finally, Grimley and Banner (2008) studied the relationship between working memory abilities and GCSE results for 205 students. A measure of central executive functioning was found to be associated with GCSE grades where students with high working memory scores achieved better GCSE grades than children with low working memory scores.

As well as predicting overall achievement in school, working memory abilities have also been shown to be associated with children identified as having special educational needs (SEN) at school. Gathercole and Pickering (2001) demonstrated that of 57 children aged 6 to 8 years, the 10 who were receiving extra provision in school for identified SEN performed significantly lower on measures of the central executive. Pickering and Gathercole (2004) conducted a much larger study in which 98 children were identified from a sample of 734 children as having SEN. The results indicated distinctive working memory profiles across SEN groups with the most marked deficits on measures of the central executive and phonological loop found in the children with problems in the area of language. Children identified as having general learning difficulties were found to perform poorly across all areas of working memory. Finally, Gathercole, Alloway, Willis and Adams (2006) found that working memory deficits contributed significantly to literacy and numeracy difficulties in a group of 46 children with reading disabilities independent of IQ and verbal ability measures.

Evidence suggests that the ability to succeed in school is closely related to working memory. These studies are limited by the use of cross-sectional designs as the causal direction of the association between working memory and school performance cannot be determined. Recently, longitudinal studies have been carried out to determine the developmental consequences of poor working memory function in childhood. Gathercole, Tiffany, Briscoe, Thorn and the ALSPAC team (2005) compared the cognitive skills and attainments of two groups of children at 5 and 8 years, one group which was identified on the basis of poor phonological loop skills at 5 years. The results indicated that there were significant differences between the literacy assessments of the two groups at age 8 and this deficit was associated with working memory tasks which tap the central executive.

Furthermore, Swanson, Jerman and Zheng (2008) investigated the influence of working memory on mathematical problem solving across a group of 353 children at three time points (Years 1, 2 and 3 at school). The results indicated that measures of central executive function and visuospatial sketchpad in Year 1 predicted problem solving solution accuracy in Year 3. Furthermore, growth in the central executive and phonological loop storage component was related to growth in solution accuracy. Therefore, there does appear to be a relationship between central executive measures and subsequent literacy and numeracy attainments.

1.4. Evidence for Theoretical Assumptions

The evidence presented so far suggests that the two major components of PET are grounded in consistent empirical findings which highlight the central role of both worry and working memory in cognitive performance. Eysenck and Calvo (1992) described how these two components interact to affect performance. In particular, it is assumed that worry leads to cognitive interference by preempting the processing and storage capacity of working memory. Worry-related thoughts are assumed to take up limited attentional resources of working memory, and therefore there is less available for the task. The theory predicts that the main effects of worry or anxiety are on the central executive and therefore, the effects of anxiety on performance will tend to be greater in tasks which place substantial demands on the processing and storage capacity of working memory. It is thought that the phonological loop rather than the visuospatial sketchpad may also be implicated as worry typically involves inner verbal activity (Eysenck et al., 2007).

Furthermore, PET predicts that worry has a second effect on performance related to motivation. In particular, the theory assumes that in order to cope with threat and worry, anxious individuals allocate additional resources or activities to completing the task (Eysenck & Calvo, 1992). For example, they may apply more effort or use different strategies. Therefore, the theory makes a key distinction between performance effectiveness and processing efficiency. Negative effects of anxiety are predicted to be significantly greater on processing efficiency than on performance effectiveness as anxiety is assumed to lead to greater allocation of effort which would mean that accuracy is not affected, but efficiency (i.e. time taken to complete the task) is affected (Eysenck & Calvo, 1992). PET therefore assumes that anxiety will have both motivational and attentional interference effects on performance.

Following these assumptions, PET makes three key predictions regarding the relationship between anxiety and performance which have subsequently been tested empirically. The three predictions will be explored in turn.

1.4.1. The adverse effects of anxiety on task performance generally become stronger as task demands on working memory capacity increase.

Ashcraft and Kirk (2001) explored the prediction that anxiety will have its primary debilitating effect in tasks that place heavy processing loads on working memory. They used a transformation task in which participants are required to transform a single letter by moving a given distance through the alphabet, and then producing the result of the transformation (e.g. T + 2 = V). As the number of letters needing to be transformed increases the tasks make greater demands on both processing and storage capacities. The complexity varied from adding between one and four letters in a problem. A significant interaction was found between mathematics anxiety and the number of letters in the problem. High mathematics anxious individuals were significantly slower and less accurate than low mathematics anxious individuals on the four-item but not the two-item list. Therefore, even with additional effort, high mathematics anxiety participants were still less able to recall transformations accurately. Beliock, Kulp, Holt and Carr (2004) found parallel findings in relation to mathematical problem-solving. State anxiety was manipulated through randomly allocating participants to high and low pressure situations. Individuals in the high-pressure group performed at a significantly lower accuracy level than low-pressure participants; however this lower accuracy was limited to those problems with the heaviest working memory demands.

Further support for PET comes from research which indicates that a reduction in demand on working memory capacity leads to improved performance for individuals with high test anxiety. Dutke and Stober (2001) distinguished between two types of complexity in tasks: coordinative complexity relates to tasks in which information needs to be processed whilst also retaining results from previous steps of the task; whereas sequential complexity refers to independent processing steps. It is assumed that sequential complexity does not make additional demands on the storage components of working memory. A sample of 24 undergraduate students carried out both a high coordinative complexity task and a task with high sequential demands. In a task with high coordinative complexity, high sequential demands had a positive effect on both the speed and accuracy of highly test-anxious participants. It is suggested that high sequential task demands may help to relieve working memory capacity therefore profiting high anxious individuals who may have reduced capacity due to task-irrelevant thoughts.

1.4.2. Anxiety does not generally impair performance on tasks not involving the central executive and/or the phonological loop components of the working memory system.

PET assumes that anxiety mainly affects the central executive; however there may also be minor effects on the phonological loop. It is not assumed that anxiety has systematic effects on the visuospatial sketchpad. Eysenck, Payne and Derakshan (2005) employed various secondary tasks to investigate which component or components of working memory are most affected by anxiety. The Corsi task (Corsi, 1972) was used in each experiment, in which nine identical black blocks are arranged in a random pattern and involves reproducing a spatial sequence immediately after it has been produced by the experimenter. There were four secondary tasks: a counting backwards task assumed to involve the central executive; a spatial tapping task assumed to require the visuospatial sketchpad; an articulatory suppression task assumed to require the phonological loop and a simple tapping task as a control task. Seventy-five undergraduate students were classified into high and low anxious groups using the State Trait Inventory (STAI; Spielberger et al., 1983). The results indicated that there was a significant difference between low- and high-anxious groups only when the secondary task involved counting backwards. There was no evidence that performance of the high- and low-anxious groups was affected by spatial-tapping or articulatory suppression therefore implying that anxiety may not produce inefficient functioning of the visuospatial sketchpad or phonological loop. This finding supports the prediction that anxiety primarily affects the central executive component of working memory.

Further evidence to support this prediction comes from research which explores the relationship between anxiety and performance on tasks that involve different components of working memory. Crowe, Matthews and Walkenhorst (2007) used six working memory tasks: forward digit span (thought to measure phonological loop capacity); visual patterns test and forward spatial span (thought to measure visuospatial sketchpad capacity); and backward digit span, backward spatial span and a dual-task (thought to involve the central executive). Sixty-one undergraduates completed the STAI (Spielberger et al., 1983) and each of the working memory tests. The results indicated that anxiety significantly and negatively contributed to performance on central executive tasks, but did not relate to verbal working memory tasks or visuospatial working memory tasks.

1.4.3. Anxiety typically impairs processing efficiency more than performance effectiveness

When focusing on situations in which high- and low- anxious individuals have comparable performance effectiveness, PET would predict that the high-anxious subjects will exert more effort and show lower processing efficiency. This is indicated by longer reaction times.

One approach to test this prediction is by using a loading paradigm, in which the same central task is performed concurrently with a second task that imposes demands on working memory capacity. According to the processing efficiency hypothesis, the high-anxious group will apply greater effort to the task than the low-anxious group and therefore this leaves less spare processing capacity for the secondary task. PET would therefore predict that this would lead to greater response times but not increased error rate for the high anxious group compared with the low anxious group.

MacLeod and Donnellan (1993) used a loading paradigm with verbal reasoning as the central task. The secondary task involved retaining six numbers in memory. The results indicated that the high anxious groups had longer decision latencies than the low anxious groups under the memory load condition, however there were no differences between the two groups on error rates. This finding was replicated in a study by Derakshan and Eysenck (1998) with 220 undergraduate students using the same loading paradigm. These findings provide support for this hypothesis as they show that anxiety impairs task efficiency, indicated through longer response times, rather than task performance, indicated through similar error rates.

1.5. Revision of Theoretical Framework

Overall, the available empirical research appears to support the general assumptions and predictions that PET makes regarding the relationship between anxiety, working memory and performance. Eysenck et al. (2007) have recently explored some theoretical limitations of PET, in particular, that it fails to specify which central executive functions are most adversely affected by anxiety. To address the theoretical limitations, Eysenck et al. (2007) proposed the Attentional Control Theory (ACT) which rests on the same key assumptions as PET, but provides a more comprehensive view of the relationship between anxiety, working memory and performance by predicting the effects of anxiety on the functioning of the central executive. Central to ACT is that anxiety affects performance through attentional processes. It is assumed that anxious individuals allocate attentional resources to threat-related stimuli and therefore anxiety impairs attentional control, a key function of the central executive (Eysenck et al., 2007). In relation to this, it is also assumed that anxiety decreases attention to goals and increases attention to stimuli such as internal worry and external distractors.

Eysenck et al. (2007) refer to the three aspects of executive functioning studied by Miyake et al. (2000): inhibition (suppression of irrelevant information from working memory); shifting (shifting of attention to remain focused on task relevant stimuli); and updating (adding or changing working memory representations). Both inhibition and shifting are thought to use attentional control, whereas updating is thought to involve storage of information rather than attentional control. Therefore it is predicted that the effects of anxiety on updating should be weaker compared to the effects on inhibition and shifting.

In relation to inhibition, anxiety has been shown to lead to greater susceptibility to distraction, especially when task demands are high. For example, Wood, Matthews and Dalgleish (2001) found that individuals high in trait anxiety showed impaired inhibitory processing of irrelevant meanings of homographs in comparison to those low in trait anxiety only when there was a concurrent demanding task. This therefore suggests that anxiety affected the ability to inhibit task-irrelevant or distracting stimuli under high task demands.

Task-switching, where participants are required to perform two tasks in rapid succession, has been used to assess the effect of anxiety on shifting. Santos and Eysenck (2006) found that anxious participants were significantly slower than non-anxious participants on the second task, following the switch, therefore suggesting that the shifting function was affected by anxiety.

Evidence is also available that supports the prediction that anxiety will not have an effect on updating. Dutke and Stober (2001) presented participants with a counting task which involved updating of the number of occurrences of each of three target numbers. The results indicated that there was no main effect of anxiety on performance. However, Eysenck et al. (2007) state that the findings relating to the effect of anxiety on updating are inconsistent, particularly when stressful conditions are used. Therefore, although ACT is an attempt to provide a more comprehensive account of the influence of anxiety on performance by indicating which components of the central executive are affected, there clearly needs to be more research into the effects of anxiety on inhibition, shifting and updating in order to provide validation of the assumptions.

Overall, both PET and ACT rest on key assumptions: firstly, that the cognitive component, worry, plays a central role in the anxiety-performance link; secondly, that working memory plays an important role in linking anxiety and performance; thirdly, that the effect of anxiety is largely on the central executive; and lastly, that the negative effects of anxiety are predicted to be significantly greater on processing efficiency than on performance effectiveness.

1.6. Areas of Development

So far, the evidence reviewed has largely supported the key assumptions of PET and ACT. However, there appear to be a number of key areas of development in terms of further testing and exploration of the theoretical models to understand the relationship between anxiety, working memory and academic performance. The majority of studies used as evidence for PET and ACT have tended to use participants selected from undergraduate students and very few studies have worked with younger populations or with targeted populations who underachieve in school. Given the breadth of research detailed in the first section which indicates an association between anxiety and academic performance in childhood, it is clearly important to explore this association further in relation to theoretical models and to ascertain whether the findings from adult literature will be replicated across developmental studies.

A further key area for development relates to methodological issues. A particularly significant limitation of the majority of studies cited in this review is that they are cross-sectional in nature and therefore it is not possible to draw conclusions regarding causal relationships. Previous longitudinal research indicates a causal role for the impact of anxiety on performance (e.g. Duchesne et al., 2008; Grover et al., 2007; Woodward & Fergusson, 2001), however further longitudinal studies are required to fully understand the relationship between anxiety, working memory and performance.

A second area of methodological limitation is that the majority of studies cited have been one-dimensional in nature where anxiety has been assessed through a single self-report measure, for example, the State-Trait Anxiety Inventory (Spielberger et al., 1983). As stated in the introduction, anxiety can be seen as a physiological state characterised by cognitive, physical, and behavioural components (Seligman et al., 2001). Although self-report measures may be able to tap into the thoughts and perceptions related to anxiety; autonomic reactions such as increases in heart rate can be viewed as an objective indicator of physiological change and therefore should also be measured alongside self-report measures.

The areas relating to developmental studies, research with children and young people considered at risk of underachieving and multi-dimensional measures of anxiety require further investigation. These will be explored in turn.

1.6.1. Developmental studies.

Gathercole et al. (2004) explored the structure of working memory across childhood with a sample of 700 children aged between 4 and 15 years. Each child completed the eight subtests of the Working Memory Test Battery for Children (Pickering & Gathercole, 2001). The correlational analysis revealed that the basic structure of the phonological loop, central executive and visuospatial sketchpad were in place from 6 years of age and showed similar linear increases in performance from 4 years through to adolescence.

The literature search revealed that the first comprehensive study which attempted to directly investigate the relationship between anxiety and working memory in children, integrating the results in the theoretical framework was by Hadwin, Brogan and Stevenson (2005). The study was designed to test two assumptions of PET with 30 children aged 9 to 10 years. The first assumption tested was that the executive and phonological components of working memory may be important in understanding performance under anxiety. The children were split into high and low state anxiety groups using a self-report measure, the State-Trait Anxiety Inventory for Children (STAIC; Spielberger, 1973). The working memory tasks used were forward digit span, backward digit span and a spatial working memory task designed to tap into the phonological loop, central executive and visuospatial sketchpad respectively. The second assumption tested was that the affect of anxiety on performance relates more significantly to efficiency than effectiveness. Task efficiency was measured though the time taken to complete tasks and also through a self-report measure, the Rating Scale of Mental Effort (Zijlstra, 1993) where participants rated each task on a scale of seven points from “I tried very little,” to “I tried very hard.”

The results indicated that children in the high anxiety group took longer to complete the backward digit span tasks and reported increased mental effort in the forward digit span task. No relationship was found between state anxiety and task efficiency or effectiveness in the visuospatial working memory task; and furthermore, the level of state anxiety in participants was not associated with differences in task accuracy for any working memory measure. Consistent with the predictions of PET and findings from the adult literature, anxiety appeared to affect the central executive and phonological components of working memory rather than the visuospatial components. Furthermore, in support of PET, anxiety appeared to affect performance efficiency in terms of time taken and subjective effort, rather than performance accuracy.

More recently, Grimley, Dahraei and Riding (2008) have explored the relationship between anxiety and working memory capacity in a sample of 179 adolescents aged 12 to 13 years. The study used teacher-ratings of anxiety-stability. Working memory capacity was measured though a computer task relating to the retention and processing of colours of train carriages passing through the screen. The study found a significant relationship between anxiety and working memory where higher working memory capacity was associated with higher stability scores. Therefore, as predicted by PET and consistent with findings with adult samples, working memory capacity was found to be affected by the level of anxiety.

These two developmental studies indicate that the theoretical predictions and findings relating to anxiety and working memory in the adult population have also been replicated with children and adolescents. However, these studies focus purely on the association between anxiety and working memory, without addressing the consequences on academic performance.

Aronen, Vuontel, Steenari, Salmi and Carlson (2005) studied the relationship between anxiety, working memory and academic performance in 60 children aged 6 to 13 years. Behavioural and emotional symptoms were obtained through the Teacher Report Child Behaviour Checklist (Achenbach, 1991) and Children's Depression Inventory (Kovacs, 1985). Academic performance was measured through the competence section of the Teacher Report Form (Achenbach, 1991). Working memory was assessed through the visuospatial and audiospatial versions of an n-back task. In these tasks, participants are asked to indicate whether the current stimulus matches the stimulus presented n-stimuli back in the series, where n equals a number between 0 and 3. Working memory performance was lowered in children with internalising symptoms (anxiety and depression), particularly in the youngest children. Furthermore, children with lower academic performance at school provided more incorrect responses in visuospatial memory tasks than children rated as higher academic performance. Therefore, poor working memory function was associated with academic problems and with anxiety. However, the working memory measure used did not allow a test of PET in terms of comparisons of central executive, phonological and visuospatial functioning.

A recent study by Owens, Stevenson, Norgate and Hadwin (2008) directly tested PET by exploring the relationship between trait anxiety, working memory and academic performance amongst 50 pupils aged 11 to 12 years. Anxiety was measured by self-report using the STAIC. The working memory tasks consisted of the backwards digit recall from the Automated Working Memory Assessment (AWMA; Alloway, 2007), designed to tap phonological working memory; and also the spatial span task from the Cambridge Neuropsychological Test Automated Battery (CANTAB, 2004) which is a computerised version of the Corsi blocks tapping test and is designed to tap visuospatial working memory. Academic performance was ascertained through the Cognitive Abilities Test which measures verbal, quantitative and nonverbal reasoning; and the national curriculum Standardised Assessment Tests in mathematics, English and science.

Verbal working memory was positively related to academic outcome as results on backward digit span correlated positively with all six academic measures. Furthermore, trait anxiety was found to be negatively related with math and quantitative reasoning. Consistent with predictions of PET, trait anxiety was associated with verbal working memory, but not with spatial working memory. Furthermore, verbal working memory was found to partially mediate the relationship between trait anxiety and academic performance, on average accounting for 51% of the association, while spatial working memory only accounted for 9%. These findings have subsequently been replicated with a sample of 31 pupils aged 12 to 13 years whereby the mediation effect between anxiety and performance was again clearest for verbal working memory (Owens, Stevenson, Norgate & Hadwin, submitted).

The developmental research available is largely consistent with findings from research with adult participants and broadly supports the assumptions of PET and ACT. However, developmental studies to date have employed a cross-sectional design and therefore it is not possible to demonstrate causal relationships between anxiety and academic performance. Longitudinal studies are required to fully understand the relationship between anxiety, working memory and academic performance in childhood. Furthermore, given that only two developmental studies are currently available which directly test the components of working memory in the relationship between anxiety and performance, it is important that further research is carried out to replicate and extend this research across different populations of children and young people.

1.6.2. Children and young people at risk of underachieving.

Although the above developmental studies give an indication of the application of the PET to achievement in school, the participants were all taken from typically developing populations in schools. Therefore, further research is required to establish whether the findings would apply to children considered 'at-risk' at school and therefore could contribute to targeted interventions to help promote achievement.

In the Governmental papers, Excellence for all Children: meeting special educational needs (Department for Education and Employment, 1997), and Breaking the Cycle (Department for Education and Skills, 2004) concern for the education and long-term underachievement of students displaying social, emotional and behavioural difficulties (SEBD) was highlighted. The Special Educational Needs Code of Practice (Department for Education and Skills, 2001) recognises SEBD as a special educational need. The term is generally used to refer to children and young people whose behaviour is a danger to themselves or others, which can involve physical aggression or running out of school; whose behaviour interferes with the efficient education of other children or with their own educational progress, as is the case with withdrawn or anxious children; and/or where the child has difficulty with social relationships or interferes with relationships of other children (Hunter-Carsch, Tiknaz, Cooper & Sage, 2006).

Research has been published which highlights the case of underachievement for students with SEBD. Cole, Visser and Upton (1998) reported that about 50% of students in their study labelled as having SEBD were significant underachievers in the core subjects and of these, 30% were severe underachievers. Farrell, Critchley and Mills (1999) found that 48% of a sample of 117 boys identified as having SEBD achieved an attainment score of 70 or less on the Wechsler Objective Reading Test (WORD, 1992) and Wechsler Objective Numerical Dimensions Test (WOND, 1992). Two percent of the general population would be expected to achieve below 70 and therefore this indicates attainment problems in literacy and numeracy for pupils identified with SEBD.

When considering how PET may apply to understanding the underachievement of pupils with SEBD, it is important to take into account previous research which has indicated associations between both externalising and internalising behaviour and working memory (Barkley, 1997; Eisenberg et al. 2001, 2004; Nigg, 2000;). For example, Martinussen, Hayden, Hogg-Johnson and Tannock (2005) conducted a meta-analysis of working memory impairments in children with attention-deficit/hyperactivity disorder (ADHD). Twenty-six studies met the inclusion criteria set, and these demonstrated that children with ADHD exhibit moderate to large impairments in working memory, and specific reductions in performance relative to controls were found for both central executive and spatial working memory components. Furthermore, Eisenberg et al. (2001; 2004) have documented the relationship between executive function and internalising disorders. Therefore, there appears to be a relationship between clinical levels of SEBD and working memory. However, it would also be useful to understand how typical levels of SEBD are associated with working memory and academic performance.

Gathercole et al. (2008) explored the relationship between working memory and externalising behaviours in a non-clinical sample of 52 children. The children were selected from an initial sample of 852 children aged 4 to 5 years and 957 children aged 8 to 9 years. The 52 children were selected as those scoring very low composite scores on listening recall and backward digit recall sub-tests of the AWMA. Externalising behaviours were rated by teachers using the Conners' Teacher Rating Scale (2001) which has subscales of oppositional behaviour, inattention and hyperactivity. The majority of children within both age groups were rated as having short attention spans, and high levels of distractibility. This therefore fits well with research from clinical populations showing a link between working memory and ADHD (Martinussen et al., 2005). This study, however, simply concentrated on the link between working memory and externalising behaviour, without considering the role played by emotional factors or the links with academic performance.

As described previously, Aronen et al. (2005) studied the relationship between working memory function, behavioural and emotional symptoms and academic performance at school in 60 non-clinical children aged 6 to 13 years. As well as finding associations between poor working memory function, academic problems and anxiety; children who were rated by teachers as having attentional and/or behavioural difficulties made more mistakes in the memory tasks than children with no such difficulties. Therefore, poor working memory function was associated with academic problems and with emotional and behavioural difficulties.

More recently, Grimley and Banner (2008) explored the relationship between working memory, SEBD and educational outcomes in 205 students aged 12 to 13 years. Working memory was correlated with measures of emotion and learning behaviour, where higher combined scores from the Emotional and Behavioural Development Scale (Grimley, Morris, Rayner & Riding, 2004) was associated with poorer working memory performance. Furthermore, students with high working memory achieved higher predicted grades than students with low working memory.

The studies above have indicated links between SEBD and both school performance and working memory. Therefore, it will be useful to carry out further research which directly tests the application of PET to the academic performance of pupils displaying SEBD, as the outcomes may help in targeting interventions to help promote achievement. In particular, to explore the role played by different components of working memory to see whether previous research with typical school populations (e.g. Owens et al., 2008) is replicated with targeted populations with SEBD.

1.6.3. *Multi-dimensional measures of anxiety.*

The final area of development to be explored relates to the measurement of anxiety. The research cited so far in support of PET and ACT has focused on the use of self-report measures of anxiety, or in the case of some developmental studies, parent- or teacher-report measures of anxiety. As anxiety has also been shown to produce autonomic changes in the body, it seems important to include these more objective measures in combination with the self-report measures. Anxiety triggers an automatic flight/fight response where the brain sends messages to the autonomic nervous system which is involved in controlling the body's energy levels and preparation for action. The autonomic nervous system has two branches: the sympathetic nervous system which releases energy and gets the body 'primed' for action; and the parasympathetic nervous system which restores the body to a normal state (Seligman et al., 2001). Activity in the sympathetic nervous system produces an increase in heart rate and strength of heart rate. Previous studies have used heart rate to validate self-report measures of state and trait anxiety against a physiological measure (e.g. Lewis & Drewett, 2006; McLeod, Hoehn-Saric & Stefan, 1986; Thyer, Papsdorf, Davis & Vallecorsa, 1984). For example, Kantor, Endler, Heslegrave and Kocovski (2000) asked graduate students to complete a state and trait anxiety questionnaire as well as attaching them to a heart rate recorder prior to a class seminar presentation. The results indicated that heart rate was significantly correlated with self-report state and trait anxiety.

Hopko, Crittendon, Grant and Wilson (2005) assessed anxiety from a multidimensional perspective using a battery of self-report instruments including the Test Anxiety Inventory (Spielberger, 1977) and the State-Trait Anxiety Inventory (STAI; Spielberger et al., 1983); together with on-line anxiety measures including heart rate. The study found that whereas higher test anxiety was associated with lower performance IQ; a higher heart rate was positively associated with performance IQ. This suggests that in relation to anxiety-performance studies, self-report and physiological measures of anxiety may produce conflicting results.

Research has also shown that heart rate variability can be used as an objective measure of autonomic activity (Appelhans & Luecken, 2006). Heart rate variability is a measure of the continuous interplay between sympathetic and parasympathetic influences on heart rate and reflects the degree to which cardiac activity can be modulated to meet situational demands (Appelhans & Luecken, 2006). Greater variability has been associated with improved and faster performance on working memory tests. For example, Kofman, Meirna, Greenberg, Balas and Cohen (2006) measured the impact of examination stress on an executive control task through the STAI (Spielberger et al., 1983) and baseline heart rate variability. The executive control task involved a visuospatial task-switching paradigm. Heart rate variability was measured through wrist and ankle electrodes. The increase in stress indicated by both the STAI and heart rate variability in fact led to enhancement of performance in the task-switching task.

Shackman et al. (2006) also investigated the influence of anxiety on working memory performance using physiological measures. The results showed that physiological measures of anxiety were negatively associated with results on a visuospatial n-back task but not a verbal n-back task. Therefore, in contrast to assumptions of the PET, anxiety was found to disrupt visuospatial working memory and not phonological working memory.

Therefore, it appears that studies which have employed multi-measures of anxiety have found conflicting evidence regarding the predictions of the PET. Further research employing multiple measures of anxiety is required to explore the anxiety-performance relationship from a multi-dimensional perspective.

1.7. Synthesis

This review has indicated that there is consistent evidence for a link between anxiety and academic performance. PET and ACT have been put forward to explain the anxiety-performance link and draw attention to the components of worry and working memory. It is proposed that anxiety increases allocation of attention to threat-related stimuli, such as worrisome thoughts, and therefore reduces focus on the current task. Furthermore, the negative effects of anxiety are assumed to be greater on tasks using the central executive and phonological loop compared to visuospatial sketchpad as worrisome thoughts are linked to verbal activity rather than imagery. Finally, negative effects of anxiety are predicted to be significantly greater on processing efficiency than on performance effectiveness as anxiety is assumed to lead to greater allocation of effort which would mean that accuracy is not affected, but efficiency (e.g. time taken to complete the task) is affected.

Overall, research to date provides support for the main assumptions of PET and ACT. However, there are a number of key areas of development required in testing these assumptions including: the application of the theory to younger populations and with targeted populations who underachieve in school; and further evidence from longitudinal and multi-modal designs incorporating physiological measures of anxiety.

Chapter 2. Empirical Paper

2.1. Abstract

This study was designed to test the application of the Processing Efficiency Theory (PET), and its more recent revision Attentional Control Theory (ACT), for pupils with social, emotional and behavioural difficulties (SEBD). It investigated whether the negative impact of anxiety on academic performance was mediated via working memory and whether this relationship was moderated by emotional regulation. Twenty-four pupils with SEBD aged 12 to 14 completed verbal working memory tasks tapping the phonological loop and central executive; and visuospatial working memory tasks tapping the visuospatial sketchpad and central executive. Anxiety was measured through the State-Trait Anxiety Inventory for Children and the Children's Test Anxiety Scale. Academic performance was assessed using the Wide Range Achievement Test, Ravens Standard Progressive Matrices and Standard Assessment Tests. Heart rate variability and parent-rated measures of conduct problems and hyperactivity/inattention were used as indicators of emotional regulation. Overall, there was a negative association between test anxiety and academic performance, which was clearer for the thoughts component of test anxiety. Visuospatial working memory was found to mediate this association on tasks involving the central executive. These findings are broadly consistent with PET and ACT. The mediation relationship was stronger for pupils identified as displaying higher levels of hyperactivity; no moderating effect was found for either heart rate variability or conduct problems.

2.2. Introduction

The presence and potential impact of stress and anxiety in children's lives has become an important focus for the government and practitioners in the UK. The Every Child Matters Agenda (Department for Education and Skills, 2007), for example, highlighted the importance for all children to be emotionally and mentally healthy. Related to this agenda, the Good Childhood Inquiry (Layard & Dunn, 2009) collated responses of over 30, 000 children and adults over three years and drew attention to the levels of stress and anxiety experienced by children and young people today. One of the recommendations of the Good Childhood Inquiry suggested the ending of all Standard Assessment Tests (SATs) in England. Similarly, the Cambridge University Primary review (Tymms & Merrell, 2007) highlighted that SATs have produced an increase in test-related anxiety among children.

Research has found that childhood anxiety is associated with lower academic performance. Two meta-analytic studies (Hembree, 1988; Seipp, 1991) have indicated small, but consistently negative effect sizes (r = -.29 and -.21 respectively) where a higher degree of self-reported test anxiety was associated with lower assessment performance. More recent research has corroborated the negative relationship between anxiety and performance through a variety of approaches. Correlational research across randomly selected school-aged populations has demonstrated a negative relationship between anxiety and performance (e.g. Gumora & Arsenio, 2002; Hopko et al., 2005; Mazzone et al., 2007). For example, Putwain (2008b) found significant negative associations between self-reported test anxiety and

GCSE performance in 558 Year 11 students. Research has also demonstrated that children displaying clinical levels of anxiety are significantly more likely to experience poorer educational achievement compared with non-clinical populations (e.g. Davis et al., 2008; Hughes, Lourea-Waddell & Kendall, 2008).

There is also longitudinal research available which indicates a causal role for the impact of anxiety on performance (e.g. Duchesne et al., 2008; Woodward & Fergusson, 2001). For example, Grover et al. (2007) examined the outcomes associated with anxiety symptoms among 149 African-American children over a seven-year period. High levels of anxiety at time 1 were associated with significantly impaired achievements in reading and mathematics at time 2, even after the effects of earlier academic performance were statistically controlled.

Finally, research has also highlighted that interventions to reduce anxiety levels have led to subsequent improvement in academic performance (e.g. Fonseca et al., 2008; Keogh, Bond & Flaxman, 2006; Lumley & Provenzano, 2003). For example, Wood (2006) found that for 40 children aged 6 to 13 years, a cognitive-behavioural intervention led to decreased anxiety and was associated with improved school performance.

It is therefore apparent that developing our understanding of how anxiety relates to academic performance will help professionals to identify children at risk and to intervene in order to alleviate negative effects. It is particularly important to consider the implications of anxiety on performance for children who are at risk of underachievement at school. Government papers have highlighted ongoing concerns for the education and long-term underachievement of students displaying social, emotional and behavioural difficulties (e.g. Department for Education and Employment, 1997; Department for Education and Science, 1989; Department for Education and Skills, 2004). For example, the Department of Children, Schools and Families (2008) has recently published revised guidance to schools which aims to promote the achievement of children and young people whose social, emotional and behavioural difficulties are persistent and provide an obstacle to their learning.

The term social, emotional and behavioural difficulties (SEBD) is generally used to refer to young people who may display externalising behaviours such as truanting and aggression and/or internalising emotional stresses relating to anxiety and depression. The social dimension is seen to relate to the difficulties in communication with adults and peers that can result from emotional and behavioural difficulties (Hunter-Carsch et al., 2006). The Special Educational Needs Code of Practice (Department for Education and Skills, 2001) refers to SEBD as a special educational need that can include children and young people displaying difficulties which do not require a clinical diagnosis.

Empirical research has highlighted the underachievement of children with SEBD (Cole, et al., 1998; Farrell et al., 1999; Grimley & Banner, 2008). For example, Cole et al. (1998) reported that approximately 50% of students identified as having SEBD were significant underachievers in core subjects and of these 30% were severe underachievers. Therefore, it is clear that further research into the potential mechanisms affecting educational outcomes for children with SEBD will be important in contributing to targeted interventions to help promote achievement. This study will focus on anxiety and working memory in particular.

As previously illustrated, the presence of anxiety appears to have a negative influence on academic performance. A further means of understanding why children and adolescents with SEBD underachieve is via models of working memory. Both verbal and visuospatial working memory have been associated with academic performance. Empirical evidence has demonstrated links between verbal working memory and language and vocabulary acquisition (Baddeley et al., 1998; Leonard et al., 2007) and with reading comprehension (Cain et al., 2004; Montgomery, Magimaira & O'Malley, 2008). Visuospatial working memory has been shown to have links to acquiring mathematical skills (Bull, Espy & Wiebe, 2008; Kyttälä, 2007). Working memory has also been linked to performance on verbal and spatial reasoning tasks (Bacon, Handley, Dennis, & Newstead, 2007).

Processing Efficiency Theory (PET; Eysenck & Calvo, 1992) and its more recent revision Attentional Control Theory (ACT; Eysenck et al., 2007) aim to understand the negative impact of anxiety on performance using models of working memory. Anxiety can consist of different components, including behaviour, physiological change and cognition (Lang, 1985). Liebert and Morris (1967) suggested that test anxiety can be divided into two components of worry and emotionality. Worry relates to the cognitive component of anxiety and can include negative self-statements concerned with performance. Emotionality refers to the perceived arousal and autonomic component of the anxiety experience. PET and ACT propose that worry rather than emotionality is responsible for the negative influence of anxiety on performance through consuming limited attentional resources and increasing motivation to minimise the anxiety state (Eysenck et al., 2007). Empirical evidence has found support for this hypothesis (Keogh et al., 2004; Meijer & Oostdam, 2007; Putwain, 2008b). For example, Goetz et al. (2008) administered Spielberger's (1977) Test Anxiety Inventory which consists of items relating to worry (e.g. "I worry about possible failure when studying for an exam") and emotionality (e.g. "When I'm taking an exam I feel uncomfortable and tense") to 789 students aged between 10 and 14 years. The worry compared with the emotionality component of test anxiety was more strongly related to academic outcomes.

PET and ACT propose that the affect of anxiety on performance is through working memory. It is suggested that worrying about performance or evaluation results in less capacity in working memory for task allocation. The working memory model used as a basis for this prediction is Baddeley's (1986) three-component model, which has since been expanded into a four-component model involving the central executive, phonological loop, visuospatial sketchpad and episodic buffer (Baddeley, 2000). In this model, there are two temporary storage components - the phonological loop for verbal information and the visuospatial sketchpad for visual and spatial information. The central executive is involved in processing information when performing tasks. It is similar to the construct of a supervisory attentional system for regulating thought and goals (Norman & Shallice, 1986) and to attentional control (Engle & Kane, 2004). The episodic buffer is assumed to form an interface between the three working memory subsystems and long-term memory (Baddeley, 2000).

PET and ACT propose that worry consumes working memory resources, therefore reducing capacity to perform a given task. Research with adults has supported this prediction by demonstrating that the adverse effects of anxiety on performance become greater as task demands on working memory increase (Ashcraft & Kirk, 2001; Beliock et al., 2004; Dutke & Stober, 2001). ACT also predicts that the main effects of worry will be on the central executive, as research has suggested an association between anxiety and attention control (Keogh et al., 2004; Santos & Eysenck, 2006), a key function of the central executive (Eysenck et al., 2007). Therefore the effects of anxiety on performance will tend to be greater in tasks which place substantial demands on both the processing and storage capacity of working memory. Research involving adult populations has supported this prediction (Crowe et al., 2007; Eysenck et al., 2005). Crowe et al. (2007) used six working memory tasks: forward digit span (thought to measure phonological loop capacity); visual patterns test and forward spatial span, (thought to measure visuospatial sketchpad capacity); and backward digit span, backward spatial span and a dual-task (thought to involve the central executive). Sixty-one undergraduates completed the State-Trait Inventory (Spielberger et al., 1983) and each of the working memory tests. The results indicated that anxiety significantly and negatively contributed to performance on central executive tasks, but did not relate to phonological loop or visuospatial sketchpad tasks.

Although the above empirical research indicates support for PET and ACT, there has been limited research exploring the application of the theories in understanding the link between anxiety and performance in children. Hadwin et al. (2005) examined the association between state anxiety and working memory amongst thirty children aged 9 to 10 years. Measures included the State-Trait Anxiety Inventory for Children (STAIC; Spielberger, 1973) and also a forward and backward digit span task and a visuospatial working memory task. Children in the high state anxiety group took longer to complete the backward digit span, but not forward digit span, indicating the influence of anxiety on tasks involving the central executive. No significant relationships were found for the visuospatial task. Although finding some support for the theoretical predictions, this study looked purely at the relationship between anxiety and working memory without considering the consequences for academic performance.

Aronen et al. (2005) studied the relationship between anxiety, working memory and academic performance in 60 children aged 6 to 13 years. Working memory performance was lowered in children with anxiety and depression. Furthermore, children with lower academic performance gave more incorrect responses in visuospatial memory tasks than children rated as higher academic performance. However, the working memory measure used in this study did not allow a test of PET and ACT in terms of comparisons of central executive, phonological and visuospatial functioning.

A recent study by Owens et al. (2008) directly tested PET and ACT by exploring the relationship between trait anxiety, working memory and academic performance among 50 pupils aged 11 to 12 years. Anxiety was measured using the STAIC. Working memory tasks consisted of the backwards digit recall and forward spatial span. The Cognitive Abilities Test (CAT) scores for verbal, quantitative and nonverbal reasoning; and SATs scores for English, mathematics and science were obtained as indicators of school performance. Consistent with predictions of PET and ACT, performance on the backwards digit recall was found to partially mediate the relationship between trait anxiety and academic performance, on average accounting for 51% of the association, while the forward spatial span task only accounted for 9%. Backwards digit recall was found to be a significantly stronger mediator than forward spatial span, therefore supporting the prediction that anxiety affects performance through the central executive component of working memory. This finding has subsequently been replicated with a sample of 31 pupils aged 12 to 13 years (Owens et al., submitted) whereby the mediation effect was again clearest for backwards digit recall.

Although these studies indicate the application of PET and ACT in understanding the relationship between anxiety and performance in school, the participants were all selected from random samples of the school population. It therefore remains unclear as to whether these results would apply to more vulnerable groups of children and particularly pupils with SEBD who are at risk of underachieving. Previous research exploring the link between anxiety, working memory and performance for children displaying SEBD has indicated that higher combined scores for SEBD were associated with poorer working memory performance (Grimley & Banner, 2008). However, further research is required that directly tests the application of the theoretical framework to pupils with SEBD. This research may prove fruitful in helping to target interventions to promote achievement of children and adolescents presenting with these difficulties.

The magnitude of a theoretical model, which highlights a mediating effect of working memory on the relationship between anxiety and underachievement, may be affected by a number of moderating variables. These include personal or contextual factors which may strengthen or weaken this relationship (Baron & Kenny, 1986). Moderating variables are useful for identifying which individual factors may put a student at greater risk from the detrimental performance effects of test anxiety (Putwain, 2008b). One potential moderator is emotional regulation. The consistent negative relationship found between anxiety and performance has led a number of researchers to explore how pupils attempt to deal with anxiety (Gross, 1998; Gross, Richards & John, 2006; Schutz, Benson & Decuir-Gunby, 2008;

Schutz & Davis, 2000). Emotional regulation related to testing involves various processes used by pupils to monitor, evaluate and modify emotional experiences (Schutz et al., 2008). Pupils can influence the experience, expression or duration of an emotional response.

Schutz et al. (2008) constructed a scale for emotional regulation related to testing which explored different strategies including maintaining focus on the test; efforts to reduce tension; and emotion-focused activities. Using the Test Emotions Questionnaire (Pekrun et al., 2004) containing both pleasant (e.g. joy and hope) and unpleasant (e.g. anxiety and shame) emotions they demonstrated that emotional regulation in relation to testing accounted for 87% of the variance in unpleasant test emotions. Gumora and Arsenio (2002) also used a self-report measure of emotion-regulation to explore the interaction with emotionality and school performance. Through regression analysis, they proposed that emotional regulation acted as a suppressor variable in the relationship between self-reported negative affect and academic performance.

Further research has also found a relationship between working memory and self-regulation of emotional experiences, whereby individuals who were able to suppress expressions of negative and positive emotion had higher working memory capacity than those who were less able to suppress their emotions (e.g. Schmeichel, Volokhov & Demaree, 2008). Therefore it appears that emotional regulation is an important factor to consider when exploring potential moderators of the relationship between anxiety, working memory and academic performance.

Emotional regulation depends critically on an individual's ability to adjust physiological arousal on a momentary basis (Gross, 1998). A key system involved in this process is the autonomic nervous system (ANS). A flexible ANS allows for rapid modulation of physiological and emotional states in accordance with situational demands. In contrast, autonomic rigidity results in a lessened capacity to alter physiological and emotional responses in synchrony with changes in the environment (Appelhans & Lueckem, 2006). Research has indicated that heart rate variability (HRV) is an objective measure of an individual's ability to adjust physiological arousal and can identify regulated emotional responding (Appelhans & Lueckem, 2006).

Empirical research with HRV has generally supported the premise that higher HRV reflects a greater capacity for regulated emotional responses and has been associated with use of constructive coping strategies and adaptive responses to examination stress (Fabes & Eisenberg, 1997; Gross, 1998). Furthermore, Hansen, Johnsen, Sollers, Stenvik and Thayer (2004) found that higher levels of HRV were associated with improved and faster performance on working memory measures and continuous performance tests. It would therefore be useful to use HRV to explore the potential moderating impact of emotional regulation on the relationship between anxiety, working memory and performance. Owens et al. (submitted) found that levels of cortisol (a physiological indictor of individual differences in emotional regulation), moderated the relationship between emotion, working memory and academic performance so that it was more clearly negative in the high cortisol group. However, whereas testing cortisol is restricted to isolated time points, HRV can be monitored continuously to enable an on-line representation of emotional regulation.

Although HRV has been shown as an objective measure of emotional regulation, it is not easily applicable when considering how schools can identify those children who may be at greater risk from the detrimental effects of test anxiety. Instead, it would be useful to highlight behavioural indicators that help to identify children who are not able to regulate their emotions. Emotional regulation can be defined as monitoring or changing internal feeling states and physiological processes, as well as the behavioural concomitants of emotion (Eisenberg et al., 2000). Cole, Michel and Teti (1994), proposed that well-regulated individuals have the ability to respond to the ongoing demands of experience with a range of responses which allow the inhibition of behaviour. In contrast, individuals with low emotional regulation can be seen as overreactive in their emotional displays and therefore more likely to show externalising behaviours such as defiance and aggression. Research with both young children and adolescents has found support for this theory (e.g. Eisenberg et al., 2001; Zeman, Shipman & Suveg, 2002). Martel et al. (2007) examined the association between adolescent regulation, executive function and externalising behaviours in a high-risk sample of 498 children aged 12 to 14 years. They found that low levels of regulation and weak executive function predicted problem behaviour in children.

The link between emotional regulation and hyperactive behaviours was highlighted by Barkley's behavioural inhibition theory (Barkley, 1997). Barkley proposed that children with ADHD have deficits in behavioural inhibition; they also have difficulty restricting their emotional reactions to evocative situations. More recent research has supported this theory by demonstrating that compared with controls, children with ADHD were less effective at emotional regulation (Maedgen & Carlson, 2000; Walcott & Landau, 2004). Evidence has also demonstrated a link between deficits in working memory, particularly visuospatial working memory and ADHD (e.g. Martinussen et al., 2005; Martinussen & Tannock, 2006). Therefore, both conduct problems and hyperactivity/inattention appear to be important behavioural indicators of emotional regulation and are useful to consider when examining moderating variables in the relationship between anxiety, working memory and performance.

The central aim of the current study was to explore the application of PET and ACT to understanding the link between anxiety and performance for pupils with SEBD. It tested the hypothesis that there would be a negative relationship between anxiety and performance and that this relationship would be stronger for worry compared to emotionality. Furthermore, it investigated the mediating role of working memory in this relationship, where this mediating working memory model would be stronger for tasks involving the central executive compared with phonological loop or visuospatial sketchpad. A further aim of the study was to explore moderating variables that strengthen or weaken the mediating relationship. In particular this focused on emotional regulation with the prediction that the mediating relationship would be stronger for pupils with lower HRV and those identified as displaying higher levels of conduct problems and hyperactivity/inattention.

2.3. Method

2.3.1. Participants

Informed written parental consent was obtained for 24 pupils aged 12 to 14 years, 16 males and 8 females (mean age = 164 months, SD = 6.77 months, range = 154 to 176 months). Pupils were drawn from Year 8 and Year 9 of a secondary school situated in the south-east of England. Approximately 60% of parents who were approached agreed to let their children take part in the study. All 40 pupils who were initially invited to participate had been identified by the school as having Special Educational Needs (SEN) relating to SEBD based upon the stages identified in the SEN Code of Practice (Department for Education and Skills, 2001). All pupils were receiving additional curriculum support in relation to SEBD that included, for example, weekly social skills groups.

2.3.2. Design

A cross-sectional design was used to explore the relationships between anxiety, working memory and academic performance.

2.3.3. Materials

Self-report anxiety measures.

The State-Trait Anxiety Inventory for Children (STAIC; Spielberger, 1973) is a self-report measure designed to assess state and trait anxiety and contains two scales of 20 items. The state scale (see Appendix A1) explores how children feel at that particular moment in time. For example, I feel: Very calm, Calm, Not calm. The trait scale (see Appendix A2) consists of statements which indicate how the participants generally feel on a 3-point scale (1 = almost never, 2 = sometimes, or 3 = often). Recent research shows that the STAIC has good internal consistency for adolescent samples with Cronbach's alpha of .87 (state) and .88 (trait) reported by Kirisci and Clark (1996); and .75 (state) and .81 (trait) in the current sample. In addition, the STAIC shows good convergent and divergent validity (Muris, Merckelbach, Ollendick, King & Bogie, 2002) and test re-test reliability coefficients have been found to range from 0.44 to 0.94 (Essau & Barrett, 2001).

The Children's Test Anxiety Scale (CTAS; Wren & Benson, 2004; see Appendix A3) is a self-report instrument with 30 items where participants respond to each with one of four choices: Almost never, Some of the time, Most of the time, Almost always (scored from 1 to 4). Three sub-scales focus on thoughts (13 items), off-task behaviours (8 items) and autonomic reactions (9 items). The thoughts component includes various test-related worries; the autonomic scale refers to the perceptions of somatic responses to test-related stress; and the off-task behaviour scale looks at object manipulation and inattentiveness. Internal consistency has been found to be

0.92 for the overall scale, 0.76 for off-task behaviours, 0.82 for autonomic reactions, and 0.89 for the thoughts subscale (Wren & Benson, 2004). In the current sample, internal consistency was found to be .94, with Cronbach's alpha of .95, .76 and .84 for thoughts, off-task behaviours and autonomic reactions respectively. The construct validity of the scale has also been demonstrated recently with school-aged children (Wren & Benson, 2004).

The Revised Child Anxiety and Depression Scale (RCADS; Chorpita, Yim, Moffitt, Umemoto, & Francis, 2000; see Appendix A4) intends to assess symptoms of anxiety disorders and major depressive disorder. The scale consists of six subscales. The depression sub-scale was used which consists of 10 items asking participants to rate statements with four options: Never, Sometimes, Often, Always (scored from 0 to 3). The original scale included an item 'thinks about death' but this was not included in this study. Examination of reliability and validity revealed internal consistency of the subscale of 0.78 (Chorpita, Moffitt & Gray, 2005) and 0.79 for the current sample. One week test re-test coefficients ranged from 0.71 to 0.84 (Chorpita et al., 2000). The RCADS also been shown to have favourable convergent, discriminant and factorial validity (Chorpita et al., 2005).

Academic performance.

The National Curriculum Standard Assessment Tests (SATs) are indicators of academic competence that are taken in all schools in England. The tests use methods and materials developed and validated by the Qualifications and Curriculum Authority (QCA; 2008). Pupils take standardised tests in English, mathematics and science at the end of key stage 2, when they are aged 11 years. Although each subject area is comprised of several different tests, the overall mark for English, mathematics and science has a range of 0 to 100, with higher scores indicating better performance. The present study used raw scores for key stage 2 English, mathematics and science.

The Wide Range Achievement Test 4 (WRAT 4; Wilkinson & Robertson, 2006) is intended to measure the basic skills of reading, spelling and arithmetic. It is normed for children aged 12 to adults aged 64. Due to group administration only the spelling and arithmetic scales were used. The spelling sub-test requires the subject to spell 40 words from dictation. The arithmetic test involves written computations. Raw scores for spelling and mathematics were obtained by summing each correct response. The manual reports Cronbach's alpha internal consistencies of .90 for spelling and .97 for mathematics (Wilkinson & Robertson, 2006). The WRAT has also been shown to have good convergent and divergent validity with measures of academic achievement and cognitive ability (Wilkinson & Robertson, 2006).

Raven's Standard Progressive Matrices (SPM; Raven, Raven & Court, 2003) is a nonverbal test of educational ability. It offers insight about capacity to solve problems and learn. The test has a total of 60 items presented in 5 sets, with 12 items per set. For each test item, a participant is asked to identify the missing segment required to complete a larger pattern. Internal consistency studies result in values ranging from .60 to .98, with a median of .90. The median test-retest value is approximately .82. Concurrent validity coefficients between the SPM and measures of academic achievement and cognitive ability range between .54 and .88, with the majority in the .70s and .80s (Raven et al., 2003).

Verbal working memory tasks.

The Automated Working Memory Assessment (AWMA; Alloway, 2007) battery is a computer-based assessment comprised of 12 tests and is designed to tap the three components of working memory (Baddeley, 1986). The phonological loop task used was Forward Digit Recall. This task involves the child recalling a sequence of spoken digits. The first block of trials contains one digit and one digit is added over successive trials up to nine digits in total. The two tasks measuring both the phonological loop and central executive were Listening Recall and Backward Digit Recall. In the Listening Recall task, the child is presented with a series of spoken sentences and is required to verify the sentence by stating ‘true’ or ‘false’, before recalling the final word for each sentence in sequence. The first block of trials contains one sentence and one sentence is then added over successive trials up to six sentences in total. In the Backward Digit Recall task, the child is required to recall a sequence of spoken digits in reverse order. The first block of trials contains two digits and one digit is added over successive trials, up to seven digits in total. Scoring for each task is automated by the software.

The AWMA has been found to have acceptable test-retest reliability, tested at four weeks apart, with correlations of .84, .81 and .64 for digit recall, listening recall and backward digit recall respectively (Alloway, Gathercole & Pickering, 2006). Furthermore, the construct stability and diagnostic validity of the AWMA has recently been demonstrated (Alloway, Gathercole, Kirkwood & Elliott, 2008).

Visuospatial working memory tasks.

The Cambridge Automated Neuropsychological Test Battery (CANTAB; 2004) uses non-verbal tasks to measure a range of executive functions. The CANTAB was developed at the University of Cambridge (see Fray, Sahakian & Robbins, 1996; Sahakian & Owen, 1992). The Spatial Span task was used from the CANTAB. This task is a computerised version of the Corsi blocks (Milner, 1971) tapping test. Children are asked to follow sequences of squares that light up on the screen (minimum 2, maximum 9) and then copy the sequence after the computer has finished. The forward version of this test was used to provide a measure of the visuospatial sketchpad and the backward version was used to provide a measure both the visuospatial sketchpad and central executive as this involved the more complex task of storing and then reversing the sequences. Scoring on the tasks is automated by the software.

The neural correlates of the CANTAB tasks have been studied and validated in neuroimaging studies with adults (Baker et al., 1996; Sahakian & Owen, 1992). More recently, the validation of the CANTAB for use with children has been established (Luciana & Nelson, 2002).

Heart rate variability.

A finger-pulse sensor was used to measure the cardiovascular pulse wave, detected through photoplethysmography (PPG) which identifies changes in blood volume. Recent research has demonstrated that PPG provides rich cardiovascular information that can be used to estimate heart rate variability and is as reliable as data extracted from an electrocardiogram (Lu et al., 2008; Srinivas, Ram Gopal Reddy & Srinivas, 2007; Wickramasinghe & Spencer, 2000). The sensor clipped to the palmer surface of the fingertip of the non-dominant hand.

Emotional and behavioural difficulties.

The Strength and Difficulties Questionnaire (SDQ; Goodman, 1997; see Appendix A5) is a one-page questionnaire for assessing the psychological adjustment of children and adolescents. Twenty-five items are divided between five scales: emotional symptoms, conduct problems, hyperactivity/inattention, peer relationship problems and prosocial behaviour. Respondents use a 3-point scale: Not true, Somewhat true, Certainly true (scored 0 to 2) which can be totalled for each sub-scale. The parent and self-report scales were used in the current study with each sub-scale except prosocial behaviour scored. Goodman (2001) found that reliability was generally satisfactory, whether judged by internal consistency (mean Cronbach's alpha: 0.73), or retest stability after 4-6 months (mean: 0.62). Internal consistencies for the current sample were satisfactory for each sub-scale for parent-reports (between .77 and .79). For the self-report scale, internal consistencies were satisfactory for peer relationship problems (.71) but low for emotional symptoms (.35), conduct problems (.48) and hyperactivity/inattention (.35). Due to the low internal reliability of the self-report data, only the parent-report data was used in the analysis.

2.3.4. Procedure

Ethics approval was obtained from the School of Psychology Ethics' Committee at the University of Southampton. An up-to-date Criminal Records Bureau check for working with children was provided as well as a Risk Assessment form.

This study took place over two sessions. Each participant began the session by completing a consent form (See Appendix B). It was made clear that they did not have to take part in the study and that they were free to leave at any time.

The first session involved groups of six to eight participants who completed the Ravens SPM task and the WRAT spelling and arithmetic tasks. Presentation of the Ravens and WRAT tasks were counterbalanced across participants. The standardised procedures set out in the manuals for group testing were followed and the participants recorded their responses in the answer booklets provided. The pupils were given 30 minutes to complete the Ravens SPM, and 20 minutes to complete the WRAT arithmetic task. The spelling task took approximately 20 minutes with a 15 second gap between each word that was read out by the researcher.

The second session involved individual testing. This took place on a separate day to the group testing. Each participant was assessed for around 50 minutes in a section of the school away from other pupils. Following the informed consent procedures, participants completed the SDQ following the standard instructions.

Participants were then introduced to the heart rate monitoring equipment. The monitor was connected to the index finger of the non-dominant hand. A baseline period of 5 minutes then followed to measure resting heart rate. During the baseline, participants were asked to sit back and relax. The experimenter recorded the start and finish of the baseline period using an event marker.

Following the baseline, participants were introduced to the working memory tasks. These were all presented on a laptop computer. The heart rate monitor continued to record data throughout the working memory tasks, for a total period of approximately 30 minutes. Each change in activity was recorded by the experimenter using an event marker. Presentation of the AWMA and CANTAB tasks were counterbalanced across the participants. For the AWMA tasks, the participants followed the automated instructions on the computer programme. For the CANTAB tasks, the participants were introduced to the forward spatial task practice items with: “you will see some of these boxes change colour, when the computer beeps, you need to select the boxes in the sequence you just saw, following exactly what the computer did.” They were introduced to the backward spatial task practice items with: “now you need to do the same as before, but this time you have to trace backwards through the sequence, so the one you saw last you select first and so on."

Once the working memory tasks were completed, participants were asked to rest again for 5 minutes in order to obtain a resting measurement of heart rate. The participants were then asked to remove the heart rate monitor from their finger. Finally, the participants were asked to complete the state and trait anxiety questionnaires followed by the RCDAS and the CTAS. Each was introduced following the standard administration instructions.

The parent version of the SDQ was sent home and completed by parents independently along with the consent form (For parent letter and consent form see appendix C). Results of the SATs tests that had already been administered were collected from school.

2.4. Data Analysis

2.4.1. Structural Equation Modelling

A structural equation modelling (SEM) analysis of the data was undertaken. SEM was selected as a statistical methodology because of its advantages over regression modelling, including: the ability to test models with latent variables and with multiple dependents; the ability to test models overall rather than coefficients individually; and the ability to model mediating variables rather than be restricted to an additive model as in regression (Garson, 2008).

SEM assumes that sample size is adequate. Estimates vary for this, but generally range from between 5 and 20 times the number of variables in the model (Garson, 2008). Data is also assumed to be interval and normally distributed. When these assumptions cannot be met, as with the present study, then it is recommended that bootstrapped estimates are used. In the present study, 1000 bootstrapped re-samples were requested by default.

SEM allows indictors in the study to make up latent variables. Two indicators or a single indicator is thought to be acceptable if the measure has evidence of validity and reliability (Garson, 2008). A number of goodness of fit tests can also be used to determine if the model being tested should be accepted or rejected. Authors generally recommend reporting chi-square (χ^2), the Comparative Fit Index (CFI) and the Root Mean Square Error Approximation (RMSEA) (Garson, 2008; Kline, 1998; McDonald & Ho, 2002). The χ^2 value should not be significant if there is a good model fit. Because χ^2 is affected by sample size, the χ^2 ratio is also reported (χ^2/df); which will be less than 2 in a well fitting model (Tabanchnick & Fidell, 2007). CFI compares the existing model fit with a null model which assumes the latent variables in the model are uncorrelated. CFI close to 1 indicates a very good fit. CFI should be equal to or greater than .90 to accept the model, indicating that 90% of the covariation in the data can be reproduced by the given model (Garson, 2008). RMSEA is thought to correct for model complexity. An RMSEA value of less that .05 indicates a very good fit, and values between .05 and .10 suggest a moderate fit (Bollen & Curren, 2006).

As a further test of the models, a chi-square difference test ($\Delta\chi^2$) assessed the change of fit when a nested model was specified that constrained weights for the paths to and from the mediator to be zero. This provided a test of the null hypothesis that mediation by working memory would not significantly add to the model. A significant $\Delta\chi^2$ indicates that the inclusion of the mediating path improves the model fit

2.4.2. Heart Rate Variability

The PPG produced a continuous measure of heart rate. After collection, the series of interbeat intervals were corrected for abnormal beats. Two datasets were discounted due to high levels of erroneous data. Software was used to define the interbeat intervals for the remaining 22 datasets in milliseconds. The standard deviation of these intervals was taken as a measure of heart rate variability across a 5-minute segment both before testing (time 1) and during testing (time 2) (Appelhans & Lueckem, 2006).

The moderated mediation hypothesis was assessed using a multi-group analysis, where heart rate variability taken during testing was split to produce low and high variability groups. Further moderation effects were explored for parent-rated conduct problems and hyperactivity/inattention using the same multi-group analysis where SDQ scores for each were split to produce low and high groups.

2.5. Results

2.5.1. Descriptive Statistics

Anxiety and Depression measures

Table 1 shows the descriptive statistics for the self-report anxiety and depression measures. Scores for the STAIC State and Trait measures can range between 20 and 60. Comparing the mean scores with normative data (Spielberger et al., 1983) the current sample is at about the 67th percentile for state anxiety and 32nd percentile for trait anxiety. For the CTAS, scores for Thoughts could range from 13 to 52; Behaviours from 8 to 32 and Autonomic from 9 to 36. Based on available normative data (Wren & Benson, 2004) the current sample is at the 60th, 86th and 54th percentile for Thoughts, Behaviours and Autonomic respectively. The maximum score for RCADS Depression was 27; comparing the scores to the normative data (Chorpita et al., 2000), the sample in this paper is at about the 66th percentile.

Table 1

Means, standard deviation, range, distribution, z-scores and percentiles for self-report anxiety and depression

Measure	Mean	(SD)	Range	Distribution[a]	z-score[b]	percentile
STAIC State	32.04	(4.68)	22-39	1.00	.40	67th
STAIC Trait	34.21	(6.37)	22-49	.56	-.50	32nd
CTAS Thoughts	31.29	(10.84)	14-50	.71	.25	60th
CTAS Behaviours	22.25	(5.12)	10-32	.72	1.11	86th
CTAS Autonomic	16.63	(5.59)	10-30	.69	.12	54th
RCADS Depression	8.96	(6.00)	1-24	.68	.40	66th

Note. N = 24. STAIC = state-trait anxiety inventory for children; CTAS = Child Test Anxiety Scale; RCADS = revised child anxiety and depression scale.
[a]Kolmogorov-Smirnov test for normality of distribution . [b]Represents number of standard deviations sample mean is above or below normative mean.

Performance measures.

Table 2 shows the descriptive statistics for each academic performance measure. For the WRAT tests, pupils were given a score that indicated the number of correct responses out of 55 for mathematics and 57 for spelling. Comparing the scores to the normative data (Wilkinson & Robertson, 2006) shows that the sample in the paper is at about the 13th percentile for mathematics and 27th percentile for spelling. For the SATs tests, raw scores are available for each subject area with a maximum score of 100 for English and mathematics and science. National performance indicators (QCA, 2008) suggest that pupils at key stage 2 are expected to achieve in the range of 43 and 68 for English; 45 and 77 for mathematics and 41 to 63 for science. The scores for each pupil within the current sample fell below the expected range for each subject. The Ravens SPM test has a maximum score of 60. Comparing to normative data (Raven et al., 2003), the sample in this paper is approximately at the 25th percentile.

Table 2

Means, standard deviations, range, distribution, z-scores and percentiles for academic performance

Measure	Mean	(SD)	Range	Distribution[a]	z-score[b]	Percentile
WRAT Maths	28.92	(6.36)	18-38	.78	-1.18	13th
WRAT Spelling	31.71	(5.60)	19-40	.46	-.60	27th
SAT Maths	23.25	(5.99)	9-30	.21	-	-
SAT English	22.88	(6.41)	9-31	.21	-	-
SAT Science	27.21	(5.27)	13-33	.23	-	-
SPM Ravens	42.83	(9.52)	14-54	.37	-.65	25th

Note. N = 24 WRAT = Wide Range Achievement Test; SAT = Standard Assessment Tests; SPM = Standard Progressive Matrices.

[a]Kolmogorov-Smirnov test for normality of distribution. [b]Represents number of standard deviations sample mean is above or below normative mean.

Working memory.

Table 3 shows the descriptive statistics for each working memory measure. The Kolmogorov-Smirnov test was significant for CANTAB forward spatial span, indicating that the data is not normally distributed. For the digit span tasks, the maximum number of digits correctly repeated was 52 for forward digit span and 48 for backward digit span. For the listening recall test, the maximum number of words repeated correctly was 48. Comparing the total scores to the normative data (Alloway, 2007) indicates that the sample in this paper is at about the 57th percentile for forward digit, 34th percentile for backward digit and 75th percentile for listening recall. For the CANTAB forward and backward spatial span, the scores indicated the number of moves correctly repeated out of a total of 9 for each. Comparing the total scores to normative data (Fray et al., 1996) the sample in this paper is at about the 25th and 18th percentile for forward spatial span and backward spatial span respectively.

Table 3

Means, standard deviation, range, distribution, z-scores and percentiles for working memory

Measure	Mean	(SD)	Range	Distribution[a]	z-score[b]	Percentile
AWMA FD	29.88	(4.57)	22-45	.80	.20	57th
AWMA BD	12.00	(4.09)	6-23	.63	-.40	34th
AWMA LR	14.33	(5.16)	5-29	.91	.70	75th
CANTAB FSS	5.54	(0.78)	5-7	1.87**	-.72	25th
CANTAB BSS	5.21	(1.47)	2-8	1.00	-.95	18th

Note. N= 24. AWMA = Automated Working Memory Assessment; FD = forward digit; BD = backward digit; LR = listening recall; CANTAB = Cambridge Neurological Test Battery; FSS = forward spatial span; BSS = backward spatial span.
[a]Kolmogorov-Smirnov test for normality of distribution. [b]Represents number of standard deviations sample mean is above or below normative mean
**<.01

Heart rate variability.

The data for heart rate variability was recorded in milliseconds and represents the variance in inter-beat intervals across a five-minute period. The current sample had a mean variance of 160.31 (SD = 71.23; range = 75 - 326) at time 1 and 153.17 (SD = 52.10; range = 76 - 287) at time 2. The Kolmogorov-Smirnov test produced distribution scores of .34 at time 1 and .28 at time 2. Previous research suggests that general cut-off points for low and high variability for adults is 70 and 100 respectively (Bilchick & Berger, 2006). Compared to a normative sample of 920 Chinese children (Ma et al., 2007) the current sample is approximately at the 66th percentile at Time 1 and 58th percentile at Time 2.

Social, emotional and behavioural difficulties measures.

Table 4 shows the descriptive statistics for parent-rated social, emotional and behavioural difficulties. Scores for each scale were out of a total of 10. Normative data is available (Goodman, 2001) which illustrates for each subscale whether the score is at a ‘normal’, ‘borderline’ or ‘abnormal’ level. For the sample in this paper, the mean parental ratings of emotional symptoms lie in the ‘normal range’; ratings of conduct problems, hyperactivity/inattention and peer problems lie in the borderline range.

Table 4

Means, standard deviation, range and distribution for parent-rated social, emotional and behavioural difficulties

Measure	Mean	(SD)	Range	Distribution[a]
SDQ Emotional symptoms	3.38	(3.00)	0-10	.99
SDQ Conduct problems	3.71	(2.56)	0-10	1.00
SDQ Hyperactivity	6.33	(2.58)	2-10	.69
SDQ Peer problems	3.21	(2.83)	0-8	1.01

Note. N = 24. SDQ = Strength and Difficulties Questionnaire
[a]Kolmogorov-Smirnov test for normality of distribution

2.5.2. Associations

The patterns of associations between study variables were analysed using Pearson correlation coefficients (r). The correlational results are presented in Table 5.

The self-report anxiety and depression variables were positively associated (r = .11 to .77). These associations were all significant with the exception of CTAS thoughts with both STAIC state anxiety (r = .11) and trait anxiety (r = .36). The academic performance variables were all significantly associated with positive intercorrelations ranging from r = .45 to r = .85.

There were mixed correlations between the self-report anxiety and depression measures with academic performance measures. The three CTAS measures were all negatively associated with the performance measures, with CTAS thoughts significantly associated with each performance measure with the exception of WRAT spelling (r = -.35). CTAS behaviours and autonomic responses were significantly correlated with only

WRAT mathematics (r = -.41). STAIC state anxiety was positively associated with each performance measure but these correlations were not significant (r = .10 to .38). STAIC trait anxiety showed low correlations with each performance measure. RCADS depression showed positive correlations with each performance measure except WRAT mathematics (r = .20), however these associations were not significant (r = .02 to .25).

The working memory measures were all positively associated, with each of the correlations being significant (r = .48 to .75) with the exception of AWMA forward digit and CANTAB forward span (r = .17) and CANTAB forward span and CANTAB backward span (r = .39). The associations between working memory and performance measures were mixed. AWMA forward and backward digit were positively associated with all performance measures (range r = .08 to .52); associations with SAT mathematics and WRAT spelling being significantly correlated. AWMA listening recall was also positively associated with each performance measure (r = .11 to .46) and the association with SAT mathematics was significant. CANTAB forward span was positively associated with SAT mathematics, SAT English, WRAT spelling and Ravens SPM, these correlations were not significant (r = .17 to .27). CANTAB backward span was positively associated with all performance measures; correlations were significant with SAT mathematics (r = .41), WRAT mathematics (r = .56), WRAT spelling (r = .51) and Ravens SPM (r = .49).

The relationships between self-report anxiety and depression measures and the working memory measures also showed a mixed pattern with none of these correlations being significant. STAIC state anxiety was positively associated with AWMA forward digit and weakly associated with the other working memory measures (r = -.02 to .08). STAIC trait anxiety was negatively associated with AWMA listening recall (r = -.17) and weakly associated with the other measures (r = -.02 to .08). CTAS thoughts was negatively associated with AWMA forward digit (r = -.19) and CANTAB backward span (r = -.32) and weakly associated with the other measures (r = -.05 to -.15). CTAS behaviours was negatively associated with CANTAB backward span (r = .22) and weakly associated with the other measures (range = r = -.01 to .15). CTAS autonomic reactions and RCDAS depression were weakly associated with all measures (r = -.12 to .11).

Heart rate variability at time 1 and 2 showed inconsistent associations with performance measures and working memory measures; and negative associations with self-report anxiety and depression measures. None of these associations reached significant levels.

Parent-rated SDQ measures were all positively associated with each other; these correlations were significant with the exception of SDQ emotional symptoms and SDQ hyperactivity/inattention (r = .38); SDQ conduct problems and SDQ peer problems (r = .23). Significant relationships were found between SDQ conduct problems and CTAS thoughts (r = .53) and SDQ hyperactivity/inattention and CTAS autonomic reactions (r = .43).

Parent-rated SDQ measures were negatively associated with each academic performance measure. Significant associations were found between SDQ emotional symptoms with WRAT spelling (*r* = -.46) and SAT mathematics (*r* = -.41); SDQ conduct problems with each performance measure (range = *r* = -.57 and -.81); SDQ hyperactivity/inattention with WRAT mathematics (*r* = -.45), SAT mathematics (*r* = -.46) and SAT English (*r* = -.45); SDQ peer problems and SAT English (*r* = -.47). There were mixed associations between parent-rated SDQ measures and working memory measures; significant correlations were found between SDQ conduct problems and AWMA backward digit (*r* = -.41), AWMA listening recall (*r* = -.47) and CANTAB backward span (*r* = -.42).

The correlations with age in months were small with most of the variables in the study having a correlation coefficient of less than .20. This may reflect the small variation in age of participants from 12 to 14 years. The largest correlations were WRAT mathematics (*r* = .23), state anxiety (*r* = -.28) and AWMA forward digit (*r* = -.30) however no correlations reached statistically significant levels.

Table 5.

Zero-order Correlations Between Performance, Anxiety and Working Memory

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1. SAT Maths	-	.85**	.75**	.56**	.70*	.63**	.33	-.05	-.58**	-.01	-.22	.02	.31	.26	.43*	.43*	.46*	.22	.41*	-.41*	-.81**	-.46*	-.34	.04
2. SAT English	-	-	.71**	.60**	.71**	.60**	.35	.11	-.45*	-.03	-.23	.12	-.03	-.05	.33	.25	.33	.17	.29	-.40	-.61**	-.45*	-.47*	.11
3. SAT Science	-	-	-	.45**	.70**	.63**	.28	-.06	-.61**	-.16	-.23	.02	-.00	.26	.29	.08	.22	-.01	.15	-.37	-.65**	-.39	-.29	.07
4. WRAT Maths	-	-	-	-	.61**	.57**	.10	.02	-.55**	-.41*	-.41*	-.20	-.11	-.13	.38	.40	.11	-.02	.56**	-.25	-.59**	-.45*	-.03	.23
5. WRAT Spelling	-	-	-	-	-	.79**	.38	.05	-.35	-.02	-.03	.25	-.05	-.03	.52**	.42*	.36	.27	.51**	-.46*	-.57**	-.18	-.14	.20
6. Ravens SPM	-	-	-	-	-	-	.37	-.05	-.43*	-.11	-.04	.14	.08	.04	.35	.33	.15	.20	.49*	-.40	-.57**	-.06	-.05	-.01
7. STAIC State	-	-	-	-	-	-	-	.50*	.11	.62**	.44*	.65**	-.15	-.17	.30	.05	.03	.08	-.02	-.24	-.24	-.06	-.05	-.28
8. STAIC Trait	-	-	-	-	-	-	-	-	.36	.56**	.52**	.64**	-.26	-.12	.05	-.02	-.17	-.08	-.07	.31	.22	.28	-.06	.13
9. CTAS Thoughts	-	-	-	-	-	-	-	-	-	.55**	.77**	.49*	-.08	-.28	-.19	-.09	-.15	-.05	-.32	-.03	.53**	.32	-.13	.03
10. CTAS Behaviours	-	-	-	-	-	-	-	-	-	-	.66**	.63**	-.01	-.06	.15	.07	-.01	.05	-.22	-.01	.13	.20	-.17	-.16
11. CTAS Autonomic	-	-	-	-	-	-	-	-	-	-	-	.79**	-.00	-.06	.04	-.01	-.07	-.01	-.12	-.17	.34	.43*	-.11	-.06
12. RCADS Depression	-	-	-	-	-	-	-	-	-	-	-	-	-.29	-.12	.11	-.05	.00	.09	-.12	.01	.23	.24	-.20	-.03
13. HR Variability 1	-	-	-	-	-	-	-	-	-	-	-	-	-	.40	-.06	.39	.25	.21	.34	-.34	-.36	-.18	-.12	-.03
14. HR Variability 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-.18	-.06	.11	-.08	.18	.01	-.41	-.14	-.23	.07
15. AWMA FD	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.61**	.59**	.17	.51*	-.16	-.39	-.06	.06	-.30
16. AWMA BD	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.58**	.48*	.75**	-.05	-.41*	-.02	.18	-.12
17. AWMA LR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.55**	.49*	-.25	-.47*	-.23	-.11	-.15
18. CANTAB FS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.39	-.05	-.07	.19	.11	.12
19. CANTAB BS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-.19	-.42*	-.05	.07	-.01
20. SDQ Emotional	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.44*	.38	.54**	.05
21. SDQ Conduct	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.54**	.23	.11
22. SDQ Hyperactivity	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.48*	-.08
23. SDQ Peer	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-.22
24. Age months	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Note. N = 24 (HR Variability N = 22). WRAT = Wide Range Achievement Test; SAT = Standard Assessment Tests; SPM = Standard Progressive Matrices; AWMA = Automated Working Memory Assessment; FD = forward digit; BD = backward digit; LR = listening recall; CANTAB = Cambridge Neurological Test Battery; FS = forward span; BS = backward span; STAIC= state-trait anxiety inventory for children; CTAS = Child Test Anxiety Scale; HR = heart rate; RCADS = revised child anxiety and depression scale; SDQ = Strength and Difficulties Questionnaire. *p<.05; **p<.01.

2.5.3. Structural Equation Modelling

Anxiety and performance.

In order to test the hypothesis of a negative association between anxiety and performance, the structural model in Figure 1 was tested. The model did not include STAIC trait anxiety or RCDAS depression as Table 5 indicates that these measures were weakly correlated to academic performance.

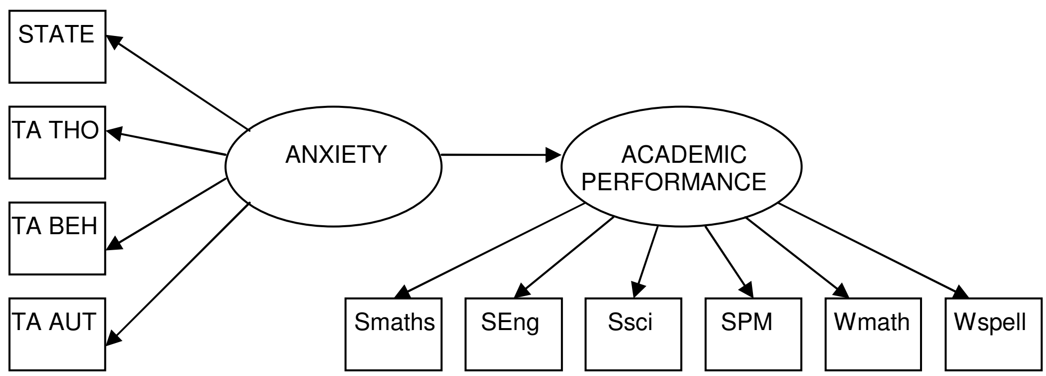

Figure 1. An illustration of the model hypothesising a negative association between self-report anxiety and academic performance. STATE = state anxiety as measured by the STAIC-S. TA THO = test anxiety thoughts; TA BEH = test anxiety behaviours; TA AUT = test anxiety autonomic reactions as measured by the CTAS. Smaths, SEng and Ssci are maths, English and science SAT KS2 results. SPM = standard progressive matrices. Wmath and Wspell are maths and spelling subsets of the WRAT.

The anxiety-academic performance model (Figure 2) was not a good fit to the data (χ^2 = 79.90, df = 34, χ^2/df = 2.35, p < .001, CFI = .73, RMSEA = .24) The chi-square test was significant and the ratio between chi-square and degrees of freedom was greater than 2. CFI was too low and RMSEA too high to indicate a well-fitting model. The direct path between anxiety and academic performance was not significant (β = -.28, p = .35).

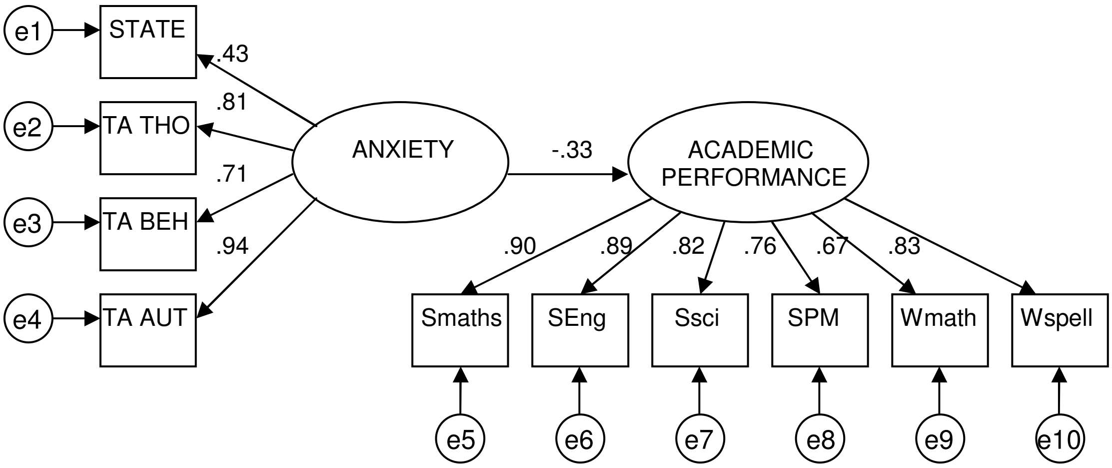

Figure 2. A structural equation model diagram showing the relationship between self-report anxiety and academic performance. STATE = state anxiety as measured by the STAIC-S. TA THO = test anxiety thoughts; TA BEH = test anxiety behaviours; TA AUT = test anxiety autonomic reactions as measured by the CTAS. Smaths, SEng and Ssci are maths, English and science SAT KS2 results. SPM = standard progressive matrices. Wmath and Wspell are maths and spelling subsets of the WRAT.

Table 5 indicates that STAIC state anxiety was not significantly correlated with any performance measure. In addition, no anxiety measure was significantly correlated with WRAT spelling, therefore it was hypothesised that excluding STAIC state anxiety and WRAT spelling from the analysis would improve model fit. This model (Figure 3) was a better fit to the data, (χ^2 = 36.04, *df* = 19, χ^2 /*df* = 1.89, $p < .01$, CFI = .86, RMSEA = .20) and the path between anxiety and performance reached significance (β = -.61, $p < .001$); however chi-square was still significant and CFI and RMSEA were not at adequate levels to accept this model.

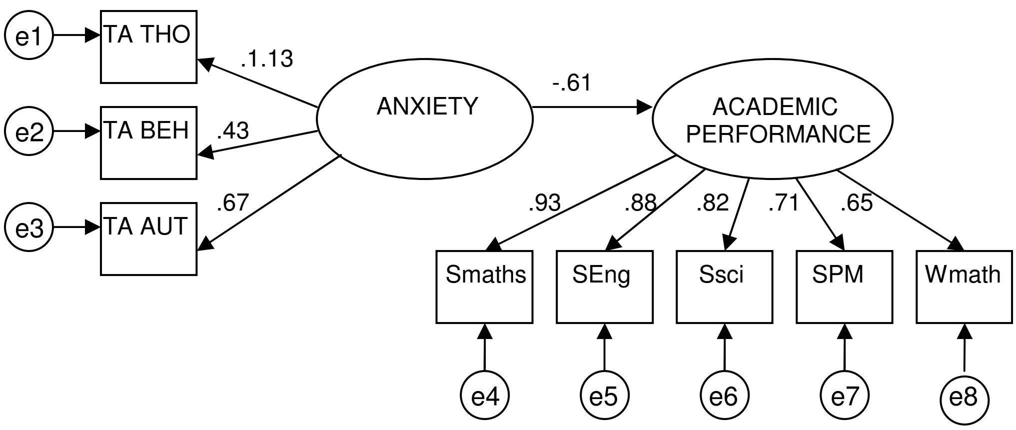

Figure 3. A revised structural equation model showing the relationship between test anxiety and academic performance. TA THO = test anxiety thoughts; TA BEH = test anxiety behaviours; TA AUT = test anxiety autonomic reactions as measured by the CTAS. Smaths, SEng and Ssci are maths, English and science SAT KS2 results. SPM = standard progressive matrices. Wmath = maths subset of the WRAT.

Worry and performance.

In order to test the hypothesis of an association between worry and performance, the structural model in Figure 4 was tested with test anxiety thoughts as a single indicator.

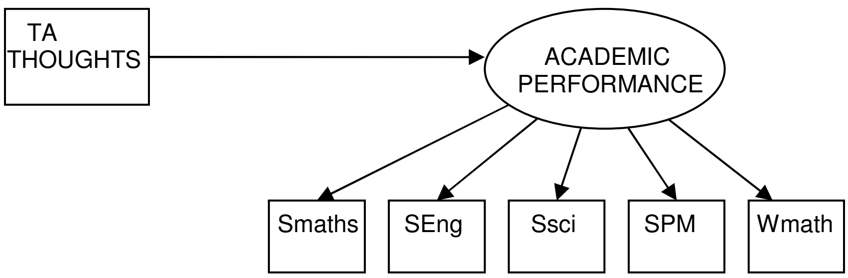

Figure 4. An illustration of the hypothesised model showing a negative association between test anxiety thoughts and academic performance. TA THO = test anxiety thoughts as measured by the CTAS. Smaths, SEng and Ssci are maths, English and science SAT KS2 results. SPM = standard progressive matrices. Wmath = maths subset of the WRAT.

This model (Figure 5) was an excellent fit to the data as chi-square proved to not be significant and also CFI was close to 1, (χ^2 = 10.97, df = 9, χ^2/df = 1.23, p = .28, CFI = .98, RMSEA = .09). The path between test anxiety and performance was also significant (β = -.62, $p < .001$). Further models with off-task behaviour (β = -.09, $p = .56$) and autonomic responses (β = -.21, $p = .28$) as single indicators were explored and the direct paths were found to be not significant.

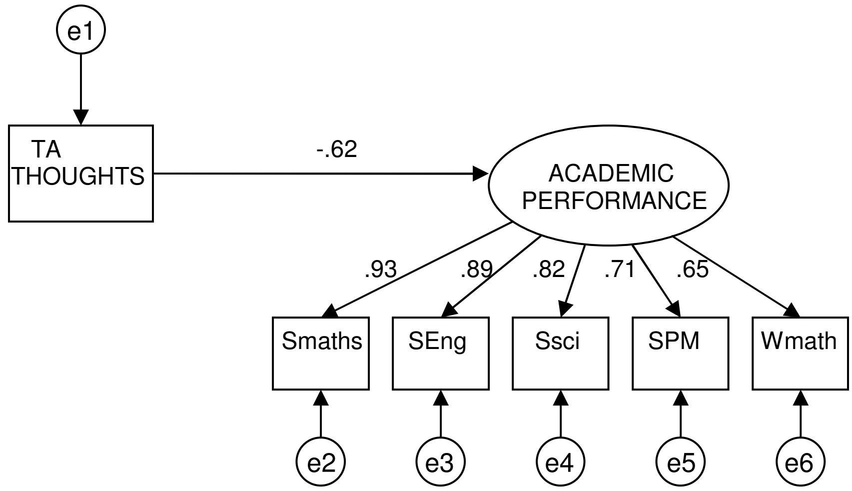

Figure 5. The structural equation model showing the relationship between test anxiety thoughts and academic performance. TA THO = test anxiety thoughts as measured by the CTAS. Smaths, SEng and Ssci are maths, English and science SAT KS2 results. SPM = standard progressive matrices. Wmath = maths subset of the WRAT.

Working memory as a mediator of the anxiety-performance relationship.

In order to explore the role of working memory as a mediator of the negative relationship found in the anxiety-performance model in Figure 5, spatial and verbal working memory were considered separately. It was expected that there would be a negative indirect path from test anxiety thoughts via working memory to the academic performance variable. According to ACT the mediating effect would be stronger for tasks involving the central executive.

Figure 6 shows the hypothesised visuospatial working memory mediation model. The hypothesised model includes the backward spatial span as a measure involving the central executive (as opposed to the forward spatial span thought to involve just the visuospatial sketchpad).

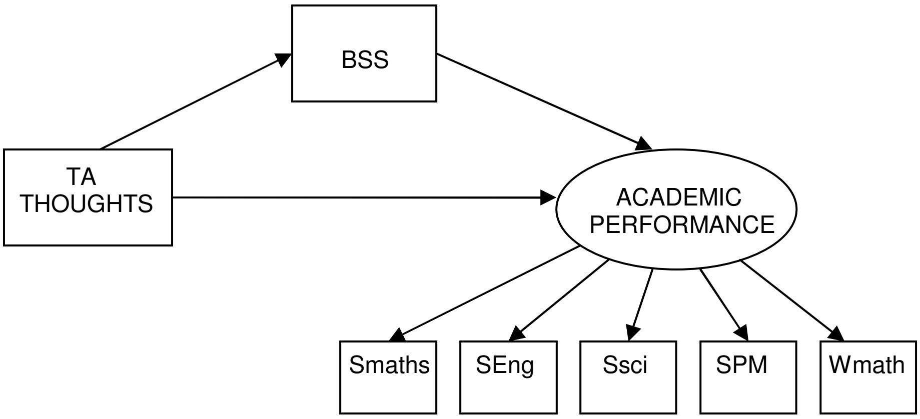

Figure 6. An illustration of the hypothesised visuospatial working memory model.
TA THOUGHTS = test anxiety thoughts as measured by the CTAS. Smaths, SEng and Ssci are maths, English and science SAT KS2 results. SPM = standard progressive matrices as measured by Ravens. Wmath = maths subset of the WRAT; BSS = backward spatial span as measured by CANTAB.

The model (Figure 7) was not an acceptable fit to data (χ^2 = 22.41, *df* = 13, χ^2 /*df* = 1.72, *p* = .05, CFI = .90, RMSEA = .17) and the indirect path was not significant (β = -.08, *p* = .10).

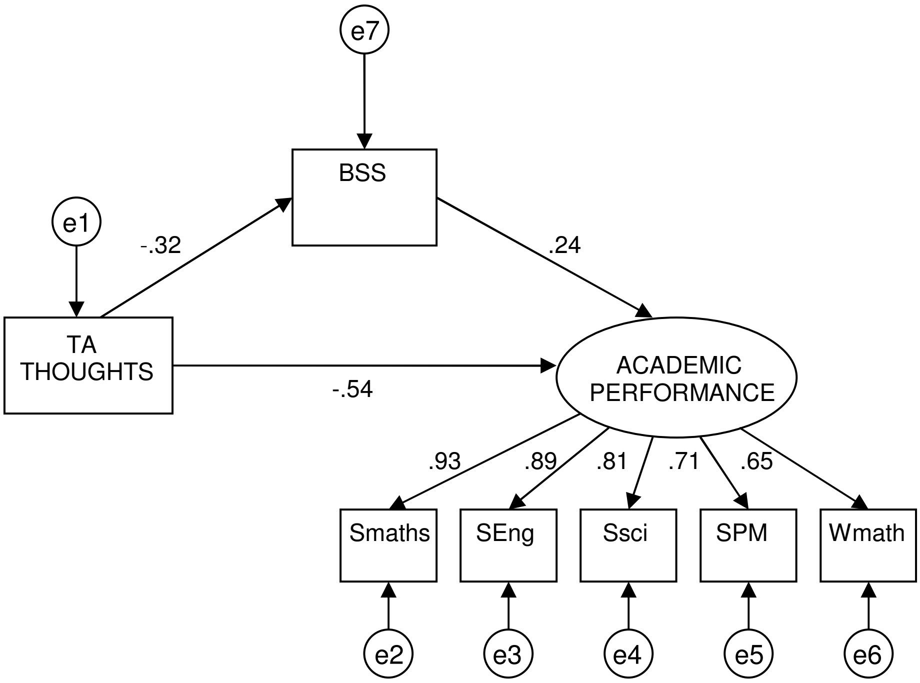

Figure 7. The structural equation model showing the relationship between anxiety, visuospatial working memory and academic performance. TA THOUGHTS = test anxiety thoughts as measured by the CTAS. Smaths, SEng and Ssci are maths, English and science SAT KS2 results. SPM = standard progressive matrices as measured by Ravens. Wmath = maths subset of the WRAT. BSS = backward spatial span as measured by CANTAB.

In order to explore the data further, a hypothesis was made that as visuospatial working memory would be more likely to influence mathematical performance and non-verbal pattern-based tasks, excluding SAT English and SAT science from the analysis would improve the model fit. This revised model (Figure 8) was an excellent fit to the data (χ^2 = 2.57, *df* = 4, χ^2 /*df* = .64, *p* = .63, CFI = 1, RMSEA = 0) and the indirect path was significant (β = -.15, *p* = .04). In addition, a model constraining the paths to and from CANTAB backward spatial span proved to be a significantly worse fit to the data than the unconstrained model ($\Delta\chi^2$ = 8.89, Δdf = 2, *p* = .01). As a final test of the role of central executive as mediator compared to the visuospatial sketchpad, the revised model was run with forward spatial span as the single indicator of spatial working memory and the indirect path proved not to be significant, (β = -.01, p = .56)

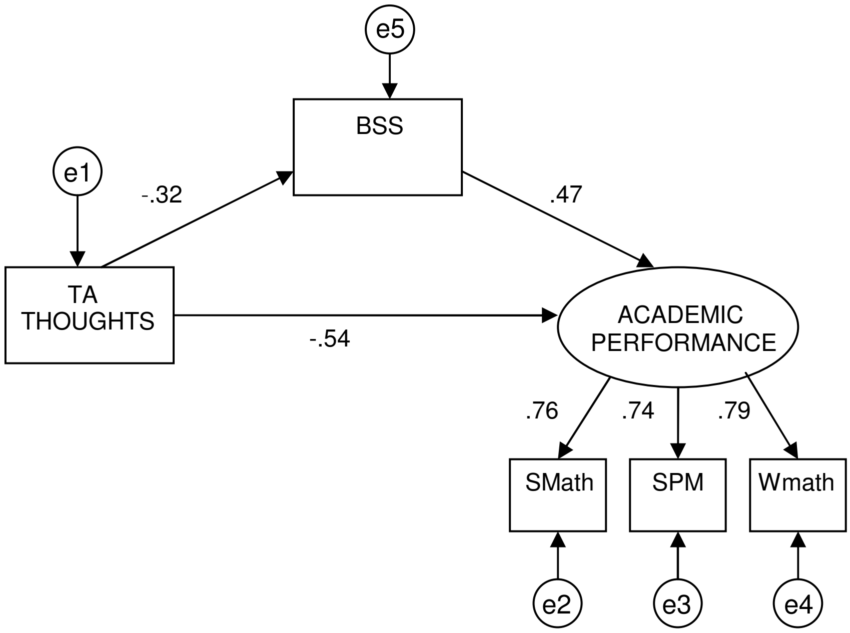

Figure 8. The revised visuospatial working memory model. TA THOUGHTS = test anxiety thoughts as measured by the CTAS. Smaths is maths SAT KS2 results. SPM = standard progressive matrices. Wmath = maths subset of the WRAT. BSS = backward spatial span.

Figure 9 shows the hypothesised verbal working memory mediation model. The model included backward digit recall and listening recall as measures of the central executive, forward digit span was not included as this is thought not to include the central executive.

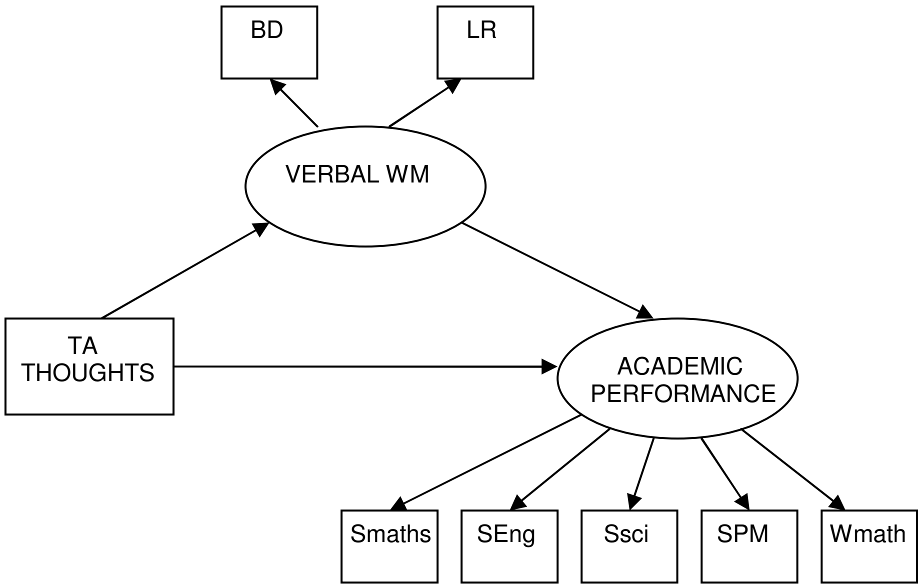

Figure 9. An illustration of the hypothesised verbal working memory model. TA THOUGHTS = test anxiety thoughts as measured by the CTAS. Smaths, SEng and Ssci are maths, English and science SAT KS2 results. SPM = standard progressive matrices. Wmath = maths subset of the WRAT. WM = working memory. BD = backward digit span, LR = listening recall as measured by AWMA.

The model (Figure 10) was a moderate fit to the data (χ^2 = 27.58, *df* = 18, χ^2 /*df* = 1.52, *p* = .07, CFI = .90, RMSEA = .15), however the indirect path was not significant (β = -.04, *p* = .33). In order to explore the model further a hypothesis was made that, as verbal working memory is associated with literacy development, excluding SPM and WRAT mathematics would improve the model as these tasks are not literacy-based. This model was a similar fit to the data (χ^2 = 8.92, *df* = 7, χ^2 /*df* = 8.92, *p* = .26, CFI = .97, RMSEA = .11) and the indirect path was again not significant (β = -.08, *p* = .18). As a final test of verbal working memory as a mediator, a model was run with SAT English as a single outcome measure. The indirect path was not found to be significant (β = -.05, *p* = .28).

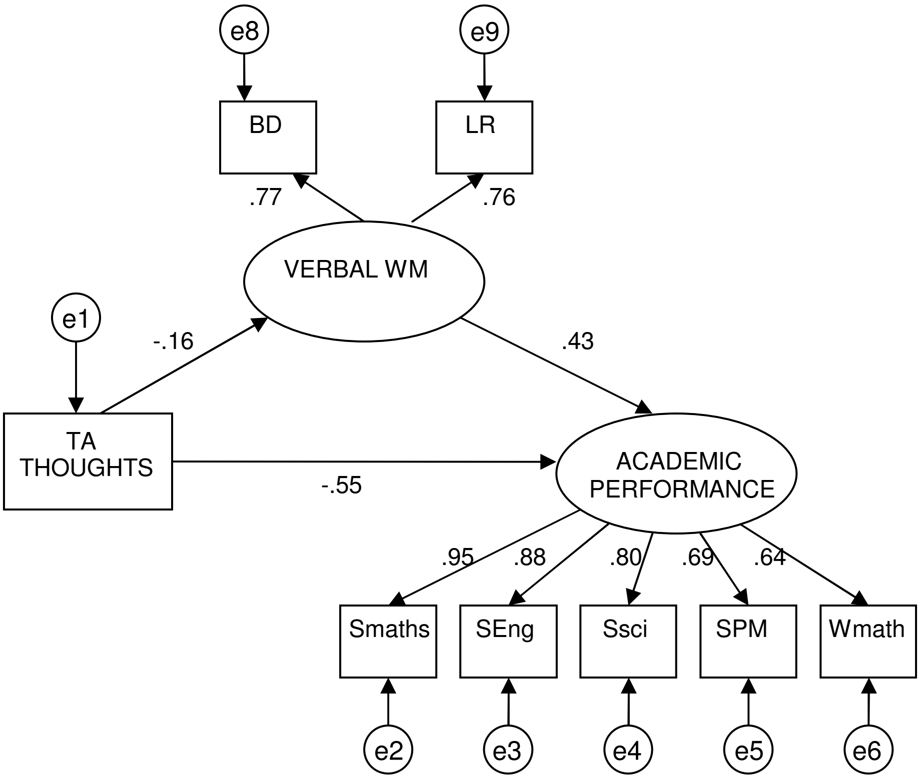

Figure 10. A structural equation model showing the relationship between anxiety, verbal working memory and academic performance. TA THOUGHTS = test anxiety thoughts as measured by the CTAS. Smaths, SEng and Ssci are maths, English and science SAT KS2 results. SPM = standard progressive matrices. Wmath = maths subset of the WRAT. WM = working memory. BD = backward digit span, LR = listening recall as measured by AWMA.

2.5.4. Exploring Moderating Variables

The moderating variables considered were heart rate variability, parent-rated conduct problems and parent-rated hyperactivity/inattention. For each of these variables, multi-group analysis was performed for the revised anxiety-performance model (Figure 5) and revised mediation anxiety-working memory-performance model (Figure 8).

Heart rate variability.

A multi-group analysis of the anxiety-performance model in Figure 5 with two groups (high and low variability) was a good fit to the data (χ^2 = 21.67, *df* = 18, χ^2/df = 1.22, *p* = .23, CFI = .96, RMSEA = .11). Both the low (β = -.44, $p < .01$) and high (β = -.45, $p < .01$) variability group had similar significant negative paths between anxiety and performance. A critical ratio test showed that the two paths between anxiety and academic performance in each of the heart rate variability groups (high and low) were not significantly different from each other (C.R = -.01, p > .05).

A multi-group analysis of the mediation model in Figure 8 was a good fit to the data (χ^2 = 8.08, df = 8, χ^2/df = 1.01, p = .43, CFI = 1, RMSEA = .02). The indirect path for both the low (β = - .07, p = .16) and high (β = - .09, p = .19) variability group were of similar strength and neither were significant.

Conduct problems.

Multi-group analysis for the anxiety-performance model in Figure 5 was a good fit to the data (χ^2 = 20.04, df = 18, χ^2/df = 1.11, p = .33, CFI = .96, RMSEA = .07) and the direct path between anxiety and performance only remained significant for the high conduct problem group (β = -.58, $p < .01$) and not for the low conduct problem group (β = -.21, p = .31). A critical ratio test showed that the two paths between anxiety and academic performance in each of the conduct problem group (high and low) were more than one standard deviation away from different from each other, however this did not reach significance levels (C.R = - 1.22, p > .05).

Multi-group analysis for the mediation model in Figure 8 was an excellent fit to the data (χ^2 = 3.83, *df* = 8, χ^2 /*df* = .48, *p* = .87, CFI = 1, RMSEA = 0); the indirect path for both the high (β = -.05, *p* = .24) and low group (β = -.04, *p* = .29) showed a similar negative effect and were not significant.

Hyperactivity/inattention.

Multi-group analysis for the anxiety-performance model was a good fit to the data (χ^2 = 21.59, *df* = 18, χ^2 /*df* = 1.20, *p* = .25, CFI = .94, RMSEA = .10) and the direct path only remained significant for the high hyperactivity/inattention group (β = -.57, *p* < .01) not the low hyperactivity/inattention group (β = -.02 *p* = .49). A critical ratio test showed that the two paths between anxiety and academic performance in each of the hyperactivity/inattention groups (high and low) were significantly different from each other (C.R = - 2.25, p < .05).

Multi-group analysis for the mediation model was an excellent fit to the data (χ^2 = 7.15, *df* = 8, χ^2 /*df* = .89, *p* = .52, CFI = 1, RMSEA = 0). The indirect path for the low hyperactivity/inattention group was not significant (β = -.03, *p* = .24) whereas for the high hyperactivity/inattention group the indirect path was significant (β = -.18, *p* = .03). Furthermore, a model constraining the paths to and from the mediator was a significantly worse fit to the data than the unconstrained model, ($\Delta\chi^2$ = 13.25, Δdf = 2, *p* < .01).

2.6. Discussion

The present study explored the relationship between anxiety, working memory and academic performance in secondary school pupils displaying SEBD. It tested some of the assumptions put forward by PET and ACT that worry rather than emotionality has a negative impact on performance and that this affect is through working memory. The results showed that overall, there was a negative association between test anxiety and academic performance and this association was most evident for the thoughts component of test anxiety, rather than for autonomic reactions or off-task behaviours. Furthermore, visuospatial working memory was found to mediate the relationship between test anxious thoughts and academic performance on tasks where the central executive was involved. These findings are broadly consistent with PET and ACT in highlighting a role for both worry and working memory (WM) in understanding the anxiety-performance relationship. The present study explored emotional regulation as a moderating variable of the mediating anxiety-WM-performance relationship. The mediating relationship was stronger for pupils identified as displaying higher levels of hyperactivity/inattention; no moderating effect was found for either heart rate variability or conduct problems.

Consistent with previous findings (Hembree, 1988; Putwain, 2008b; Seipp, 1991), the results of the present study found a negative relationship between self-reported test anxiety and academic performance across a range of academic measures including English, mathematics, science and non-verbal reasoning. Spelling was the only measure not to correlate significantly with test anxiety and similar results have been found in previous research (Owens et al., submitted). More importantly, the thoughts component of test anxiety was more strongly associated with negative performance compared with autonomic response. The thought component taps into the cognitive component of anxiety and is associated with test-related worries such as “I worry about doing something wrong,” (Wren & Benson, 2004). This result is consistent with previous findings (Goetz et al., 2008; Keogh et al., 2004; Meijer & Oostdam, 2007; Putwain, 2008b) and supports the assumption made by PET and ACT that the cognitive component of anxiety (worry) rather than the autonomic component of anxiety (emotionality) is more strongly related to performance. In the present study, self-report measures of state and trait anxiety were not significantly correlated with academic performance measures. This is congruent with previous research (Hopko et al., 2005; Seipp, 1991) and suggests that more specific anxieties such as test anxiety are particularly important in understanding the negative impact on performance compared with more general trait and state anxiety.

The links between working memory and academic performance were also illustrated in the present study. In line with previous research, visuospatial working memory was significantly associated with mathematical (Bull et al., 2008; Kyttälä, 2007) and non-verbal reasoning measures (Bacon et al., 2008). Verbal working memory was also associated with SAT mathematics but not WRAT mathematics. This finding could reflect the nature of the two tests - the WRAT test is based on arithmetic calculations whereas the SAT test also contains word problems and therefore requires reading comprehension, a task thought to involve verbal working memory (Cain et al., 2004). Both verbal and visuospatial working memory measures were positively associated with SAT English, but these associations were not significant. This is inconsistent with previous research identifying links between verbal working memory and literacy-based tasks (Montgomery et al., 2008). Given that the effect sizes in the current study ranged between .25 and .33 for associations between verbal working memory and SAT English, it is possible that the small sample size reduced power to obtain significant results.

Interestingly, in the present study, self-report measures of anxiety were not significantly correlated with measures on working memory tasks. Previous research has produced mixed findings. Some studies employing similar measures have also found no significant association between self-report anxiety and working memory measures (Owens et al., 2008; submitted). Other studies have found significant associations between anxiety and working memory where different measures of working memory have been used (e.g. Aronen at al., 2005) or where performance efficiency (i.e. time taken to complete the tasks) as well as accuracy has been measured (Hadwin et al., 2005). Consistent with previous research with adults (e.g. Derakshan & Eysenck, 1998) PET and ACT predict that anxiety leads to greater allocation of effort and therefore the negative effects of anxiety are predicted to be greater on processing efficiency compared to performance effectiveness. It will be important for future research to look at the affect of anxiety on working memory using measures of both accuracy and efficiency.

In support of PET and ACT, the present study found that test anxiety thoughts (worry) were more strongly associated with backward spatial span compared to forward spatial span. More importantly, backward spatial span was found to significantly mediate the association between test anxiety thoughts and academic performance. PET and ACT propose that the main effects of worry will be on tasks that also tap into the central executive components of working memory, because previous research suggests an association between anxiety and attention control (Keogh et al., 2004; Santos & Eysenck, 2006); a key function of the central executive. This finding is congruent with previous research with adult populations, which has highlighted that worry is associated with poorer central executive functioning, particularly for tasks involving visuospatial WM (Crowe et al., 2007). In particular, the present study found that visuospatial working memory mediated the relationship between anxiety and performance on mathematics and non-verbal reasoning tests, but not English or science. This finding can be explained with evidence that visuospatial working memory plays a role in performing mathematical calculations (Kyttälä, 2007) and non-verbal reasoning tasks (Bacon et al., 2008); but has not been linked more broadly to reading or comprehension tasks (Cain et al., 2004).

The present study did not find that verbal working memory mediates the relationship between anxiety and performance. This is in line with some previous studies with adults which have suggested that anxiety is linked more strongly to visuospatial working memory compared to verbal working memory (Crowe et al., 2007; Shackman et al., 2006). However, it does not follow previous research with school-aged populations which has found that verbal working memory rather than visuospatial working memory plays a role in the anxiety-performance relationship (Hadwin et al., 2005; Owens et al., 2008). It is possible that previous research has employed visuospatial working memory measures which are not complex enough to tap into the central executive. For example, Owens et al. (2008) used the forward spatial span as a measure of visuospatial working memory rather than backwards spatial span which is thought to tap both the sketchpad and central executive. In support of this position, Owens et al. (submitted) evidenced that visuospatial working memory had a mediating role when a more complex measure was used.

Finding a mediating relationship for visuospatial rather than verbal memory is particularly significant given the assumption of PET and ACT that the effect of anxiety on performance will be more prominent on tasks tapping the central executive and phonological loop, as worry typically involves inner verbal activity (Eysenck et al., 2007). It is possible that this discrepancy may indicate a difference in the populations used in the studies. Previous research has used random sampling, whereas the current research focused on pupils with SEBD. Given evidence which suggests that externalising behaviours such as hyperactivity/inattention are linked to visuospatial rather than verbal working memory deficits (e.g., Martinussen et al., 2005) it may be that the impact of visuospatial working memory is more prominent for the pupils in the current sample.

This assumption is further supported by the results of the current study which indicate that hyperactivity/inattention acted as a moderating variable whereby the mediation relationship between anxiety, spatial working memory and performance remained significant only for pupils rated as displaying higher levels of hyperactivity/inattention. The fact that this moderation effect was found for both the anxiety-performance relationship and the anxiety-WM-performance suggests that hyperactivity/inattention may be an important behavioural indicator of pupils who are at greater risk from the detrimental performance effects of test anxiety. Linking to Barkley's behavioural inhibition theory (Barkley, 1997), pupils displaying higher levels of hyperactive behaviour may be at a greater risk as they are less able to regulate their emotional response to situations. Given the small group sizes used in the multi-group analysis, further research should aim to explore these associations in a larger sample. A between-groups study could be employed which compares a group of pupils identified as displaying hyperactivity/inattention with a group of 'typical' pupils. This may provide interesting insights into the application of PET and ACT to specific populations and also may help to target interventions for different populations.

Although the present study predicted that conduct problems may also be a useful behavioural indicator of emotional regulation (see Eisenberg et al., 2001; Martel et al., 2007; Zeman et al., 2002), no moderating effects were found in this study. This is surprising given the fact that conduct problems were significantly correlated with each performance measure, with test anxiety thoughts and with the backward spatial span measure. Therefore, it is possible that the reduced power from the small sample sizes in the multi-group analysis led to a lack of significance for conduct problems.

The difference in findings between conduct problems and hyperactivity/inattention may also relate to the presence of visuospatial working memory, rather than verbal working memory in the mediating model tested. Hyperactivity/inattention has been shown to have clear links to visuospatial working memory in particular (Martinussen et al., 2005; Martinussen & Tannock, 2006). Previous research has indicated that conduct problems are linked to language difficulties (e.g. Botting, & Conti-Ramsden, 2000; Ripley & Yuill, 2005); therefore it is possible that conduct problems would have a stronger moderating effect in an anxiety-verbal WM-performance relationship as language development has been found to be associated with verbal working memory rather than visuospatial working memory (Baddeley et al., 1998; Leonard et al., 2007). Further research which explores conduct problems as a potential moderating factor across both visuospatial and verbal working memory could be important in identifying further groups of individuals who may be more at risk from the detrimental impact of anxiety on performance.

The hypothesised moderating effect of heart rate variability (HRV) was also not found. This hypothesis was based on evidence that HRV is an objective measure of emotional regulation (Appelhans & Lueckem, 2006) and has been associated with the use of constructive coping strategies and adaptive responses to examination stress (Fabes & Eisenberg, 1997; Gross, 1998), as well as improved and faster performance on working memory measures (Hansen et al., 2004). Although it is possible that as with conduct problems, small sample size may have produced a lack of significant results - HRV in fact had weak associations with the performance, anxiety and working memory measures. A finger-pulse sensor measured the cardiovascular pulse wave through photoplethysmography (PPG) and research has demonstrated that PPG provides rich cardiovascular information that can be used to estimate heart rate variability and is as reliable as data extracted from an electrocardiogram (Lu et al., 2008; Srinivas et al., 2007; Wickramasinghe & Spencer, 2000). However, in the present study, although pupils wore the sensor on their non-dominant hand, the nature of the tasks and the general level of movement by this particular group of pupils led to a high level of erroneous data and two of the datasets being discounted completely. Future research may benefit from using a monitor which attaches to the chest as this may be less vulnerable to movement compared to a finger sensor.

As well as limitations with equipment, the main limitations with the design of the current study should also be highlighted. As an initial exploratory study with a specific group of pupils displaying SEBD, a number of interesting findings have emerged. There are, however, limitations in using a small sample size. Firstly, when using structural equation modelling, some researchers suggest that sample sizes of around 200 participants should be used (Garson, 2008). Although bootstrapping was used as a means to address this difficulty with the current sample, it is possible that the parameter estimates in the models may be biased. Secondly, with a smaller sample size, there is a reduction in power to significantly detect an effect. In particular, when testing for moderation effects, multi-group analysis was used which compared groups of approximately 12 participants. Therefore, further studies are required which aim to replicate the current findings using a larger sample size.

A further limitation relates to the cross-sectional nature of the present study which means that it is not possible to draw conclusions regarding causal relationships. The path diagrams presented in the results are indicative of potential hypothesised causal paths; however, no path in the results section is causal. Previous longitudinal research indicates a causal role for the impact of anxiety on performance (e.g. Duchesne et al., 2008; Grover et al., 2007; Woodward & Fergusson, 2001) however further longitudinal studies are required to fully understand the relationship between anxiety, working memory and performance.

Despite the limitations highlighted above, the findings indicate several implications for application to clinical and educational settings. This study has further highlighted the interrelationships between emotions and cognition in academic performance that has been documented previously (Aronen et al., 2005; Owens et al., 2008). It has extended this work to demonstrate that both test anxiety and working memory may contribute towards understanding underachievement in pupils identified as displaying SEBD. There is potential scope for raising attainment for these pupils by addressing test anxiety. In particular, given the consistent findings of a link between worry and performance (Goetz et al., 2008; Keogh et al., 2004; Meijer & Oostdam, 2007; Putwain, 2008), interventions that target the cognitive component of test anxiety should be considered. Initial findings suggest that cognitive-behavioural interventions with a focus on cognitive restructuring and mastery experiences show beneficial effects for school performance (Fonseca et al., 2008; Wood, 2006). For example, Fonseca et al. (2008) found that a programme focused on challenging negative thoughts led to a reduction in anxiety and enhanced IQ performance in adolescents with Generalised Anxiety Disorder.

As working memory has been demonstrated as one potential mechanism in which anxiety affects academic performance, it can be a factor to consider when developing interventions to promote achievement. Previous research has highlighted significant success in training working memory skills in children with ADHD (Klingberg, Forssberg & Westerberg, 2002; Klingberg et al., 2005). Klingberg et al. (2005), for example, found that asking children with ADHD between 7 and 12 years of age to complete a relatively short working memory training protocol (25 days of around 30-40 minutes of training per day over a 5 week period) led to significant improvements in working memory, as well as a reduction in parent report symptoms of ADHD. Previous research has also demonstrated increased activation in brain regions following working memory training (e.g., Olesen, Westerberg & Klingberg, 2004).

In addition to individual training programmes, it may also be important for practitioners to consider working memory when developing teaching and learning strategies to promote achievement. For example, strategies such as teaching information in small steps, linking information to current knowledge and experience, and using external memory aids including number lines or vocabulary charts appear to reduce load on working memory (Gathercole & Alloway, 2008). Furthermore, individual working memory strategies could also be taught to pupils – visuospatial strategies such as imagery have been shown to be particularly valuable for mathematics (McLean & Hitch, 1999). Additional research is needed that examines whether supporting working memory through teaching strategies and individual strategies can help to reduce the negative impact of anxiety on performance.

In conclusion, the present exploratory study has found further support for the assumptions of PET and ACT and in particular has highlighted that anxiety and working memory are important factors to consider in understanding underachievement in pupils with SEBD. Initial findings suggest that within this group, those pupils identified as displaying higher levels of hyperactivity/inattention may be more at risk from the negative impact of anxiety. Further research is required to explore this and other potential moderating variables. The results have direct implications in terms of understanding the relationship between anxiety and academic performance and for considering interventions to promote achievement in school.

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Appendix A. Self-Report Measures

A1. The State Trait Anxiety Inventory for Children State Form

A2. The State Trait Anxiety Inventory for Children Trait Form

A3. The Children's Test Anxiety Scale

A4. The Revised Children's Anxiety and Depression Scales -

Major Depressive Disorder Scale

A5. Strength and Difficulties Questionnaire

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