The Impact of a Concurrent Auditory Stimulus on Attentional Processes in Children with ADHD

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The Australian National University

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Declaration

This thesis contains original research undertaken at the Research School of Psychology, Australian National University. The ideas, research and writing contained in these chapters and manuscripts are entirely my own, except in instances where I have acknowledged the original source accordingly, and as below. In her capacity as supervisor, Dr Kristen Pammer provided valuable feedback on the text and provided advice on editing.

The Visual Search Task and Continuous Performance Task computer programs were adapted from the originals created by Andrew Thomson.

_________________________________________
Ms Rosemary Allen

February 2016
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Abstract

Attention Deficit/Hyperactivity Disorder (ADHD) is a common neurodevelopmental disorder that can have a significant impact on multiple facets of a child’s life. Children with ADHD are generally considered to be more susceptible to distraction than other children; however, recent research has suggested that under certain circumstances, concurrent noise (e.g., music or white noise) may improve academic and cognitive performance in children with ADHD (Abikoff, Courtney, Szeibel, & Koplewicz, 1996; Pelham et al., 2011; Söderlund, Sikström, & Smart, 2007). These studies were not able to draw conclusions about which underlying cognitive processes may be improving with the addition of a concurrent auditory stimulus.

This thesis contributes to current knowledge by investigating the impact of a concurrent auditory stimulus on attention in children with ADHD, as measured by performance on computer-based attention tasks. We are interested in whether a possible improvement in basic attentional processes could account for the improvements in task performance observed in previous studies. The aim of the current thesis was to start to tease out which attentional processes, if any, may benefit from the presence of concurrent auditory stimulus such as white noise. Twenty-eight children with a diagnosis of ADHD-PI or ADHD-C were administered a battery of computer-based attention tasks under two noise conditions: a classroom noise only condition, and a classroom noise + white noise condition. The white noise stimulus comprised sounds of rain, administered using an iPhone application called Sleep Machine.

The test battery consisted of four tasks assessing different types of attention – selective attention, sustained attention/vigilance, and aspects of executive attention (response inhibition and conflict resolution). White noise had no impact on children’s performance on the task measuring response inhibition. For two of the attention tasks, the effects of white noise differed for medicated and non-medication children. Overall,
a pattern emerged on the visual search and continuous performance tasks that suggested that white noise could improve attention in children with ADHD who are on stimulant medication (i.e., beneficial as an adjunct to medication). Further research is needed to clarify the impact of white noise on attentional processes for non-medicated children with ADHD. For the two executive attention tasks, a Go/no-go task and a Simon task, the white noise had no meaningful impact on task performance.
Overview

Chapter 1 provides a background on Attention-Deficit/Hyperactivity Disorder. It outlines some of the literature on the nature of the attention deficits in children with ADHD, and the leading theoretical conceptualisations of ADHD. Chapter 2 then summarises the few studies that have explored the impact of concurrent noise on task performance for children with ADHD, and the frameworks that have been proposed to account for the observed beneficial effect of noise observed.

Chapters 3 and 4 follow the structure of an empirical research paper, with each exploring the impact of a concurrent auditory stimulus on a different type of attention or attentional process. Chapter 3 provides the results from the visual search task, which measured selective attention. The Journal of Attention Disorders has accepted this paper for publication.


Chapter 4 provides the results from the continuous performance task, which measured sustained attention and vigilance. This paper has been submitted for publication to PLOS ONE.


Chapter 5 is presented as an unpublished research chapter, and provides the results from two executive attention/attentional control tasks. Chapter 6 will summarise and compare the findings from the three empirical chapters, and discuss the possible clinical implications in terms of treatment and interventions for children with ADHD.
Table of Contents

Acknowledgements ........................................................................................................ iii
Abstract ............................................................................................................................ iv
Overview ........................................................................................................................ vi
List of Tables ................................................................................................................... x
List of Figures ................................................................................................................ xi
Chapter 1 ........................................................................................................................ 1
Introduction ...................................................................................................................... 1
1.1 Defining ADHD ........................................................................................................ 1
   1.1.1 DSM-IV-TR Diagnostic Criteria ..................................................................... 1
   1.1.2 Changes in DSM-V ......................................................................................... 3
1.2 Prevalence ................................................................................................................ 4
1.3 Comorbidity .............................................................................................................. 5
1.4 Social and Academic Functioning in Children with ADHD ............................. 6
1.5 Etiology ................................................................................................................... 8
1.6 Theoretical Conceptualizations of ADHD ......................................................... 8
   1.6.1 Hybrid Neuropsychological Model of Executive Functions (Barkley, 1997) .. 9
   1.6.2 Dual Pathway Model (Sonuga-Barke, 2002) ............................................... 12
   1.6.3 Cognitive-energetic model (Sergeant, 2000) ............................................... 14
   1.6.4 Optimal Stimulation Theory (Zentall & Zentall, 1983) ......................... 16
1.7 ADHD and Concurrent Noise ............................................................................. 17
1.8 Explanatory Frameworks ...................................................................................... 21
1.9 Current Program of Research ............................................................................ 23
1.10 References .......................................................................................................... 25
Chapter 2 ....................................................................................................................... 34
Attentional Deficits in ADHD ................................................................................. 34
  2.1 Attentional Networks ......................................................................................... 34
  2.2 Attention Deficits in ADHD ............................................................................. 36
     2.2.1 Selective Attention in Children with ADHD ........................................... 37
     2.2.2 Sustained Attention in Children with ADHD ......................................... 38
     2.2.3 Executive Attention in Children with ADHD ....................................... 39
  2.3 Battery of Attention Tasks ............................................................................... 39
  2.4 References ........................................................................................................ 40
Chapter 3 ....................................................................................................................... 47
The Impact of Concurrent Noise on Visual Search in Children with ADHD .... 47
<table>
<thead>
<tr>
<th>Chapter 3</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1 Introduction</td>
<td>49</td>
</tr>
<tr>
<td>3.2 Method</td>
<td>54</td>
</tr>
<tr>
<td>3.3 Results</td>
<td>58</td>
</tr>
<tr>
<td>3.4 Discussion</td>
<td>64</td>
</tr>
<tr>
<td>3.5 Conclusion</td>
<td>70</td>
</tr>
<tr>
<td>3.6 References</td>
<td>71</td>
</tr>
<tr>
<td>Chapter 4</td>
<td>76</td>
</tr>
<tr>
<td>Impact of Concurrent Noise on Sustained Attention and Vigilance in Children with ADHD</td>
<td>76</td>
</tr>
<tr>
<td>4.1 Introduction</td>
<td>78</td>
</tr>
<tr>
<td>4.2 Method</td>
<td>83</td>
</tr>
<tr>
<td>4.3 Results</td>
<td>87</td>
</tr>
<tr>
<td>4.4 Discussion</td>
<td>92</td>
</tr>
<tr>
<td>4.5 References</td>
<td>96</td>
</tr>
<tr>
<td>Chapter 5</td>
<td>100</td>
</tr>
<tr>
<td>The Impact of Concurrent Noise on Executive Attention Processes in Children with ADHD</td>
<td>100</td>
</tr>
<tr>
<td>5.1 Introduction</td>
<td>100</td>
</tr>
<tr>
<td>5.2 Method</td>
<td>104</td>
</tr>
<tr>
<td>5.3 Results</td>
<td>108</td>
</tr>
<tr>
<td>5.3.1 Go/No-go Task</td>
<td>109</td>
</tr>
<tr>
<td>5.3.2 Simon task</td>
<td>110</td>
</tr>
<tr>
<td>5.4 Discussion</td>
<td>111</td>
</tr>
<tr>
<td>5.5 References</td>
<td>113</td>
</tr>
<tr>
<td>Chapter 6</td>
<td>118</td>
</tr>
<tr>
<td>Discussion</td>
<td>118</td>
</tr>
<tr>
<td>6.1 Summary of Research Findings</td>
<td>118</td>
</tr>
<tr>
<td>6.2 Comparison with Previous Research</td>
<td>119</td>
</tr>
<tr>
<td>6.3 Theoretical and Practical Implications of Findings</td>
<td>120</td>
</tr>
<tr>
<td>6.4 Limitations and Future Directions</td>
<td>123</td>
</tr>
<tr>
<td>6.5 Conclusion</td>
<td>125</td>
</tr>
<tr>
<td>6.6 References</td>
<td>125</td>
</tr>
<tr>
<td>Appendix A</td>
<td>129</td>
</tr>
<tr>
<td>Appendix B</td>
<td>130</td>
</tr>
<tr>
<td>Appendix C</td>
<td>132</td>
</tr>
</tbody>
</table>
List of Tables

Table 1.1. DSM-IV-TR Symptoms of Inattention and Hyperactivity-Impulsivity........3
Table 3.1. Participant Characteristics.................................................................55
List of Figures

Figure 1.1. Hybrid Neuropsychological Model of Executive Functions (Barkley, 1997). .......................................................... 11
Figure 1.2. The Dual Pathway Theory of ADHD (Sonuga-Barke, 2002) .................. 14
Figure 1.3. Sergeant’s (2000) Cognitive-Energetic Model of ADHD ...................... 16
Figure 3.1. Log mean reaction time for response on target present trials ............ 62
Figure 3.2. Response accuracy on target present trials for medicated and non-medicated children ...................................................... 64
Figure 4.1. Difference in omission error rate between conditions ..................... 88
Figure 4.2. Omission error rates for medication and non-medicated children ........ 89
Figure 4.3. Commission error rates according to medication status and subtype diagnosis ................................................................. 90
Figure 4.4. Mean reaction time between conditions for detecting the target ........ 91
Figure 4.5. Mean reaction time for medicated and non-medicated children ......... 91
Figure 5.1. Go/No-go task screen shots .................................................. 106
Figure 5.2. Simon task screen shots ......................................................... 107
Chapter 1

Introduction

1.1 Defining ADHD

Attention-Deficit/Hyperactivity Disorder is a neurodevelopmental disorder characterized by developmentally inappropriate levels of inattention and/or hyperactivity-impulsivity (American Psychiatric Association [APA], 2013). There are two diagnostic manuals currently available that provide guidelines for diagnosing ADHD: *The International Classification of Diseases, 10th Edition* (ICD-10) developed by the World Health Organization, and the more widely used *Diagnostic and Statistical Manual of Mental Disorders, 5th Edition* (DSM-V) developed by the American Psychiatric Association. The previous edition, the *Diagnostic and Statistical Manual of Mental Disorders-Fourth Edition, Text Revision* (DSM-IV-TR; APA, 2000) was used in the current project.

1.1.1 DSM-IV-TR Diagnostic Criteria

At the time the current research was designed and conducted, the DSM-IV-TR (APA, 2000) was still in use. The diagnostic criteria have since been updated in the DSM-V (APA, 2013), and the changes are outlined below. According to the DSM-IV-TR (pp. 85-93, see Table 1), there are three ADHD subtypes: Predominantly Inattentive Type (ADHD-PI), Predominantly Hyperactive-Impulsive Type (ADHD-PHI), and Combined Type (ADHD-C). These subtypes differ in the number of clinically significant inattentive and/or hyperactive-impulsive symptoms present. For an ADHD-PI diagnosis to be given, the child must exhibit at least six of the inattentive symptoms listed in Table 1, and these symptoms need to have been present for at least six months. For an ADHD-PHI diagnosis to be given, the child must have exhibited at least six hyperactive-impulsive symptoms for six or more months. If a child exhibits six (or more) inattentive symptoms as well as six (or more) hyperactive-impulsive symptoms,
and these symptoms have been present for at least six months, then an ADHD-C diagnosis is given. An ADHD diagnosis should only be provided if some inattentive and/or hyperactive-impulsive symptoms were present before the child was seven years of age. Additionally, some impairment resulting from these symptoms must have been observed across at least two settings (e.g., school and home), and it must be demonstrated that they cause clinically significant impairments in social, academic or occupational functioning. The DSM-IV-TR (APA, 2000) further specifies that an ADHD diagnosis should not be provided if a Pervasive Developmental Disorder, episodes of psychosis (e.g., Schizophrenia), Mood Disorder, Anxiety Disorder, Dissociative Disorder or Personality Disorder could better explain the inattentive or hyperactive-impulsive symptoms observed (APA, 2000).
Table 1.1

DSM-IV-TR Symptoms of Inattention and Hyperactivity-Impulsivity

<table>
<thead>
<tr>
<th>Inattention</th>
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<tbody>
<tr>
<td>Often fails to give close attention to details or makes careless mistakes in schoolwork, work or other activities</td>
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<tr>
<td>Often has difficulty sustaining attention in tasks or play activities</td>
</tr>
<tr>
<td>Often does not seem to listen when spoken to directly</td>
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<tr>
<td>Often does not follow through on instructions and fails to finish schoolwork, chores, or duties in the workplace</td>
</tr>
<tr>
<td>Often has difficulty organizing tasks and activities</td>
</tr>
<tr>
<td>Often avoids, dislikes, or is reluctant to engage in tasks that require sustained mental effort (e.g., schoolwork or homework)</td>
</tr>
<tr>
<td>Often loses things necessary for tasks or activities (e.g., toys, school assignments, pencils, books or tools)</td>
</tr>
<tr>
<td>Is often easily distracted by extraneous stimuli</td>
</tr>
<tr>
<td>Is often forgetful in daily activities</td>
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<table>
<thead>
<tr>
<th>Hyperactivity-Impulsivity</th>
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<tbody>
<tr>
<td>Hyperactivity</td>
</tr>
<tr>
<td>Often fidgets with hands or feet or squirms in seat</td>
</tr>
<tr>
<td>Often leaves seat in classroom or in other situations in which remaining seated is expected</td>
</tr>
<tr>
<td>Often runs about or climbs excessively in situations in which it is inappropriate (in adolescents or adults, may be limited to subjective feelings of restlessness)</td>
</tr>
<tr>
<td>Often has difficulty playing or engaging in leisure activities quietly</td>
</tr>
<tr>
<td>Is often &quot;on the go&quot; or often acts as if &quot;driven by a motor&quot;</td>
</tr>
<tr>
<td>Often talks excessively</td>
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<tr>
<th>Impulsivity</th>
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<tr>
<td>Often blurts out answers before questions have been completed</td>
</tr>
<tr>
<td>Often has difficulty awaiting turn</td>
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<tr>
<td>Often interrupts or intrudes on others</td>
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*Note.* Adapted from DSM-IV-TR (APA, 2000 p92).

### 1.1.2 Changes in DSM-V

The definition of ADHD has been updated in the fifth edition of *The Diagnostic and Statistical Manual of Mental Disorders* (DSM-V; APA, 2013). With a growing body of literature demonstrating that the deficits observed in ADHD are associated with neuroanatomical abnormalities (Dickstein, Bannon, Castellanos, & Milham, 2006; Valera, Faraone, Murray, & Seidman, 2007), ADHD is now listed as a ‘Neurodevelopmental Disorder’. While the symptom criteria shown above have not
changed in the DSM-V, examples of the types of behaviours that might be seen in children, adolescents or adults with ADHD have been added (APA, 2013). Children are still required to have at least six symptoms from either (or both) symptom categories. Older adolescents or adults (over 17 years of age) however, now require five symptoms. The age of onset has changed, with the DSM-V specifying that ADHD symptoms must be present prior to 12 years of age (compared to seven years of age onset specified in the DSM-IV-TR). With these changes, the DSM-V provides clearer guidelines for clinicians to diagnose the condition in teenagers and adults, and reflects current literature, which suggests that ADHD continues to have a big impact on individuals beyond adolescence and into adulthood.

The three types of ADHD referred to as ‘subtypes’ in the DSM-IV-TR are now referred to as ‘presentations’ (i.e., combined presentation, predominantly inattentive presentation or predominantly hyperactive/impulsive presentation). This terminology better illustrates how the disorder can affect a person at different points in their life. Because symptoms may change over time, a person’s specific ‘presentation’ could change. Severity can now be specified as mild, moderate or severe based on the number of symptoms and functional impact of these symptoms in daily life. A further change is that the DSM-V does not have exclusion criteria for people with an autism spectrum disorder diagnosis.

1.2 Prevalence

ADHD is one of the most common childhood psychiatric disorders, affecting approximately 5% of children worldwide (APA, 2013). However, in research studies the prevalence of ADHD among school-age children has been found to vary widely from as low as 1% to as high as 20% (Polanczyk, De Lima, Horta, Biederman, & Rohde, 2007). Recent reviews suggest that this variability in ADHD prevalence estimates is explained primarily by methodological variables such as functional
impairment criteria, diagnostic criteria, and source of information (Polancyzk et al., 2007; Skounti, Philalithis, & Galanakis, 2007). ADHD is more frequent in males than females, with a ratio of approximately 2:1 in children (APA, 2013). The National Survey of Mental Health and Well-being (Sawyer et al., 2001) estimated that 11.2% of children in Australia aged 6-17 years met criteria for a diagnosis of ADHD (15.4% of males, and 6.8% of females).

1.3 Comorbidity

Children with ADHD often have other co-existing neurodevelopmental or mental health conditions. Common comorbidities include oppositional defiant disorder, conduct disorder, tic disorders, anxiety disorders, mood disorders and specific learning disabilities in areas such as reading, writing, arithmetic, and spelling (Brown, 2009; Connor, Chartier, Preen, & Kaplan, 2010; Daviss, 2008; Gillberg et al., 2004). A National Survey of Children’s Health in the United States (Larson, Russ, Kahn & Halfon, 2011) found that a large proportion of children with ADHD had at least one comorbid disorder: 33% had one, 16% had two, and 18% had three or more. Root and Resnick (2003) report similar high comorbidity rates, with 44% of children with ADHD found to have at least one co-occurring disorder, 33% found to have two co-occurring disorders, and 10% found to have three co-occurring disorders. Similarly, research has shown approximately one quarter to one third of children with ADHD have a comorbid anxiety disorder (Bowen, Chavira, Bailey, Stein, & Stein, 2008; Barkley, 2014; Schatz & Rostain, 2006; Brown, 2009), and rates of depression are up to 5.5 times higher in youths with ADHD than those without ADHD (Angold, Costello & Erkanli 1999). Approximately 25-30% of children with ADHD have been found to have comorbid depression (Barkley, 2014). Co-morbid tic disorders are seen in about 20% of children with ADHD (Rothenberger, Roessner, Banaschewski, & Leckman, 2007).
ADHD is often associated with elevated rates of externalizing behaviours, including aggression, delinquency, oppositional behaviours and conduct problems (Barkley 2014; Connor et al., 2010), with higher rates found in children with ADHD-C compared to those with ADHD-PI (Biederman, Newcorn, & Sprich, 1991). There is a high comorbidity between ADHD and both Oppositional Defiant Disorder (ODD) and Conduct Disorder (CD; Angold et al., 1999; Conner et al., 2010; Kessler et al., 2005; Mitchison, & Njardvik, 2015; Wolraich et al., 2005). The combined prevalence of comorbid ODD and CD in children with ADHD is estimated to be around 30% to 50% (Mitchison & Njardvik, 2015).

A recent literature review conducted by DuPaul, Gormley and Laracy (2013) found that the prevalence of learning disabilities in children with ADHD ranged from 8% to 76%, with a mean comorbidity rate of 45.1%. Up to 40% of children with ADHD have a comorbid reading disorder (Tannock & Brown, 2009), 5% to 30% have a comorbid mathematics disorder, and up to 77% have a comorbid writing disorder (DuPaul et al., 2013). Children with ADHD have also been shown to have a higher prevalence of language problems, with such problems contributing to markedly poor academic outcomes (Sciberras et al., 2014).

From these studies we can see not only that a large proportion of children with ADHD have difficulties that extend beyond the symptoms that characterize ADHD, but also that the types of comorbidities present can differ greatly among these children.

1.4 Social and Academic Functioning in Children with ADHD

Children with ADHD often experience substantial difficulties in their social relationships (Barkley, 2014; Hoza, 2007; Wehmeier, Schacht, & Barkley, 2010). They are often less liked by other children, have fewer friends and are more likely to be rejected by their peers (Hoza et al., 2005). Children with ADHD are also more likely to engage in bullying and to be the victims of bullying (Unnever & Cornell, 2003). These
peer relationship problems are often the result of difficulties with social exchanges such as sharing, cooperation and turn taking (Wehmeier et al., 2010). Children with ADHD also tend to be more impulsive, intrusive, commanding, and socially disruptive than their peers. They also tend to have emotional difficulties, which likely contribute to problems with peer relationships. Children and adolescents with ADHD have been shown to have poor emotion regulation, lower thresholds for provoked aggression, greater problems coping with frustration, and reduced empathy (Barkley, 2014). While most children with ADHD experience difficulties within their peer relationships, greater social problems are seen if these children have comorbid ODD or CD (Barkley, 2014). These children are at an increased risk for antisocial behaviours, substance abuse, peer rejection, depression, and personality disorders later in life (Sattler & Hoge, 2006).

ADHD is strongly associated with poor academic functioning and educational outcomes, which persist over time (Loe & Feldman, 2007; Preston, Heaton, McCann, Watson, & Selke, 2009). As such, children with ADHD show poorer school grades, higher rates of school failure and grade retention, and are more likely to be enrolled in special education classes (Loe & Feldman, 2007). They are also more likely to be expelled or suspended than are children without ADHD (Preston et al., 2009). Impairments in social and academic functioning often give rise to additional problems such as low self-esteem, anxiety and depression (Barkley, 2014).

These studies help to illustrate the ways in which ADHD can impact every aspect of a child’s life (i.e., social, emotional and academic). Given that these broader problems often arise from the significant challenges that these children face in the classroom, it is important to explore interventions that may have the potential to improve attention and focus in this setting.
1.5 Etiology

While there is a vast amount of research into the possible etiologies of ADHD, only a brief summary of the key findings will be provided here. The etiology of ADHD is thought to involve the interplay of multiple environmental, genetic and biological risk factors (Rey, 2012; NCCMH, 2009). Twin studies and adoption studies provide evidence for a strong genetic component, with approximately 76% of the variation in ADHD symptoms attributed to genetic factors (heritability estimate of 0.7 to 0.8; Faraone et al., 2005). Molecular genetic research has sought to identify specific genetic variants in ADHD, with evidence suggesting that ADHD is associated with catecholaminergic dysfunction (Prince, 2008; Solanto, 2002). Indeed, several genes responsible for catecholaminergic function have been shown to be associated with ADHD, including dopamine receptor genes (DRD4, DRD5), the dopamine transporter gene (DAT), dopamine beta-hydroxylase (DBH), serotonin receptor and transporter genes (HTR1B, 5-HTT) and synaptosomal-associated protein 25 (SNAP 25; Faraone et al., 2005; Gizer, Ficks & Waldman, 2009; Mill et al., 2005). Variations in each of these individual genes likely increase the risk of ADHD by only a small amount (NCCMH, 2009).

A range of factors that adversely affect brain development during the perinatal period and early childhood have been associated with an increase the risk of ADHD (NCCMH, 2009). Environmental risk factors such as prematurity, intra-uterine exposure to alcohol, maternal smoking, maternal emotional stress, low birth weight and severe early deprivation have been linked to ADHD (Banerjee, Middleton & Faraone, 2007; Linnet et al., 2003; Mick, Biederman, Faraone, Sayer, & Kleinman, 2002; Thapar, Cooper, Eyre, & Langley, 2013).

1.6 Theoretical Conceptualizations of ADHD

A number of conceptual models have been proposed, each offering different
perspectives on the mechanisms underlying ADHD. What follows is a brief summary of the three most prominent theories, which are: Barkley’s (1997) Hybrid Neuropsychological Model of Executive Functions, Sonuga-Barke’s (2002) Dual Pathway Model, and Sergeant’s (2000) Cognitive-Energetic Model. Each of these models, presented below, propose different pathways to account for ADHD and its associated symptoms.

1.6.1 Hybrid Neuropsychological Model of Executive Functions (Barkley, 1997)

Barkley’s (1997) Hybrid Neuropsychological Model of Executive Functions states that the core deficit in ADHD is poor response inhibition (or behavioural inhibition), which is critical for self-regulation. According to Barkley (1997), behavioural inhibition is necessary for other executive functions to occur. That is, inhibiting a prepotent or ongoing response produces a time delay during which other executive functions are performed. Behavioural inhibition “sets the occasion for their performance” and protects that performance from interference (Barkley, 1997 p. 68). A deficit in behavioural inhibition thus results in secondary impairments in the four executive functions: (1) non-verbal working memory, (2) internalization of speech (verbal working memory), (3) self-regulation of arousal and motivation, and (4) reconstitution. The four executive functions are self-directed actions that are used by the individual to anticipate changes in the environment and guide behaviours towards a goal (Barkley, 2014). As shown in Figure 1.1, executive functions have a controlling influence over the motor system, which Barkley (1997) has labelled as the “motor control/fluency/syntax”.

According to Barkley (1997), a primary deficit in response inhibition and subsequent secondary impairments in the four executive functions produce difficulties with self-regulation of behaviour, and thus account for the motor problems observed in
ADHD (i.e., hyperactivity and impulsivity). Although the model does not make reference to attentional processes, Barkley (1997, 2014) argues that it can account for the ‘appearance’ of inattention and distractibility symptoms in ADHD. Poor sustained attention is proposed to represent an impairment in goal-directed (internally guided) persistence, which requires self-regulation of motivation and effort. Distractibility is said to be due to poor interference control that allows other internal and external events to disrupt the four executive functions (Barkley, 1997). Inattention symptoms are thus conceptualized as resulting from a core deficit in behavioural inhibition (Barkley, 2006). A major limitation however, is that the model only applies to the ADHD-PHI and ADHD-C subtypes. Barkley (1997) stated that the model applies only to ADHD subtypes with clinically significant hyperactivity and impulsivity, and provided no explanation for the attentional difficulties observed in ADHD-PI. A further weakness is that the model makes no attempt to link deficits in inhibition and executive functioning with neural correlates or neurobiological differences in ADHD (e.g., dopamine dysfunction). Thus, while the model may tell us about the symptoms associated with ADHD, it does not tell us why they occur.
Figure 1.1. Hybrid Neuropsychological Model of Executive Functions (Barkley, 1997).

**Behavioural Inhibition**
- Inhibit Prepotent response
- Stop an ongoing response
- Interference control

**Working Memory**
- Holding events in mind
- Manipulating or acting on the events
- Retrospective function (hindsight)
- Prospective function (foresight)
- Anticipatory set
- Sense of time
- Cross-temporal organization of behaviour

**Self-regulation of affect/motivation/arousal**
- Emotional self-control
- Objectivity/social perspective taking
- Self regulation of drive and motivation
- Goal – directed action

**Internalization of Speech**
- Description and reflection
- Rule-governed behaviour (instruction)
- Problem solving/self-questioning
- Generation of rules and meta-rules
- Moral reasoning

**Motor control/fluency/syntax**
- Inhibiting task – irrelevant responses
- Excluding goal directed responses
- Execution of novel/complex motor sequences
- Sensitivity to response feedback
- Task re-engagement following disruption
- Control of behaviour by internally represented information

**Reconstitution**
- Analysis and synthesis of behaviour
- Verbal fluency/behavioural fluency
- Goal directed behavioural creativity
- Behavioural simulations
- Syntax of behaviour
1.6.2 Dual Pathway Model (Sonuga-Barke, 2002)

Sonuga-Barke’s (2002) dual pathway model of ADHD suggests that there are two distinct psycho-patho-physiological pathways that can account for the symptoms seen in ADHD. As shown in Figure 1.2, these are the executive dysfunction pathway and the delay aversion pathway. Sonuga-Barke (2002; 2003) explains that although there are different neurobiological and psychological processes at work within each of these pathways, both can account for the inattentive and hyperactive-impulsive symptoms seen in children with ADHD-C.

The executive dysfunction pathway proposes a core deficit in inhibitory control (Sonuga-Barke, 2002), which leads to dysregulation of thought and action. Poor inhibitory control is associated with disturbances in the pre-frontal cortex, specifically the fronto-dorsal striatal circuit and meso-cortical dopaminergic branches (Sonuga-Barke, 2003). The dysregulation of thought and action is said to explain the poor task-engagement and poor attentional flexibility, behavioural monitoring, planning and working memory seen in ADHD (Sonuga-Barke, 2002).

The delay aversion pathway assumes that ADHD symptoms reflect an underlying motivational style rather than deficits in executive functions (Sonuga-Barke, 2002). It points to a dysfunction in the meso-limbic branch of the dopamine system (i.e., the brain’s reward circuit). This dysfunction is said to result in a shortened ‘delay of reward gradient’ (Sonuga-Barke, 2002), which leads children with ADHD to have a tendency to discount future rewards and prefer immediate rewards. As a result, children with ADHD try to escape or avoid delay (delay aversion), and in situations where they have a choice, they impulsively seek an immediate reward. The model predicts that in situations where they cannot escape or avoid delay, children with ADHD will focus their attention on aspects of the environment that reduce their perception of delay (and thus appear to be off-task), and/or engage in behaviours that create non-temporal
stimulation (e.g., fidgeting). Delay aversion can therefore manifest as both inattention and hyperactivity.

Consistent with the dual pathway model, research has demonstrated that delay aversion and poor inhibitory control are unrelated processes, but that both are strongly associated with the ADHD-C subtype (Solanto, 2002). The fact that dopamine is a key neuro-modulator for both the executive and reward circuits in the brain provides further support for the model, since dopamine dysfunction has been implicated in ADHD (Sonuga-Barke, 2003).

Unlike Barkley’s (1997) model, the dual pathway model provides a link between neural circuits implicated in ADHD and the proposed pathways (i.e., provides a link between brain and behaviour). As with Barkley’s (1997) model however, a limitation of the dual pathway model is that Sonuga-Barke (2002) claims that it relates only to the ADHD Combined subtype (ADHD-C). No explanation is given by Sonuga-Barke (2002; 2003) as to how the ADHD Predominately Inattentive (ADHD-PI) or ADHD-Predominately Hyperactive-Impulsive (ADHD-PH) subtypes may or may not fit within this framework.
1.6.3 Cognitive-energetic model (Sergeant, 2000)

Sergeant’s (2000) Cognitive-Energetic Model of ADHD was based on Sanders’ (1983) cognitive-energetic model of information processing. As shown in Figure 1.3, Sergeant’s (2000) model is comprised of three levels. At the first level, are the four computational mechanisms of attention: encoding, search, decision, and motor response organization. The second level refers to three energetic states: effort, arousal, and activation (Sergeant, 2000). The effort pool refers to the energy needed to meet the demands of a given task, and is responsible for exciting and/or inhibiting the other energetic pools. The arousal pool is defined as phasic responding that is temporally linked to stimulus processing. The activation pool refers to a child’s physiological readiness to respond. The third level is the management or evaluation mechanism,
which is associated with executive functioning (Sergeant, 2000; 2005). This involves processes such as planning, monitoring, detection of error and error correction.

Sergeant (2005) asserts that ADHD is associated with deficits in all three levels of this model, however the primary deficit is in the energetic state of the child and how that child distributes energy to meet task demands. Specifically, the model suggests that deficits in the activation pool, and to a lesser extent, the effort pool, lead to poor motor organization (Sergeant, 2005). Studies have shown that children’s performance on response inhibition tasks is influenced by rewards, response costs and event rate (e.g., Oosterlaan & Sergeant, 1998), Since these factors alter the child’s energetic state these studies provide some support for Sergeant’s model (Sergeant, 2005).

Sergeant (2000; 2005) did not specify how this model applies to the subtypes of ADHD. A weakness of this model compared to the previous models is that it does not explicitly account for the inattention and/or hyperactivity-impulsivity symptoms that are characteristic of ADHD. Sergeant’s (2000; 2005) models suggests that the primary deficit in ADHD is seen at the state factors level (energetic pools), which differs from Barkley’s (1997) model that proposed a primary deficit at the executive level (i.e., response inhibition). Sergeant (2000; 2005) acknowledges that studies have consistently demonstrated ADHD to be associated with deficit in inhibition, but argues that poor response inhibition is not specific to ADHD. According to the cognitive-energetic model, it is the deficit at the state factor level that can differentiate ADHD from other childhood disorders. A limitation of the cognitive-energetic model however, is that direct measures of these energetic state factors are yet to be developed, and the role that these energetic pools play in ADHD therefore remain speculative (Sergeant, 2005).
While these preceding models present different perspectives on the causal mechanisms in ADHD, both the delay aversion pathway (Sonuga-Barke, 2002) and the cognitive-energetic model (Sergeant, 2000) identify state factors as important in explaining deficits in ADHD. Sergeant (2000; 2005) briefly touches on the idea that task variables influencing state factors (e.g., event rate) can lead to under- or over-activation. Another theory that has referenced the need to obtain an optimal level of activation or arousal is the Optimal Stimulation Theory (Zentall & Zentall, 1983). In many ways, this theory has now been superseded in the literature by the models of ADHD discussed previously, however its explanation of ADHD symptomatology makes it important to review here.

**1.6.4 Optimal Stimulation Theory (Zentall & Zentall, 1983)**

According to The Optimal Stimulation Theory (Zentall & Zentall, 1983) children with ADHD have demonstrated lower levels of arousal than children without ADHD. Zentall and Zentall (1983) propose that the hyperactivity, impulsivity and inattentiveness seen in children with ADHD serves to maintain an optimal level of...
arousal. If a task is not stimulating enough, children with ADHD will likely lose interest in the task, and look for extra stimulation in the surrounding environment. During routine or repetitive tasks, these stimulation-seeking behaviours (e.g., fidgeting, getting out of their seat, talking, looking around the room) are thought to help to increase their arousal to a more optimal level (Abikoff, Courtney, Szeibel, & Koplewicz, 1996). The Optimal Stimulation Theory thus suggests that stimulation-seeking behaviors could be viewed as functional and adaptive. Zentall and Zentall (1983) propose that children could achieve ‘optimal stimulation’ through the use of medication, physical activity, or increased sensory input. Research demonstrating that increases in within-task stimulation (e.g., by increasing the rate of stimulus presentation, or adding colour) have been shown to enhance task performance in children with ADHD, provides some support for the Optimal Stimulation Theory of ADHD (Abikoff et al., 1996; Conte, Kinsbourne, Swanson, Kirk, & Samuels, 1986; Lee & Zentall, 2002).

1.7 ADHD and Concurrent Noise

Children with ADHD are generally considered to be more distractible than other children (Rapport, Kofler, Alderson, Timko, & DuPaul, 2009). Especially in the classroom, children with ADHD often pay more attention to what is happening around them and less attention to their schoolwork than do their peers. Children with ADHD also find it much harder to return to work (i.e., re-focus their attention back on the task at hand) after a distraction than do children without ADHD (Barkley, 2013). Generally, it has been thought that noisy environments impair cognitive processing because auditory distractors remove attention from the task at hand. As children with ADHD struggle to focus, it seems intuitive that additional noise would be particularly detrimental for these children. Indeed, studies have shown that auditory and visual distractors impair performance in children with ADHD (Adams, Finn, Moes, Flannery, & Rizzo, 2009; Cassuto, Ben-Simon, & Berger, 2013; Geffner, Lucker, & Koch, 1996;
Higginbotham & Bartling, 1993). Classroom-based interventions have therefore generally encouraged teachers to eliminate or reduce distractions, for example, seating the child in a place that is away from windows or doorways, or having a designated quiet area in which child can work (Carbone, 2001; NCCMH, 2009).

Recent research however, has revealed that under certain circumstances, distraction may not hinder, and may even facilitate academic and cognitive performance in children with ADHD (Abikoff et al., 1996; Pelham et al., 2011). These studies report that listening to music or white noise can improve task performance for children with ADHD (Abikoff et al., 1996; Pelham et al., 2011; Söderlund, Sikström, & Smart, 2007). While this finding is counterintuitive given previous research regarding greater distractibility in ADHD, the notion that the addition of a task-irrelevant auditory stimulus may be beneficial for cognitive performance in a non-clinical sample, is not unique in the attention literature (Beanland, Allen, & Pammer, 2011; Olivers & Nieuwenhuis, 2005).

So far, there are few studies that have directly investigated the impact of a constant concurrent auditory stimulus on children with ADHD. To our knowledge, Abikoff and colleagues (1996) were the first to show that the addition of noise can improve task performance for these children. Their study examined the arithmetic performance of boys with ADHD compared to controls under three noise conditions: music (child’s favourite song), speech (nightly business report) and silence. Children with ADHD benefited from the presence of concurrent background music, whereas control children performed similarly under the three noise conditions (Abikoff et al., 1996). Children with ADHD provided 23-33% more correct answers in the music condition compared to the speech and silence conditions. Interestingly, the background music enhanced performance only when it was the first condition administered. Based on this study it is not clear whether it is music specifically or auditory stimuli more
generally that improves performance for children with ADHD. As noted by the authors, it is possible that if the speech content had been more interesting or relevant for children, it may have had a different effect on the children’s performance (Abikoff et al., 1996).

Pelham and colleagues (2011) provided further evidence to suggest that concurrent noise has the potential to improve task performance for children with ADHD. The study investigated the effects of two types of distractors on academic task performance for a group of boys with ADHD in a classroom setting – music (radio station chosen by the students) and video (age-appropriate movies or cartoons chosen by the students). The music or video distractors were present for periods of 45 minutes while the children worked on a range of different academic tasks, including maths, reading comprehension, spelling or writing, and language arts. Overall, children with ADHD completed fewer tasks than controls in all conditions, but this difference was only significant when the video distractor was present (i.e., greater decline in performance for children with ADHD than controls in presence of video distractor; Pelham et al., 2011). For the most part, the children without ADHD were found to be unaffected by the background music. However, the boys with ADHD showed mixed responses to the background music; 10% showed a decrease in performance, 61% were unaffected, and 29% showed an improvement in performance. Pelham et al. (2011) conducted a follow-up study that replicated the music distractor and no-distractor conditions with ADHD children only. Again, for the majority of these children, their productivity was unaffected by the music (76%), while for some it improved (15%) and others it decreased (8%). Based on these findings, it seems that background music is not detrimental for most children with ADHD, and may even be beneficial for some (Pelham et al., 2011).
Söderlund and colleagues (2007) demonstrated that background white noise enhanced performance on a self-performed memory task (SPT) in children with ADHD compared to controls. Participants were read lists of verb-noun sentences (e.g., ‘roll the ball’ or ‘break the match’) and asked to simultaneously perform the action described in each sentence. The free-recall memory test involved repeating out loud as many of these sentences as possible. Children with ADHD performed better on the free-recall test when the background white noise had been played during the encoding phase (sentence presentation). White noise did not influence SPT performance for the control group. The authors suggest that for peak cognitive performance, children with ADHD need more noise than controls (Söderlund et al., 2007). It is worth noting that the white noise was played during sentence presentation only, not for the free-recall test, which suggests that the observed improvement was more to do with the amount of information encoded in memory rather than the amount of information retrieved from memory.

Building on these findings, Söderlund, Silkström, Loftesnes and Sonuga-Barke (2010) assessed whether white noise had a similar impact on memory performance in a non-clinical sample of children with attentional problems. Children identified as inattentive based on teacher ratings were compared with children reported to have no attentional difficulties on the SPT paradigm described above. The ‘inattentive children’ showed a significant improvement in performance on the free-recall task with the addition of white noise, while the ‘attentive children’ performed significantly better in the no noise condition.

Taken together, there is a pattern appearing across all of these studies, in which there is the potential for children with attentional problems to benefit from the addition of noise, whereas performance is either unaffected, or hindered, for control children. Söderlund and colleagues (2010) conclude that this is evidence that the children’s level of attentional ability is the key factor that determines the impact of a concurrent
auditory stimulus on cognitive performance, in this case, specifically memory. It could be inferred from these studies that white noise appears to be beneficial for attention in children with ADHD. However, while it is possible that concurrent noise may improve attention for these children, to our knowledge no studies that have directly assessed the impact of noise (music or white noise) on attentional processes.

It is possible that the improvement in task performance observed in the studies discussed above may due to a reduction in off-task behaviour (which could again point to a possible improvement in underlying attentional processes). Cook and colleagues (2014, 2015) are the only researchers to have measured levels of off-task behaviour in children with ADHD with and without concurrent white noise. A case study design was used by Cook, Bradley-Johnson and Johnson (2014) to examine the effects of white noise on three different categories of off-task behaviour in the classroom setting: verbal off-task behaviour (i.e., conversations with teacher or another student about something unrelated to the current task), motor off-task behaviour (i.e., standing or walking), and passive off-task behaviour (i.e., looking at something around the room). All three children observed showed lower levels of passive-off task behaviours in the presence of white noise played to them through headphones, compared to baseline (no headphones) or headphones with no noise playing (Cook et al., 2014).

1.8 Explanatory Frameworks

The exact mechanism behind the beneficial effects of concurrent auditory noise is not yet known. Two theoretical models have been used to explain why listening to music or white noise may improve task performance in children with ADHD, the Optimal Stimulation Theory (Zentall & Zentall, 1983) and the Moderate Brain Arousal Model (Sikström & Söderlund, 2007). The Optimal Stimulation Theory, (see section 1.8.4), was referenced by Abikoff and colleagues (1996) to help explain why children with ADHD showed improved task performance with the addition of noise. The
argument made was that auditory distractors such as music (or white noise) increase children’s arousal to an optimal level, which effectively reduces the need for stimulation-seeking behaviours (Abikoff et al., 1996). That is, noise helps to maintain attentional focus by reducing behaviours that would have previously taken the child’s focus away from the primary task.

According to the Moderate Brain Arousal (MBA) model of Sikström and Söderlund (2007), the attentional problems seen in ADHD (i.e., distractibility, sustained attention difficulties) are due to a hypoactive dopamine system. A low level of extracellular dopamine leads to an up-regulation in stimuli-dependent dopamine release, which causes hypersensitivity to environmental stimuli (Sikström & Söderlund, 2007). Low levels of extracellular dopamine are associated with lower levels of internal neural noise. In the MBA model, Sikström and Söderlund (2007) propose that concurrent white noise compensates for this reduced neural activity through a process called Stochastic Resonance (SR). SR is when signals that are too weak to be detected, become detectable when external noise is added. With additional noise, these weak signals are then strong enough to pass the detection threshold. Neural systems with low levels of internal noise (linked to dopamine levels) are thought to require higher levels of concurrent noise for SR to occur (Sikström & Söderlund, 2007). Since children with ADHD have lower extracellular dopamine levels than children without ADHD, they may need more concurrent noise to achieve ‘optimal’ cognitive performance. The MBA model further proposes that a moderate level of concurrent noise is beneficial for performance, whereas too much or too little hinders performance (Sikström & Söderlund, 2007).

The Optimal Stimulation Theory and the MBA model both propose that concurrent noise helps children to achieve an optimal level of arousal. The MBA model takes it a step further and makes the link between physiological differences found in
ADHD (i.e., dysfunctional dopamine system) that could explain why noise has been shown to be beneficial for children with ADHD but not so for children without ADHD. The MBA model also appears to provide a potential explanation for the individual differences identified by Pelham et al. (2011). That is, individual differences in dopamine levels lead to individual differences in the amount of external noise required for optimal cognitive performance.

1.9 Current Program of Research

Since the beneficial effect of music or white noise is a relatively recent finding, there are still a number of research questions that have not yet been addressed. For example, it is not yet clear whether concurrent noise improves performance on all academic tasks, or only specific tasks (and if so, which tasks). It is possible that noise effects are dependent on task difficulty, and may become less helpful on more cognitively demanding tasks. It also remains to be seen whether certain types of auditory noise (e.g., white noise, music, familiar vs. unfamiliar) are more beneficial than others. Another feature that may influence the effects that concurrent music has on task performance is whether or not the music has lyrics. Perhaps more pressing is the need to determine where the improvement lies for these children (i.e., attention, memory, executive functioning). Previous studies were not designed to tease out which cognitive processes may improve with the addition of noise. Söderlund and colleagues (2007, 2010) showed that children improved on a memory task, but whether this was due to an improvement in memory processes specifically, or an improvement in the children’s ability to focus and attend to the sentences presented which resulted in more information being encoded initially cannot determine. Addressing each of the points raised above will be important in clarifying the nature of the positive effect of concurrent noise, and establishing the circumstances under which it is beneficial. However, it is not possible to explore all of these factors within the current thesis.
Focus is given here to identifying the cognitive processes that benefit from the addition of noise as the first step. This is a question important for both the field’s clinical and theoretical understanding of ADHD. In a climate of increasing availability and sharing of clinical experiences, internet searches reveal numerous blogs and personal sites in which individuals claim that white noise has been shown to improve attention for those with ADHD. As science-practitioners, we have an obligation to develop research projects to systematically test these assertions. While the anecdotal evidence suggesting that noise may improve focus and concentration (e.g., Batho, 2014), is consistent with the emerging scientific literature, it is an idea that still requires empirical support if it is to be recommended in addition, or as an alternative to, other evidence-based interventions for ADHD.

Given the unsubstantiated recommendations about white noise improving attention and concentration that are currently available on the internet, it was decided that exploring the impact of white noise on attention directly was an important first step in clarifying the nature of this beneficial effect observed in recent studies. If white noise was found to improve attention for children with ADHD, there is potential for it to be used as an intervention in classrooms and at home for these children. It is possible that noise may not have the same impact on different types of attention. Therefore different aspects of attention were chosen for closer analysis, including selective attention, sustained attention and vigilance, and executive attention. As outlined in the previous section, the broad research question is to investigate the impact of a concurrent auditory stimulus on basic attentional processes in children with ADHD. More specifically, do children perform better on computer-based attention tasks in the presence of concurrent white noise?

While this thesis does not directly address the underlying reason for why concurrent noise may be beneficial for task performance in children with ADHD, a
better understanding of what cognitive processes may (or may not) benefit, will help to inform future studies that seek to build on the frameworks proposed above and further explore the ‘why’. Teasing out which underlying cognitive process may be improving with the addition of noise will enable researchers to make more accurate recommendations about when it might be helpful for children, parents and teachers to use concurrent noise at home or in the classroom.

1.10 References


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Chapter 2

Attentional Deficits in ADHD

“Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalisation, concentration of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others.” (James 1890/ 1981, p. 403)

There is no clear or universally accepted definition of attention in the literature. Broad definitions have been proposed, whereby ‘attention’ refers to several capacities or processes which facilitate stimulus perception and processing (e.g., Lezak, Howieson, Bigler, & Tranel, 2012). The above quote highlights some of the key characteristics of attention. Attention has a limited capacity; it is not possible to attend to everything in our environment. We must therefore be selective, filtering out unnecessary information so that we can focus on stimuli that are important or of interest. When we attend to one thing, we are at the same time refraining from attending to other stimuli in the environment. Attention thus involves both perceptual and inhibitory processes (Lezak et al., 2012). As the quote implies, attention controls our disengagement from one stimulus in order to shift our focus so that we can easily process new or different stimuli in our environment. Shifting of visual attention is controlled by both bottom-up factors (stimulus driven) and top-down factors (goal driven; Egeth & Yantis, 1997; Theeuwes, 1994; Yantis, 1993).

2.1 Attentional Networks

Models of attention can be divided into two categories: modular and non-modular. Modular models will be the focus here, which identify different ‘types’ of attention. One of the most prominent models of attention is Posner and Petersen’s (1990) Attention System of the Brain. According to this model, attention involves three separate neural networks that serve different attentional functions: (1) alerting, (2) orienting, and (3) executive control. Alerting refers to a person’s ability to increase and
maintain response readiness in preparation for an impending stimulus (Raz & Buhle, 2006). Orienting refers to a person’s ability to select and process specific information from multiple sensory inputs (Posner & Rothbart, 2007; Raz & Buhle, 2006). The orienting network is responsible for the movement of attention between targets, spatial locations and modalities (Fan et al., 2009). Exogenous (bottom-up) orienting occurs when a stimulus event captures the person’s attention, whereas endogenous (top-down) orienting is when a person searches the visual field looking for a specific target (Raz & Buhle, 2006). The executive attention network is involved in a number of different processes, including the control of goal-directed behaviour, error detection, target detections, conflict resolution and response inhibition (Berger & Posner, 2000).

Neuroimaging studies have provided consistent support for the presence of separate attentional networks related to different types of attention (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005), and different brain regions and neurotransmitters have been implicated in each of the attention networks described above (Posner & Rothbart, 2007; Raz & Buhle, 2006). The anterior cingulate cortex (ACC) and the dorsolateral prefrontal cortex (DLPFC) have been identified as key areas in the executive attention network (Raz & Buhle, 2006). The superior parietal lobe, temporoparietal junction, superior temporal lobe, superior colliculus, pulvinar and frontal eye fields are involved in the orienting network (Raz & Buhle, 2006). The locus coeruleus, and right frontal and parietal regions of the cortex have been linked to the alerting network (Posner & Rothbart, 2007).

An alternative model of attention is Mirsky, Anthony, Duncan, Ahearn, and Kellam’s (1991) Restricted Taxonomy of Attentive Functions, which identifies four different components of attention: focus-execute, sustain-stabilise, shift, and encode. Focus-execute was defined as the capacity to select target information, whilst ignoring distracting peripheral stimuli, and to execute quickly the manual or verbal responses
required by the task (Mirsky et al., 1991; Mirsky & Duncan, 2001). Sustain-stabilize refers to the capacity to maintain focus and alertness over time. Shift was defined as the capacity to flexibly and efficiently shift attentional focus from one aspect of a stimulus to another (Mirsky et al., 1991). Encode refers to the capacity to hold information briefly in mind while performing some cognitive operation on it (Mirsky & Duncan, 2001).

The Attention System of the Brain (Posner & Peterson, 1990) and the Restricted Taxonomy of Attentive Functions (Mirsky et al., 1991) share some similarities. The orienting network of Posner and Peterson (1990) orienting network and the focus-executive component of Mirsky and colleagues (1991) both involve directing attention towards a specific subset of stimuli within the environment, which is often referred to in the literature as ‘selective attention’. Additionally, the alerting network of Posner and Petersen (1990) and the sustain-stabilize component of Mirsky and colleagues (1991) both work to maintain a person’s focus on a task or target stimulus over time (i.e., sustained attention or vigilance). From these models, three types of attention have been identified: selective attention, sustained attention (and vigilance), and executive attention.

2.2 Attention Deficits in ADHD

There has been much debate among researchers as to the nature of the attention deficits in ADHD (Wilding, 2005). According to the DMS-V (American Psychiatric Association [APA], 2013), children with an ADHD-PI or ADHD-C diagnosis display attentional deficits to a degree that causes clinically significant impairment in their everyday functioning. These attentional difficulties are reflected in parent and teacher ratings of frequent off-task behaviours (e.g., poor concentration, poor listening skills, distractibility, and reduced persistence on tedious tasks; Stefanatos & Baron, 2007). While these behavioural observations of “inattention” have been shown to reliably
distinguish children with ADHD from non-ADHD children (e.g., Conners 2009),
determination of the core attentional deficits in ADHD using cognitive attention tasks
has proven to be more difficult. Researchers have investigated the performances of
children with ADHD compared to children without ADHD on cognitive tasks
measuring different types of attention (e.g., selective attention, sustained attention and
executive attention), with mixed results (Wilding 2005). It is likely that this is due, at
least in part, to the range of tasks chosen to assess the different types of attention.
Moreover, certain tasks have been used to assess multiple attention processes (e.g., the
Stroop task has been used to assess both selective attention and conflict resolution).
Diagnostic guidelines continue to recognize attentional difficulties as a core symptom in
ADHD (DSM-V; APA, 2013). What follows is a summary of the literature on attention
deficits in children with ADHD, focusing specifically on the three different types of
attention identified above.

2.2.1 Selective Attention in Children with ADHD

Selective attention refers to the ability to focus on relevant target stimuli while
ignoring irrelevant distracting items (Huang-Pollock, Nigg, & Carr, 2005). A number
of cognitive tasks have been used to measure selective attention, including Visual
Search, the Trail Making task, the Flicker task, the Flanker task and the Stroop task. For
example, Carter, Kerner, Chaderjian, Northcutt and Wolfe (1995) used a Stroop colour-
naming task to demonstrate that task-irrelevant information is more disruptive for
children with ADHD. Similarly, both Jonkman et al. (1999) and Brodeur and Pond
(2001) found that children with ADHD showed greater distractor interference on
Flanker tasks compared to controls. Hooks, Milich, and Puzzles Lorch (1994) found no
evidence of a selective attention deficit using a speeded classification task. These tasks
however, have been used to assess multiple attention systems, and are therefore not
specific to selective attention.
Visual search paradigms provide a more specific measure of selective attention. Using visual search tasks, several studies (e.g., Hazell et al., 1999; Mason, Humphreys, & Kent, 2003; Mason, Humphreys, & Kent, 2004) have found that while children with ADHD are consistently slower and more error-prone compared to controls, children with ADHD do not show evidence of a selective attention deficit (i.e., there was no difference in serial search efficiency between groups). According to a meta-analysis by Mullane and Klein (2008) however, children with ADHD do appear to demonstrate less efficient visual search compared to controls.

### 2.2.2 Sustained Attention in Children with ADHD

Sustained attention is defined as a person’s ability to maintain attention on a task over a period of time (Huang-Pollock, Karalunas, Tam, & Moore, 2012). ‘Vigilance’ has often been used interchangeable with ‘sustained attention’, however some researchers have made the argument that these are two distinct but related processes (Huang-Pollock et al., 2012; Tucha et al., 2009). Vigilance is defined as the ability to remain alert and responsive to infrequently occurring stimuli (Tucha et al., 2009), while sustained attention is believed to reflect the ability to continuously engage attention over time. Continuous performance tests (CPTs) have been one of the most popular measures used to study sustained attention and vigilance, although few studies have differentiated these two processes when interpreting the results (Egeland, Johansen, & Ueland, 2009; Huang-Pollock, 2012).

Several researchers have found that children with ADHD are less accurate and slower to respond to targets on CPT’s compared to controls (Corkum & Siegel, 1993; Huang-Pollock, Nigg, & Halperine, 2006; Huang-Pollock et al., 2012; Losier, McGrath, & Klein, 1996), which would suggest poorer vigilance in ADHD. However, since few studies reported data of performance over time, it remains less clear whether ADHD is associated with deficits in sustained attention or vigilance. Some have shown a greater
vigilance decrement (decrease in vigilance over time) for ADHD children compared to controls (Huang-Pollock et al., 2012; Epstein et al., 2003), while others have found no differences in performance over time (Stins et al., 2005).

### 2.2.3 Executive Attention in Children with ADHD

‘Executive attention’ refers to the effortful control of attention (Berger & Posner, 2000). It is important for the control of goal-directed behaviour, error detection, target detections, conflict resolution (interference control) and the inhibition of automatic responses (Berger & Posner, 2000; Rueda, Posner & Rothbart, 2005). Several tasks have been used to measure aspects of executive attention, including the Stroop task, the Flanker task, the Simon task, Go/No-go tasks and the Stop-signal task.

Studies using the Stroop Colour-word task have provided mixed results in regards to a deficit in executive attention in ADHD compared to normal controls (Homack & Riccio, 2004; Lansberger. Kenemans, & Van Engeland, 2007; Schwartz & Verhaeghen, 2008; Van Mourik et al., 2009; Van Mourik, Oosterlaan, & Sergeant 2005). More consistent evidence for weaker executive attention in children with ADHD has been found using the Flanker and Simon tasks (Konrad, Neufang, Hanisch, Fink, & Herpertz-Dahlmann, 2006; Mullane, Corkum, Klein, & McLaughlin, 2009; Mullane, Corkum, Klein, McLaughlin, & Lawrence, 2011). Studies using Go/No-go and Stop tasks to measure response inhibition provide further support for weaker executive attention in children with ADHD (Oosterlaan, Logan & Sergeant, 1998; Nigg, 2001; Rueda, Posner, & Rothbart, 2005; Sergeant, Geurts, & Oosterlaan, 2002; Wodka et al., 2007).

### 2.3 Battery of Attention Tasks

The existing empirical evidence suggesting that concurrent noise may be beneficial for children with ADHD points to possible improvements in cognitive and academic task performance, and reductions in off-task behaviours. However, as
discussed previously, these studies were not able to draw conclusions about which cognitive processes may benefit from the addition of noise. The research in the current thesis will expand on this previous research by investigating whether the presence of concurrent white noise improves specific attentional processes in children with ADHD. Posner and Petersen’s (1990) model of attention provided a framework with which to select specific attention tasks. The current project will involve a series of experiments in which a group of children with ADHD will complete several computer-based attention tasks, each assessing one of the three types of attention proposed by Posner and Petersen (1990) – selective attention, sustained attention, and executive attention. The children will complete these attention tasks in the presence and absence of a concurrent white noise stimulus. We hypothesize that white noise will have a beneficial effect on the children’s selective attention, sustained attention and executive attention, and from this, it is predicted that the children will perform better on each of the computer-based attention tasks in the presence of white noise. The current research will help to clarify the nature of the effect of white noise for children with ADHD. If concurrent white noise was found to improve attention, there is potential for it to be used as an additional intervention in classrooms and at home for children with ADHD.

2.4 References


Chapter 3

The Impact of Concurrent Noise on Visual Search in Children with ADHD

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Abstract

**Objective:** The purpose of this study was to investigate the impact of a concurrent ‘white noise’ stimulus on selective attention in children with ADHD. **Method:** Participants were 33 children aged 7 to 14 years, who had been previously diagnosed with ADHD. All children completed a computer-based conjunction search task under two noise conditions: a classroom noise condition, and a classroom noise + white noise condition. The white noise stimulus was sounds of rain, administered using an iPhone application called Sleep Machine. **Results:** There were no overall differences between conditions for target detection accuracy, mean reaction time (RT), or reaction time variability (SD). The impact of white noise on visual search depended on children’s medication status. **Conclusion:** White noise may improve task engagement for non-medicated children. White noise may be beneficial for task performance when used as an adjunct to medication.

**Keywords:** ADHD, visual search, selective attention, white noise
3.1 Introduction

ADHD is characterized by a persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development (American Psychiatric Association [APA], 2013). ADHD is one of the most commonly diagnosed childhood psychiatric disorders, affecting approximately 5% of children (APA, 2013). It is associated with poorer school grades, enrollment in special education classes, and an increased likelihood of repeating a school year (Loe & Feldman, 2007). Compared with their peers, children with ADHD exhibit greater impairments in academic achievement and higher rates of learning disabilities (Daley & Birchwood, 2010; National Institute for Health and Clinical Excellence [NICE], 2008). Moreover, children with ADHD often develop other comorbid psychiatric conditions such as conduct disorder, oppositional defiant disorder, and depression (NICE, 2008). It is therefore important to have a clear understanding of interventions that may enhance attention among these children, especially in a classroom setting.

Children with ADHD have generally been regarded as being more vulnerable to distraction than children without ADHD (Rapport, Kofler, Alderson, Timko, & DuPaul, 2009). Recent research, however, has suggested that under certain circumstances, distraction may actually facilitate academic and cognitive performance in children with attentional problems (Abikoff, Courtney, Szeibel, & Koplewicz, 1996; Pelham et al., 2011). Specifically, task-irrelevant noise has been shown to improve task performance when presented concurrently with a target task (Abikoff et al., 1996; Pelham et al., 2011; Söderlund, Sikström, & Smart, 2007). For example, Abikoff et al. (1996) showed that task-irrelevant background music improved performance on arithmetic problems for children with ADHD (i.e., greater number of correct answers). Similarly, Pelham et al. (2011) examined the effect of two types of distractors (i.e., music and videos) on the academic performance of children in a classroom setting. The presence of a video
distractor (i.e., movie or cartoon) was associated with a decline in academic performance for children with ADHD, whereas background music had a beneficial impact on academic task performance for some children with ADHD (10% showed a decrease in performance, 61% were unaffected, and 29% showed an improvement in performance).

An increase in cognitive performance has also been demonstrated with simple auditory stimuli, such as white noise. Söderlund et al. (2007) found that the presence of background white noise enhanced performance on a self-performed memory task (SPT) in children with ADHD. Children were presented with simple verb-noun sentences (e.g., “roll the ball” or “break the match”) and asked to perform the action indicated by the command. The children performed a subsequent free recall task in which they were required to remember as many of the verb-noun sentences as possible. Children with ADHD performed the recall task with higher accuracy when the white noise had been present during the encoding phase, whereas white noise impaired subsequent recall performance for the control group. Söderlund, Sikström, Loftesnes, and Sonuga-Barke (2010) also examined the impact of white noise on memory for children rated as inattentive or attentive by teachers. Again, white noise improved performance on a verbal sentence recall task for inattentive children and impaired performance for attentive children.

Within the classroom setting, Cook, Bradley-Johnson, and Johnson (2014) conducted a series of case studies, which evaluated the within-subject effects of white noise played through headphones on off-task behavior, assignment completion, and accuracy for three children with ADHD on stimulant medication. Assignment tasks consisted of mathematical calculations, providing written responses to reading comprehension questions, or copying spelling words from a list. The children displayed significantly lower levels of passive off-task behavior (i.e., looking at something other
than the assignment) while white noise was played to them through headphones compared with the baseline and headphones-only control conditions, suggesting that concurrent white noise can reduce off-task behavior for children with ADHD on stimulant medication (Cook et al., 2014).

Although the results of these studies would seem to suggest that concurrent noise may be beneficial for attention in children with ADHD, to our knowledge, researchers have not yet examined the impact of noise on separate attentional processes directly (e.g., selective attention, sustained attention). Previous studies have used memory tasks or academic classroom activities that required a combination of highly complex cognitive processes, including attention, memory, language, and arithmetic. This makes it difficult to determine which specific cognitive processes may benefit from the presence of a concurrent auditory stimulus such as white noise. The present study was designed to start to tease out which aspects of attention, if any, may benefit from concurrent noise by looking at one attentional process: selective attention.

### 3.1.1 Selective Attention

Selective attention refers to the ability to focus on relevant target stimuli while ignoring irrelevant distracting items (Huang-Pollock, Nigg, & Carr, 2005). Several paradigms have been used to measure selective attention in children with ADHD, including the flanker task, the Stroop task, and the flicker task, all with mixed results (Brodeur & Pond, 2001; Maccari et al., 2013).

Visual search is one task that has been widely used to examine selective attention in different populations (Quinlan, 2003). Visual search tasks require participants to scan spatial locations as quickly as possible to locate a single target among a field of one or more “non-target” distractor items (Mullane & Klein, 2008; Treisman & Gelade, 1980). The target is either present or absent, and the participant’s task is to make a target-present versus target-absent decision as quickly and accurately
as possible (Quinlan, 2003). The relationship between the number of distractors present (i.e., the display size) and the speed or accuracy of task performance provides a measure of search efficiency (Mason et al., 2003). When the target is defined on the basis of one dimension (e.g., shape), it is referred to as a “single feature” search or a “pop out” search and tends to be relatively easy regardless of the number of distractors in the display (Mason et al., 2003; Mullane & Klein, 2008). When the target is defined on the basis of a combination of features relative to distractors (e.g., shape and color), it is referred to as a “conjunction search” or “serial search.” Under these circumstances, the target tends to be harder to detect, and the speed of detecting the target increases with the number of distractors in the display. Visual search is a particularly good candidate task to determine the impact of concurrent noise on attention, as it taps into the ability of the individual to isolate task-relevant information from task-irrelevant information in an increasingly complex visual environment.

Studies using the visual search paradigm to assess selective attention in children with ADHD have produced mixed results (Booth et al., 2005; Mason, Humphreys, & Kent, 2003, 2004; Mullane & Klein, 2008). Some studies have found that compared with controls, children with ADHD are more error-prone and show slower and more variable reaction times overall, especially in conjunction search, but the slopes of the search functions suggest no differences in search efficiency between groups (Hazell et al., 1999; Mason et al., 2003, 2004). Mason, Humphreys, and Kent (2005) suggest that although the mechanisms underlying selective attention may be relatively intact in ADHD, performance may be more variable due to lapses of control of these processes. Other researchers, however, (e.g., Karatekin & Asarnow, 1998) have found a significant group by display size interaction, which would suggest that ADHD children do show less efficient visual search than controls.
Visual search paradigms have been used in a wide range of research areas (e.g., dyslexia, ageing, autism spectrum disorders, Alzheimer’s disease; O’Riordan, Plaisted, Driver, & Baron-Cohen, 2001; Tales et al., 2002; Vidyasagar & Pammer, 1999). Conjunction search tasks allow for a highly controlled means of examining basic attentional processes, particularly low-level, stimulus-driven processes such as the spatial allocation of attention, serial scanning of stimulus locations, and the filtering out of irrelevant stimuli (Quinlan, 2003). Given that the design of these tasks is based on strong theoretical models (e.g., Horowitz & Wolfe, 1998; Treisman & Gelade, 1980), they are a valuable tool for assessing the effects of interference on differential aspects of attention, in this case, whether or not concurrent noise improves the low-level attentional mechanisms mediating selective attention.

The purpose of this study is to assess the impact of concurrent white noise on selective attention in children with ADHD, using a conjunction search paradigm. As previous visual search studies have consistently shown no differences in performance on single-feature search tasks between ADHD children and controls, the current experiment used a conjunction search task only. A notable strength of this study is that we have included larger display sizes (i.e., 16-64 items) than have been used in previous visual search studies looking at selective attention in ADHD children. It may be that a difference between noise conditions may only become apparent as task difficulty increases, such as is the case in other areas such as dyslexia research (Vidyasagar & Pammer, 1999). The present study was conducted as a within-subject experiment as it is likely that there will be individual differences in how participants respond to the addition of the concurrent white noise. A within-subject design allowed us to minimize the number of variables that needed to be controlled for, such as IQ and age, as the children are compared with themselves. The sound of rain was the concurrent auditory stimulus used, rather than pure white noise. Even if pure white noise is beneficial for
attention, it is unlikely that children would want to listen to it for extended periods of
time, and therefore it is less likely to be used as an intervention. The sound of rain,
which has similar properties to pure white noise, in that it is a constant unvarying sound
consisting of a range of frequencies, would be more pleasant to listen to while
completing homework/classroom activities. We acknowledge that the rain sounds are
not technically white noise, however for simplicity, we will refer to it as “white noise”
here.

It was hypothesized that, overall, children would perform better (i.e., greater
accuracy, faster reaction time) when completing the visual search task in the presence of
white noise. If concurrent white noise were to improve search efficiency of children
with ADHD, we would expect to see a steeper slope function in the classroom noise
condition compared with the white noise + classroom noise condition (a condition by
display size interaction).

3.2 Method

3.2.1 Participants

Thirty-three children between 7 and 14 years of age ($M = 9, SD = 1.97$ years)
with a previous ADHD diagnosis participated in the present study. Five participants
were excluded due to a comorbid pervasive developmental delay (PDD) diagnosis or
failure to attend both testing sessions. The final sample consisted of 28 children aged 7
to 14 years ($M = 9.07, SD = 1.89$ years). Of these, 18 (64%) were male and 10 (36%)
were female (see Table 1). Eighteen of the children were diagnosed ADHD–combined
type (ADHD-C) and 10 were diagnosed ADHD–predominantly inattentive type
(ADHD-PI). Diagnoses had been given prior to the experiment by a pediatrician,
psychologist, or psychiatrist. Where provided, professional diagnoses that specified
ADHD subtype were used to classify children. For participants whose parents did not
specify an ADHD subtype, the Conners’ 3 Parent Rating Scale (Conners, 2008) was
used to classify children as ADHD-C or ADHD-PI. Based on information provided by parents, 22 participants had had previous cognitive assessments. The reported IQ (or General Ability Index) estimates for these children ranged from 77 to 128. Seven children had a comorbid learning disorder diagnosis, 5 children had a comorbid oppositional defiant disorder or conduct disorder diagnosis, and 5 children had a comorbid mood or anxiety disorder diagnosis. One of the objectives of the current study was to investigate whether white noise is a viable and easily implementable everyday intervention for improving attention in children with ADHD. Given the high degree of comorbidity in ADHD (Larson, Russ, Kahn, & Halfon, 2011; Root & Resnick, 2003), including children with the above comorbid diagnoses allowed us to assess this within a more ecologically valid sample.

Table 3.1.

<table>
<thead>
<tr>
<th>Participant Characteristics</th>
<th>( n )</th>
<th>Age (SD)</th>
<th>Male</th>
<th>LD</th>
<th>ODD/CD</th>
<th>Mood/Anx</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADHD</td>
<td>28</td>
<td>9.07 (1.89)</td>
<td>18</td>
<td>7</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>ADHD-PI</td>
<td>10</td>
<td>9.50 (1.90)</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>ADHD-C</td>
<td>18</td>
<td>8.83 (1.89)</td>
<td>14</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>ADHD medicated</td>
<td>20</td>
<td>9.25 (1.92)</td>
<td>13</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>ADHD non-medicated</td>
<td>8</td>
<td>8.63 (1.85)</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

*Note. LD = Learning Disorder. ODD = Oppositional Defiant Disorder. CD = Conduct Disorder. Anx = Anxiety.*

Twenty-one children were on medication for their ADHD at the time of their involvement in the study. Medicated children were using Concerta, Ritalin, or Dexamphetamine (or a combination of these). For ethical and practical reasons, the medicated children continued their regular medication regimen. It must be noted that the
parents of one participant on medication for his ADHD chose not to give medication on the days their child participated in the study; this child was therefore classified as “non-medicated.” Twenty children were classified as “medicated,” and 8 were classified as “non-medicated.”

Prior to testing, the first author conducted a screening interview with parents via telephone to enquire about the child’s ADHD diagnosis (i.e., had the child received a formal ADHD diagnosis), medication status, and exclusion criteria (i.e., a comorbid autism spectrum disorder or color blindness). The Conners’ 3 Parent Rating Scale (Conners, 2008) and the Child Behavior Checklist (CBCL/6-18; Achenbach & Rescorla, 2001) were completed for each child. Parents completed an additional questionnaire developed for the present study to obtain background information about the child’s ADHD diagnosis (i.e., which professional made the diagnosis), comorbid diagnoses, current medication status and medication history, treatment history, and home environment (e.g., noise levels while completing homework tasks).

3.2.2 Materials

Visual stimuli. Visual stimuli were presented on a laptop using a Dell Precision 17 in. (43.18 cm) monitor with 60 Hz refresh rate and screen resolution 1,920 × 1,080 pixels. Stimuli were programmed using Presentation 16.0 (Neurobehavioral Systems Inc.). Two versions of the task were created to reduce practice effects. In both versions, the display area consisted of a black background with a white fixation cross, which remained visible throughout the trials. The target was either a red square (Version A; 0.8 cm side; 0.92° × 0.92°) appearing among red circles (0.8 cm diameter; 0.92° × 0.92°) and green squares (0.8 cm side; 0.92° × 0.92°), or a purple triangle (Version B; 0.8 cm height; 0.92° × 1.03°) appearing among orange triangles (0.8 cm height; 0.92° × 1.03°) and purple circles (0.8 cm diameter; 0.92° × 0.92°). There were three display sizes of 16, 32, or 64 items, which were equally frequent and randomly intermixed within a
block. The items were randomly positioned within an $11 \times 6$ matrix. The matrix was 38.5 cm wide and 21.5 cm high ($37.2^\circ \times 23.3^\circ$).

The experiment consisted of two blocks of 42 trials, with 14 trials of each of the three possible display sizes (16, 32, or 64 items). Half of the trials at each display size contained a target. All participants completed 12 practice trials prior to commencing the first test block. Participants were required to respond as fast and as accurately as possible to the presence of the target (red square or purple triangle) by pressing the “1” key, and to the absence of the target by pressing the “2” key on the number pad.

**Audio stimuli.** The white noise stimulus “Medium Rain” was taken from an iPhone application titled *Sleep Machine* (SleepSoft LLC, 2011). It was presented using an iPhone 5 via Apple EarPods at medium volume, which was reported by all participants to be a comfortable level. The background classroom noise audio consisted of pre-recorded tracks of classroom noises downloaded from www.audiosparx.com and linked together using GarageBand ’09 Version 5.1(398). The classroom noise was presented using an iPod Nano via speakers (Sony iPhone dock, Model ICF-C1iPMK2). The classroom noise ranged from 36.0 to 59.2 dBA. Noise level was measured using a Digitech QM-1589 sound level meter.

**3.2.3 Procedure**

Participants were tested individually in a quiet room, at a viewing distance of approximately 50 cm. The visual search task was included as part of a battery of tests, the results of which are reported elsewhere. The full test session took approximately 60 min per participant. The order of the test battery was randomized across participants, so the visual search task was given at a different point for each child. All participants completed the test battery on two separate occasions, and the order was maintained across test sessions (participants were either given Version A at Time 1 and Version B at Time 2 or vice versa). Test sessions were scheduled 2 to 4 weeks apart. The condition
order was randomized across participants. In both the *white noise + classroom noise* and *classroom noise* conditions, the classroom noise audio played via speakers in the background for the duration of the test session. In the *white noise + classroom noise* condition, participants completed the test battery while also listening to the white noise audio via headphones. Participants were advised that the “rain sounds” would be playing through the headphones while they completed the attention tasks. Participants were instructed to remove the headphones while the experimenter provided verbal instructions for each task. Participants were given stickers for each task completed and were given short 5- to 10-min breaks as needed, in which they were allowed to play board games with the examiner. Parents were seated outside the testing room for the duration of the testing sessions.

### 3.3 Results

For each condition and display size, each participant had a mean reaction time (RT), a standard deviation (*SD*; i.e., a measure of RT variability), and an accuracy percentage. Mean RTs and *SD*s were then sorted for target-present and target-absent trials. Mean RTs and *SD*s were calculated by excluding any response that was (a) incorrect, (b) below 100 ms, or (c) more than 3.29 *SD*s (Tabachnick & Fidell, 2007) from that participant’s individual mean. There were 28 trials (14 target present, 14 target absent) for each display size in each condition. Excluding errors and outliers meant that the mean RTs could be based on fewer than 28 trials.

#### 3.3.1 Impact of White Noise on Visual Search

**Reaction times.** Due to significant positive skew, a log transformation was conducted prior to analyses. A 2 (condition: classroom noise + white noise vs. classroom noise × 3 (display size: 16 vs. 32 vs. 64) × 2 (target: present vs. absent) within-subject ANOVA was conducted to assess mean RTs for correct trials. There was a significant main effect of display size, \(F(2, 27) = 115.56, p < .001, \eta^2_p = .811\), with
mean RTs increasing with display size. This confirms that the children did engage in serial conjunction search. RTs were significantly slower on target-absent trials compared with target-present trials, $F(1, 27) = 113.70, p < .001, \eta^2_p = .808$.

**SDs.** Prior to analyses, two outliers were removed from the data set, and a log transformation was conducted. The SDs for correct trials were analyzed in the same way as for RTs, with a 2 (condition) × 3 (display size) × 2 (target) within-subject ANOVA. There was a significant main effect of display size, $F(2, 25) = 39.854, p < .001, \eta^2_p = .615$. RT variability increased as the display size increased. There was also greater RT variability on target-absent trials compared with target-present trials, $F(1, 25) = 18.618, p < .001, \eta^2_p = .427$.

**Accuracy percentages.** Due to the high degree of accuracy on target-absent trials ($M$ accuracy = 94.64%-98.47%), accuracy percentages were analyzed for target-present trials only. Prior to analyses, one outlier was removed from the data set. Participants’ accuracy percentages on target-present trials were analyzed using a 2 (condition) × 3 (display size) within-subject ANOVA. There was a significant main effect of display size, $F(2, 52) = 52.726, p < .001, \eta^2_p = .670$, with accuracy decreasing in both conditions as the number of distractors increased. There was a significant Condition × Display Size interaction, $F(2, 52) = 5.330 p < .05, \eta^2_p = .170$. Post hoc paired-sample $t$ tests using a Bonferroni adjustment ($p = .017$) were conducted to compare accuracy between conditions at each display size. At the smallest display size (16 items), participants were significantly more accurate in the classroom noise + white noise condition ($M = 89.95, SD = 12.73$) compared with the classroom noise condition ($M = 84.13, SD = 18.08$), $t(26) = 2.740, p = .011$ (two-tailed). At the 32-item display size, participants were more accurate in the classroom noise condition, $t(26) = -1.586, p = .038$ (two-tailed); however, this result became non-significant when the Bonferroni
correction was used. There was no difference between conditions at the largest display size.

Based on these results, there was no overall effect of white noise on visual search. However, the group of children who participated in the study was not homogeneous in terms of medication status. We were unable to control for this for local ethical reasons, however, it is likely that medication status could affect the results. For example, although Söderlund et al. (2007) found that ADHD children performed more accurately on memory tasks when associated with white noise, a closer analysis of their findings showed that although there was a trend suggesting that white noise improved performance for non-medicated children, it was only significant when medicated children were included in the analyses. It is possible that this was due to increased statistical power, but it is also possible that the medicated children may have been driving this result. Thus, it is possible, based on the Söderlund et al. (2007) study, that the beneficial effects of white noise may only become apparent when the medication has allowed the child to establish a certain cognitive equilibrium.

Mixed three-way (Condition × Display Size × Medication Status) ANOVAs were conducted for RT, SDs, and accuracy to assess whether noise effects differed for medicated and non-medicated children. There were homogeneity of variance violations for SDs and accuracy, likely due to the unequal number of medicated and non-medicated children in the sample.

3.3.2 Medication Status

Multilevel linear modeling with restricted maximum likelihood estimation (REML) was used to further assess whether the impact of white noise differed for medicated and non-medicated children. A two-level hierarchical model assessed the effects of condition, display size, and medication status on the dependent variables of mean RT, SD of RT, and accuracy percentages (target-present trials only). First-level
units were the condition, display size, and medication status variables. ADHD subtype was included in the original model but was removed from the final model because there was no significant effect of ADHD subtype on RT, SD, or accuracy. Second-level units were the 28 participants. For the dependent variables of RT_target absent and SD_target absent, more complex models including a random slope and intercept were significantly better than those including the intercept only: RT_target absent, $\chi^2(5, N = 168) = 41.395, p < .05$, and SD_target absent, $\chi^2(5, N = 156) = 15.156, p < .001$; however, these models failed to converge. For the dependent variables of accuracy, RT_target present and SD_target present, the model including both intercept and slope were not significantly better than intercept-only model: accuracy, $\chi^2(5, N = 162) = 0.412, p = .99$; RT_target present, $\chi^2(5, N = 168) = 2.100, p = .84$; and SD_target present, $\chi^2(5, N = 156) = 2.545, p = .77$. For these reasons, random intercept models were retained for all dependent variables.

**Reaction times.** For target-present trials, there was a significant main effect of display size on mean RT, with both conditions showing an increase in RT as display size increased, $F(2, 130) = 42.557, p < .001$. Combining results across conditions, mean RT was significantly different from 16 items to 32 items, $M$ difference $= -.229 (.047)$, 95% confidence interval [CI] = [0.114, 0.343], $p < .001$, and from 32 items to 64 items, $M$ difference $= .208 (.047)$, 95% CI = [0.093, 0.322], $p < .001$. There were also significant medication status by condition, $F(1, 130) = 7.243, p < .01$; display size by condition, $F(2, 130) = 8.189, p < .001$; and medication status by display size by condition interactions, $F(2, 130) = 12.127, p < .001$ (see Figure 3.1).
For target-absent trials, there was a significant main effect of display size, with both conditions showing an increase in RT as display size increased, $F(2, 130) = 56.164, p < .001$. Combining results across conditions, mean RT was significantly different from 16 items to 32 items, $M$ difference $= -.265 (.052)$, 95% CI $= [0.140, 0.391]$, $p < .001$, and from 32 items to 64 items, $M$ difference $= .284 (.052)$, 95% CI $= [0.159, 0.410]$, $p < .001$. The condition by medication status interaction was significant, $F(1, 130) = 12.817, p < .001$. For children on ADHD medication, mean RT was faster in the classroom noise + white noise condition than in the classroom noise condition. For non-medicated children, mean RT was slower in the classroom noise + white noise condition than in the classroom noise condition.

**SDs.** For target-present trials, there was a main effect of display size on RT variability, $F(2, 120) = 24.830, p < .001$, with RT variability increasing as display size increased. Combining results across conditions, RT variability was significantly different from 16 items to 32 items, $M$ difference $= .321 (.100)$, 95% CI $= [0.078, 0.564]$, $p < .001$, and from 32 items to 64 items, $M$ difference $= .383 (.100)$, 95% CI $=$
There was a significant condition by display size by medication status interaction, $F(2, 120) = 3.097, p = .049$. For non-medicated children, there was greater RT variability in the presence of white noise at 64-item display size only. For medicated children, there was no difference between conditions.

For target-absent trials, there was a main effect of display size, with RT variability increasing with display size, $F(2, 120) = 13.566, p < .001$. Combining results across conditions, RT variability was significantly different from 16 items to 32 items, $M$ difference = .321 (.100), 95% CI = [0.078, 0.564], $p < .001$, and from 32 items to 64 items, $M$ difference = .383 (.100), 95% CI = [0.140, 0.626], $p < .001$.

**Accuracy percentages.** There was a significant main effect for display size on accuracy, with both conditions showing a decrease in accuracy as display size increased, $F(2, 125) = 61.323, p < .001$. Combining results across conditions, accuracy was significantly different from 16 items to 32 items, $M$ difference = −10.179 (3.412), 95% CI = [−18.459, −1.898], $p = .010$, and from 32 items to 64 items, $M$ difference = −19.847 (3.412), 95% CI = [−28.127, −11.567], $p < .001$. There was also a main effect of medication status, with medicated children significantly more likely to accurately identify the target as present than non-medicated children, $F(1, 125) = 7.118, p = .013$. The condition by medication status interaction was approaching significance, $F(1, 125) = 3.234, p = .075$. As shown in Figure 3.2, the pattern suggests that white noise was associated with greater response accuracy for non-medicated children, while having little to no impact on medicated children’s accuracy. The interaction effect of condition by display size was not significant, $F(2, 125) = 1.491, p = .229$. 

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63
3.4 Discussion

The aim of this study was to assess the impact of concurrent white noise on selective attention in children with ADHD. The study assessed children’s performance (i.e., response accuracy, RT, and RT variability) on a conjunction search task in the presence and absence of a white noise stimulus played via headphones.

Guided by previous studies that have demonstrated concurrent noise (e.g., white noise, music) to be beneficial for task performance in children with ADHD, it was hypothesized that participants would perform better on the conjunction search task in the presence of white noise. Initial results did not support this hypothesis, with no main effect of condition for any of the three dependent variables. There were no overall differences between conditions for accuracy, RT, or RT variability. The white noise did not improve children’s performance on the conjunction search task, nor was it detrimental.

Figure 3.2. Response accuracy on target present trials for medicated and non-medicated children.
Children’s mean RTs and RT variability increased with display size in both the classroom noise + white noise and classroom noise conditions, while their response accuracy decreased with display size in both conditions. These results are consistent with previous visual search studies that have shown that responses become slower and less accurate as the number of distractors in the display increases (Booth et al., 2005; Mullane & Klein, 2008), and is indicative of a serial search strategy. The absence of a condition by display size interaction for RT data suggests that there was no difference in search efficiency between conditions.

These results would seem to suggest that the white noise had no impact on the children’s performance on the conjunction search task. However, the disparity in medication status of the participating children prompted us to explore this factor more carefully. When we ran additional analyses to check whether the impact of white noise differed for medicated and non-medicated children, some interesting patterns emerged, which suggested that the white noise may increase performance on visual search for ADHD children, but only if they were already on medication.

Children on ADHD medication were faster at correctly identifying the presence of the target item in the classroom noise + white noise condition than the classroom noise condition. Non-medicated children, on the other hand, were slower at correctly identifying the target item in the presence of white noise. An interesting pattern emerged when we broke this down further. Looking at the differences in RT between conditions across the three display sizes, the children’s RTs at the 64-item display size were significantly slower in the classroom noise + white noise condition compared with the classroom noise condition. There was a much smaller increase in RT from the 32-item to the 64-item display in the classroom noise condition than the classroom + white noise condition. This pattern appears to be driven by the RTs of non-medicated children in the classroom noise condition. Their RTs did not increase with display size as is
normally seen on conjunction search tasks. It is possible that these children were either not using serial search or that they were simply not engaged in the task. If we compare this with the pattern in target detection accuracy observed for non-medicated and medicated children across the two conditions, the latter appears to be the more likely explanation. For non-medicated children in the classroom noise condition, target detection accuracy is near chance levels, but improves in the presence of white noise. Further research is needed to assess whether the pattern observed in the current study could indeed reflect a noise-induced improvement in task engagement for non-medicated children with ADHD.

Based on these results, and the possibility that the non-medicated children were simply not engaged in the task in the classroom noise condition, it is difficult to comment as to the impact white noise had on the non-medicated children’s visual search as a measure of selective attention. Because mean RT for non-medicated children in the classroom noise + white noise condition was slower than RTs shown by medicated children in both the classroom + white noise and classroom noise conditions at the largest display size, we speculate that white noise may be detrimental for task performance (separate from task engagement) in non-medicated children when tasks are more difficult.

A similar pattern was observed for RT on target-absent trials. For medicated children, white noise was associated with faster RTs, while for non-medicated children, RTs were slower in the presence of white noise. Interestingly, the non-medicated children appeared to show smaller RTs (i.e., were faster) in the classroom noise condition than medicated children. It is possible that the non-medicated children were simply giving up earlier (i.e., terminated their search early rather than continuing to search the display until they were confident the target was not present). Although, further research is needed to confirm these findings, this would be consistent with the
suggestion that the non-medicated children were disengaged from the task in the
classroom noise condition.

The finding that, at the largest display size, non-medicated children showed
greater RT variability in the classroom noise + white noise condition than was shown by
medicated children in either condition, again suggested that white noise may be
detrimental for non-medicated children’s task performance when tasks are more
difficult. If future research were to reveal a similar pattern to that found in our results, it
would mean that white noise may not be a useful replacement for medication as an
intervention for children with ADHD, as has been suggested (Söderlund et al., 2007).

Two theoretical explanations have been proposed to account for the potential
beneficial effect of concurrent noise on cognitive performance in children with ADHD:
the optimal stimulation theory (Abikoff et al., 1996; Zentall & Zentall, 1983) and the
moderate brain arousal (MBA) model (Sikström & Söderlund, 2007). The optimal
stimulation theory of ADHD (Zentall & Zentall, 1983) suggests that the distractibility
seen in children with ADHD is due to a state of underarousal, which leads them to seek
additional stimulus input from their environment. Researchers have proposed that
concurrent auditory noise may improve task performance because it increases the
child’s arousal to an optimal level, thereby reducing stimulation-seeking behaviors that
take their attention/focus off the primary task (Abikoff et al., 1996).

The MBA model (Sikström & Söderlund, 2007) is based on the phenomenon of
stochastic resonance (SR). SR is when signals that are too weak to be detected become
detectable with the addition of noise. ADHD has been shown to be associated with a
hypofunctional dopamine system caused by low levels of extracellular dopamine
(Solanto, 2002). Sikström and Söderlund (2007) note that a low extracellular dopamine
level is associated with low levels of internal neural noise. The MBA model suggests
that the presence of concurrent white noise could compensate for this reduced neural
activity in ADHD, by introducing additional noise into the neural system through the perceptual system (Sikström & Söderlund, 2007; Söderlund et al., 2007). Thus, the MBA model proposes that via the process of SR, concurrent noise has the potential to improve cognitive performance in children with ADHD. The amount of concurrent noise needed to achieve optimal cognitive performance depends on dopamine levels in the brain (Sikström & Söderlund, 2007). Sikström and Söderlund (2007) predict that a moderate amount of noise may be beneficial for cognitive performance, while an insufficient or excessive amount of noise will be detrimental.

It has been proposed that the distractibility observed in the classroom in children with ADHD could be caused by an enhanced orienting reaction to novel auditory information (van Mourik, Oosterlaan, Heslenfeld, Konig, & Sergeant, 2007). Research has shown that children with ADHD were more distracted by novel sounds during performance of a visual discrimination task than control children (Gumenyuk et al., 2005). It is therefore also possible that the beneficial effect of concurrent noise (i.e., music or white noise) may be because the constant noise makes it less likely that unexpected sounds in the child’s environment will capture their attention. To control for this possibility, that concurrent noise simply neutralizes the impact of novel sounds, we created an audio track of classroom noise (e.g., varying amounts of chatter, quiet chatter, chairs scraping across the floor), which was played in the background in both conditions. The volume of these noises was varied to reflect the different levels of noise expected in a real classroom. The current study could be extended by adding two more conditions: a silence condition (no noise) and a classroom noise + headphones-only condition. This would help to clarify whether it is the specific addition of a concurrent noise that improves performance, or that it simply cancels out background noises (in which case we would expect noise-cancelling headphones to produce the same improvement in performance as headphones with noise playing).
Although the results of the current study must be interpreted with caution due to the small number of non-medicated children in the sample, we would encourage researchers to consider distinguishing between task engagement (whether or not children are focused on the task) and task performance (accuracy and speed of target detection) in future studies. It may be that for non-medicated children, white noise is sufficient to improve task engagement (e.g., because it cancels out distracting background noise) but does not improve task performance. For medicated children that are already engaged in the task, white noise improves certain elements of task performance. If we consider the MBA model proposed by Sikström and Söderlund (2007), it is possible that the level of white noise provided in the current study was sufficient to improve performance for medicated children (combined effect of medication and noise compensates for hypofunctional dopamine system) but that non-medicated children may require more noise to see a benefit. Because the current study did not intend to directly address possible reasons why white noise may be beneficial, these are simply hypotheses that need to be explored further.

It is important to consider the limitations in the present study in interpreting the findings. Normal controls have not been included in the current study design, as we were more interested in the nature of the impact of noise on selective attention in children with ADHD specifically (i.e., could it be a helpful intervention for children with ADHD in the future), rather than the differential impact of noise on controls versus children with ADHD. Previous studies have shown individual differences in how children responded to concurrent noise in previous studies (e.g., Pelham et al., 2011). A within-subjects design allowed us to assess whether the positive effect of noise is strong enough to produce significant improvements in visual search performance within the individual. The absence of a normal control group, however, means we cannot comment on whether this specific group of children showed inefficient visual search (i.e., were
they performing below controls to start with?). Future research could extend the current study by including a normal control group. This would allow researchers to assess whether the specific sample shows differences in visual search compared with controls in the absence of concurrent noise. If they were to demonstrate inefficient search for ADHD children compared with controls, a normal control group would further allow them to determine whether or not the white noise brings ADHD children’s visual search performance up to the level of that of children without ADHD.

The current study could be also be extended by comparing the impact of different types or frequencies of noise (e.g., instrumental music, music with words, or white noise vs. pink noise) on attentional processes, such as selective attention. We have started to examine the impact of noise on different attentional processes (results are presented elsewhere); however, further research is needed to determine whether concurrent noise has a similar or differential effect on different academic tasks. It would also be of interest to examine the impact of noise on qualitatively different tasks (e.g., easy vs. challenging tasks, boring vs. interesting tasks).

3.5 Conclusion

Findings of this research indicate that white noise may improve the speed with which children with ADHD can accurately identify a visual target among task-irrelevant distractors. However, this was only the case for children on medication for their ADHD. Although the possibility that white noise may improve task engagement for non-medicated children warrants further investigation; overall, the results suggest concurrent white noise should not be recommended as an alternative to medication for children with ADHD but rather may be beneficial as an adjunct intervention.
3.6 References

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Chapter 4

Impact of Concurrent Noise on Sustained Attention and Vigilance in Children with ADHD

This paper has been submitted for publication to PLOS ONE. The content of the published work has been reproduced here. However, there are minor formatting differences in order to maintain consistency of formatting through the thesis.
Abstract

Objective: The study examined the effects of white noise on sustained attention and vigilance in children with ADHD, as measured by a continuous performance task (CPT). Method: Participants were 33 children aged 7 to 14 years, with a prior ADHD-PI or ADHD-C diagnosis. All children completed the computer-based CPT under two noise conditions: (a) classroom noise only and (b) classroom noise + white noise. The white noise stimulus (rain sounds) was administered via headphones using an iPhone application called Sleep Machine. Results: Overall, omission error rates were significantly lower in the presence of white noise, suggesting white noise may improve sustained attention for children with ADHD. Further analysis revealed that for medicated children, white noise improved vigilance, whereas for non-medicated children white noise had a negative impact on vigilance. Conclusion: The effects of white noise on a CPT performance differed for medicated and non-mediated children with ADHD.

Keywords: ADHD, continuous performance task, sustained attention, vigilance, white noise
4.1 Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder that is characterized by a persistent pattern of inattention and/or hyperactivity/impulsivity that interferes with a child’s functioning or development (American Psychiatric Association [APA], 2013). ADHD is estimated to affect 5% of children worldwide (APA, 2013; Polanczyk, De Lima, Horta, Biederman, & Rohde, 2007). Children with ADHD are generally considered to be more susceptible to distraction than other children (Rapport, Kofler, Alderson, Timko, & DuPaul, 2009), indeed “easily distracted” is a defining symptom of ADHD in the Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (DSM-V; APA, 2013). Recent research however, has begun to suggest that under certain circumstances, external distractors have the potential to improve academic and cognitive performance in children with ADHD (Abikoff, Courtney, Szeibel & Koplewicz, 1996; Pelham et al., 2011).

Several research groups have independently found that task-irrelevant noise (e.g., music, white noise) can improve task performance in children with ADHD, when it is presented concurrently with the target task (Abikoff et al., 1996; Pelham et al., 2011; Söderlund, Sikström, & Smart, 2007). Abikoff and colleagues (1996) for example, showed that for some children with ADHD, the presence of background music was associated with a greater number of correct answers to arithmetic problems. More recently, Pelham et al. (2011) compared the impact of video and music distractors on children’s academic task performance in a classroom setting. For children with ADHD, there was a decline in task performance declined in the presence of video distractors (i.e., a movie or cartoon), whereas background radio music was associated with an improvement in task performance some children with ADHD (10% showed a decrease
in performance, 61% were unaffected, and 29% showed an improvement in performance; Pelham et al., 2011).

Similarly, Söderlund and colleagues (2007, 2010) demonstrated that background white noise improved performance on a self-performed memory task (SPT) in children with attentional problems. Söderlund et al. (2007) presented children with a series of simple verb-noun sentences (e.g., “roll the ball”) and instructed them to perform the actions indicated by the verbal command. Sentences were presented concurrently either with or without background white noise. Children were then asked to recall as many of these sentences as possible. Children with ADHD performed better on the free-recall task if the to-be-remembered sentences had been presented with background white noise. For control children however, background white noise had no effect on performance on the free-recall task (Söderlund et al., 2007). Using the same SPT paradigm, Söderlund et al. (2010) found that white noise improved performance on the free-recall task for children rated as inattentive by their classroom teachers, whereas it was associated with a decline in performance for those children who had been rated as attentive. Both studies indicated that white noise has a differential impact on memory performance in children with and without attention problems (Söderlund et al., 2010).

Building on the work of Söderlund and colleagues (2007, 2010) Cook, Bradley-Johnson, and Johnson (2014) used a case study design (n = 3) to examine the impact of white noise on off-task behaviour, assignment completion and accuracy for children with ADHD on stimulant medication in the classroom setting. Assignment tasks included mathematics, spelling, and providing a written response to reading comprehension questions. Fewer passive off-task behaviours (e.g., looking at something other than their classwork) were observed when the assignment tasks were completed in the presence of white noise (played to them through headphones), compared to baseline (no headphones) or headphones only. No difference in assignment completion or
accuracy across conditions was found. These results suggest that white noise can reduce off-task behaviour in the classroom for children with ADHD (Cook et al., 2014).

From these studies, it could be supposed that concurrent noise may have the potential to improve attention in children with ADHD. However, we caution that the studies discussed above did not examine the impact of noise on attentional processes directly (e.g., selective attention, sustained attention, attentional control). The academic and memory recall tasks used by previous studies require a combination of highly complex cognitive processes, including memory, language skills, arithmetic skills, and attention. Therefore, based on these studies alone it is difficult to identify which cognitive processes benefit from the addition of a concurrent auditory stimulus such as white noise. The present study was designed to extend previous findings by starting to investigate which cognitive processes may be most influenced by concurrent noise. Specifically, we have used a continuous performance task (CPT) to explore the impact of concurrent noise on vigilance and sustained attention.

4.1.1 Vigilance and Sustained Attention

‘Vigilance’ and ‘Sustained attention’ are terms that have often been used interchangeably. Recently however, some researchers have made the argument that these are two distinct but related processes (Huang-Pollock, Karalunas, Tam, & Moore, 2012; Tucha et al., 2009). Sustained attention refers to a person’s ability to direct attention to one or more sources of information over a period of time. Disturbances in sustained attention are therefore indicated by deterioration in task performance over time (Tucha et al., 2009). Vigilance on the other hand, has been defined as a person’s ability to remain alert and responsive to infrequently occurring stimuli. Vigilance, by definition, requires sustained attention (Tucha et al., 2009). Continuous performance tests (CPTs) have been one of the most popular measures used to study sustained attention and vigilance, although few studies have differentiated these two processes.
when interpreting the results (Egeland, Johansen, & Ueland, 2009; Huang-Pollock, 2012).

CPT paradigms are generally characterized by a rapid presentation of stimuli (e.g., letters, numbers, pictures of objects/animals, coloured shapes). The participant is required to respond to the infrequently and randomly presented target item. There are many variations of the CPT paradigm but the two most common versions are the CPT-X and the CPT-AX (e.g., Riccio, Reynolds, Lowe, & Moore, 2002; Rosvold, Mirsky, Sarason, Bransome & Beck, 1956). In the CPT-X version, participants are presented with a series of individual letters and must respond, via button press, to the presentation of an “X”. In the CPT-AX version, participants respond to the “X” only if the “X” immediately follows the letter “A”. Some researchers have modified the CPT-AX, with a response required only when the target is preceded by itself (Coons, Klorman & Borgstedt, 1987). The CPT-Identical Pairs (CPT-IP), which is a more cognitively demanding task, requires the participant to respond when any stimulus appears twice in a row (Riccio et al., 2002). The number of targets missed (omission errors) is usually considered to be a measure of inattention, and the number of incorrect responses to a non-target (commission errors) is considered to reflect impulsivity (Corkum & Siegel, 1993).

Target type is not the only variation among CPTs. Researchers have also varied the frequency of the target (target to non-target ratio), stimulus duration, time lapse between presentations of the stimuli (inter-stimulus interval), task duration, and the sensory modality in which the stimuli are presented (i.e., visual or auditory; Riccio, Waldrop, Reynolds, & Lowe, 2001). Another modification has been to change the response requirements such that the participant must respond to all stimuli except the target item (e.g., Conners’ CPT; Conners, 1995). Due to the high frequency with which the participant must respond to non-targets and then inhibit their response to the less
frequent target stimuli, the Conner’s CPT is best described as an inhibitory control paradigm and is fundamentally different to traditional CPTs (Ballard, 2001; Huang-Pollock et al., 2012). Therefore, studies using the Conner’s CPT to measure vigilance or sustained attention are not included here.

4.1.2 Continuous Performance Tasks and ADHD

Some researchers have demonstrated that children with ADHD make more errors and have slower RTs on CPTs than normal controls overall (Corkum & Siegel, 1993; Huang-Pollock, Halperin & Nigg, 2006; Huang-Pollock et al., 2012; Losier, McGrath & Klein, 1996), while others have found no differences between groups (Corkum & Siegel, 1993). The argument has been made that significant differences in overall error rates and RTs is an indication of vigilance deficits only, and is not an accurate measure of sustained attention because it does not speak to changes in performance over time (Huang-Pollock et al., 2012). Few CPT studies have reported performance over time data (i.e., group x time interactions). Huang-Pollock et al. (2006) demonstrated that children with ADHD committed more omission errors over time compared to controls, providing evidence for a sustained attention deficit in ADHD. The meta-analysis conducted by Huang-Pollock et al.’s (2012), found small (commission errors, RT and SDRT) to moderate (omission errors) effect sizes for those studies reporting performance over time data.

Therefore, based on current literature, we could say that in order to remain alert and responsive to infrequently occurring stimuli (vigilance), we must first be able to maintain our focus on the stimulus source (sustained attention). We have tried to design an experiment that taps into both processes, without relying on the output of performance over time (POT) data. Rather than varying ISIs within trial blocks as most CPT studies have done, we chose to vary the ISIs across blocks (i.e., each block of trials had a different ISI). We propose that any changes in accuracy and reaction time across
the trial blocks will reflect changes in vigilance demands. We further propose that any differences between conditions over and above changes in ISI (e.g., a main effect of condition), would then reflect participants ability to maintain their attention and focus on the task (i.e., sustained attention).

This study was designed to examine the impact of concurrent white noise on vigilance and sustained attention in children with ADHD, using a CPT-X paradigm. A within-subject design was used to minimize the influence of individual differences such as IQ and age, and to control for potential difference in participants’ responses to the addition of concurrent white noise. The concurrent auditory stimulus was the sound of rain, rather than pure white noise. While pure white noise may be beneficial for children’s sustained attention, it is unlikely that children would want to listen to it for extended periods of time, and is therefore less likely to be adopted as an intervention. The sound of rain has similar properties to pure white noise (i.e., it is a constant unvarying sound consisting of a range of frequencies), and it was thought of as more pleasant to listen to while completing homework/classroom activities. We acknowledge that the rains sounds are not technically white noise however, for simplicity, we will refer to rain sounds in this study as ‘white noise’.

It was hypothesized that, overall, children with ADHD would perform better on the CPT-X in the presence of white noise (i.e., lower omission error rates, lower commission error rates, and faster reaction times).

4.2 Method

4.2.1 Participants

Participants were 33 children ($M_{age} = 9, SD = 1.97$; age range: 7-14 years) with a previous ADHD diagnosis. Parents provided written consent for their children to participate. Five participants were excluded due to a comorbid Pervasive Developmental Delay (PDD) diagnosis or failure to attend both testing sessions. The
final sample consisted of 28 children aged 7-14 years (18 male, 10 female, $M_{age} = 9.07, SD = 1.89$). Of these, 18 children had an ADHD-combined type (ADHD-C) diagnosis and 10 had an ADHD-predominantly inattentive type (ADHD-PI) diagnosis. All ADHD diagnoses had been given prior to the experiment by a paediatrician, psychologist, or psychiatrist. Professional diagnoses that specified ADHD subtype were used to classify children as ADHD-C or ADHD-PI. The Conners 3 Parent Rating Scale (Conners, 2008) was used to classify children in cases where their parents were not able to specify subtype diagnosis. Information provided by parents indicated that 22 participants had had previous cognitive assessments. The reported IQ (or General Ability Index) estimates for these children ranged from 77 to 128. Seven children had a comorbid Learning Disorder diagnosis, five children had comorbid Oppositional Defiant Disorder or Conduct Disorder diagnoses, and five children had comorbid Mood or Anxiety Disorder diagnoses.

Twenty-one children were on medication for their ADHD at the time they participated in the study. Medications included Concerta, Ritalin or Dexamphetamine (or a combination of these). For ethical and practical reasons, children who were taking medication continued their regular medication regime. Parents were asked not to make any changes to their child’s treatment for the duration of their involvement in the study. It must be noted that the parents of one participant on medication for his ADHD chose not to give the medication on the days their child participated in the study. This child was considered to be part of the ‘non-medicated’ group. Therefore, for the purposes of analysis, 20 children were classified as medicated and eight were classified as non-medicated.

Prior to testing, the first author conducted a screening interview with parents via telephone to enquire about the child’s ADHD diagnosis (i.e., whether or not the child had received a formal ADHD diagnosis), medication status and exclusion criteria (i.e., a
comorbid Autism Spectrum Disorder or colour blindness). The Conner’s 3 Parent Rating Scale (Conners, 2008) and the Child Behaviour Checklist (CBCL/6-18; Achenbach & Rescorla, 2001) were completed for each child. Parents also completed a questionnaire developed for the present study to gather background information about their child’s ADHD diagnosis (i.e., professional who provided the diagnosis), comorbid diagnoses, current medication status and medication history, treatment history and home environment (i.e., noise levels while completing homework tasks). This research was approved by the ANU Human Ethics Committee.

4.2.2 Materials

Visual Stimuli. Visual stimuli were presented on a laptop using a Dell Precision 17 inch monitor with 60 Hz refresh rate and screen resolution 1920 x 1080 pixels. Stimuli were programmed using Presentation 16.0 (Neurobehavioral Systems, Inc.). The display area consisted of a dark green background (37.2° x 23.3°). Two version of the task were created to reduce practice effects. In version A, participants were presented with a sequence of white letters presented one at a time in the center of the screen. In version B, participants were presented with a sequence of numbers. Arial size 60 font was used for both letter and number versions of the task. Each stimulus was presented for 100 milliseconds and was separated from the next by an inter-stimulus interval (ISI) of 1000, 2000, or 4000 milliseconds.

The task consisted of three blocks (ISI = 1000, 2000 or 4000 milliseconds) of 65 trials presented in ascending order. The target item (‘x’ or ‘7’) appeared 15 times in each block (23% of trials). A similar-to-target item (‘k’ or ‘1’) appeared 10 times in each block (15% of trials). The remaining eight items appeared five times in each block. Participants were required to respond as quickly as possible to the target item by pressing ‘spacebar’. The CPT task took approximately eight minutes to complete.
Audio Stimuli. The white noise stimulus ‘Medium Rain’ was taken from an iPhone application titled ‘Sleep Machine’ (SleepSoft LLC, 2011). The white noise stimulus was presented using an iPhone 5 via Apple EarPods at medium volume, which all participants reported was a comfortable noise level. The background classroom noise audio consisted of a series of pre-recorded tracks of classroom noises downloaded from www.audiosparx.com, and linked together using GarageBand ‘09 Version 5.1(398). The classroom noise audio was presented using an iPod Nano via speakers (Sony iPhone dock, Model ICF-C1iPMK2). The classroom noise ranged from 36.0 – 59.2 dBA. Noise level was measured using a Digitech QM-1589 sound level meter.

4.2.3 Procedure

All participants were tested individually in a quiet room, seated at a viewing distance of approximately 50 cm from the screen. The CPT was included as part of a battery of attention tasks, the results of which are reported elsewhere. The full test session took approximately 60 minutes per participant. The order of the attention tasks was randomized across participants, such that the CPT was given at a different point for each child. All participants completed the battery of attention tasks on two separate occasions, under different noise conditions. The task order was maintained across the testing sessions, which were scheduled between two and four weeks apart. The order of the two noise conditions was counter-balanced across participants. In both the classroom noise + white noise and classroom noise conditions, the classroom noise audio played via speakers in the background for the duration of the testing session. In the classroom noise + white noise condition, participants completed the attention tasks while also listening to the white noise audio via headphones. Participants were simply told that the “rain sounds” would be playing through the headphones while they completed each of the attention tasks. They were asked to remove the headphones while the experimenter provided verbal instructions for each task. Participants were given
stickers as a reward for completing each task, and were given 5-10 minute breaks as needed. Parents were seated outside the testing room for the duration of the testing sessions.

4.3 Results

Three dependent variables were analyzed: missed targets (omission errors), incorrect responses to non-targets (commission errors), and mean reaction time (RT) for correct responses to the target stimulus. Mean RTs, omission errors and commission errors were sorted for each participant, condition and ISI length.

Ethics had not been obtained to remove children from their medication, therefore, those children who were taking medication for their ADHD, continued with their regular medication regime for the duration of their involvement in the study. Consequently, the participant group was made up of unequal numbers of medicated (20) and non-medicated (8) children. As noted above, the CPT was completed as part of a battery of attention tasks. Upon analyzing results from another attention task in this battery (Allen & Pammer, 2015) we found that the impact of white noise on task performance differed for medicated and non-medicated children. For this reason, we have included medication status in the analyses presented below.

Multilevel linear modeling with restricted maximum likelihood estimation (REML) was used due to the unequal numbers of medicated and non-medicated children within the sample. A two-level hierarchical model assessed the effects of condition, ISI, medication status and ADHDSubtype on the dependent variables of mean RT (RT), omission errors (Om_Errors) and commission errors (Comm_Errors). First-level units were the condition, inter-stimulus interval and medication status variables. Second-level units were the 28 participants. ADHDSubtype was removed from the final Om_Error and RT models because there was no ADHDSubtype x Condition interaction; however children with an ADHD-PI diagnosis appeared to make
fewer omission errors than children with an ADHD-C diagnosis \( (F (1, 24) = 4.224, p = .051) \). ISI was removed from the final Comm_Error model because there was no main effect of ISI and no ISI x Condition interaction. For the dependent variable Comm_Error, the more complex model including a random slope and intercept was significantly better than the model including the intercept only however, this model failed to converge: \( \chi^2(5, N = 162) = 21.643, p = .00 \). For the dependent variables of Om_Errors and RT, the models including both intercept and slope were not significantly better than intercept-only models: Om_Errors, \( \chi^2(5, N =162 ) = 5.67 , p = .34 \); RT, \( \chi^2(5, N =168 ) = 9.97, p = .08 \). For these reasons, random intercept models were retained for all three dependent variables.

\textbf{Omission Errors.} One outlier was removed prior to analyses. There was a main effect of condition \( (F (1, 125) = 8.572, p = .004) \), with fewer omission errors made in the white noise + classroom noise condition compared to the classroom noise only condition (see Figure 4.1). There was no main effect of medication status and no significant medication status interactions \( (p >.05) \).

![Figure 4.1. Difference in omission error rate between conditions. CN = classroom noise; WN = white noise.](image)
While there was no three-way interaction found for omission error rate, we graphed the non-significant interaction in order to confirm that the mean RT results reported below did not reflect a speed accuracy tradeoff. Upon graphing the non-significant interaction, an interesting pattern emerged (see Figure 4.2). We decided to re-run the above analyses separately for medicated and non-medicated children. There was a main effect of condition for both medicated (F (1, 95) = 5.290, \( p = .024 \)) and non-medicated children (F (1, 30) = 4.330, \( p = .046 \)). For medicated children, the Condition x ISI interaction approached significance (F (2, 95) = 2.547, \( p = .084 \)).

![Figure 4.2](image)

**Figure 4.2.** Omission error rates for medication and non-medicated children. (A) medicated children, (B) non-medicated children. CN = classroom noise; WN = white noise.

**Commission Errors.** One outlier was removed prior to analyses. The main effect of ADHDSubtype was significant (F (1, 23) = 7.059, \( p = .014 \)), with fewer overall commission errors made by children with an ADHD-PI diagnosis compared to children with an ADHD-C diagnosis. The Condition x ADHDSubtype interaction (F (1, 131) = 4.217, \( p = .042 \)) and the Condition x ADHDSubtype x Medication Status interaction (F (1, 131) = 7.600, \( p = .007 \)) were both statistically significant. The Condition x Medication Status interaction approached significance (F (1, 131) = 3.381, \( p = .068 \)).
Non-medicated children with an ADHD-C diagnosis were less likely to incorrectly respond to a non-target in the presence of white noise (see Figure 4.3).

Figure 4.3. Commission error rates according to medication status and subtype diagnosis. CN = classroom noise; WN = white noise.

Reaction Times. There was a main effect of ISI (F (2, 130) = 56.857, p < .001), with mean RTs increasing with ISI. The main effect of medication status was also significant (F (1, 26) = 12.143, p = .002). As shown in Figure 4.4, there was a significant condition x ISI interaction (F (2, 130) = 6.491, p = .002). Mean RTs were comparable at 1000 ms and 2000 ms ISIs however, at 4000 ms ISI children’s RTs were slower in the classroom noise + white noise condition than the classroom noise only condition. The condition x medication status (F (1, 130) = 8.906, p = .003), medication status x ISI (F (2, 130) = 13.184, p < .001), and condition x ISI x medication status interactions (F (2, 130) = 4.184, p = .017) were also significant. For medicated children, RTs were comparable across conditions (see Figure 4.5). For non-medicated children, RTs were slower in the white noise condition + classroom noise at 4000 ms ISI (no difference at 1000 ms and 2000 ms ISI).
Figure 4.4. Mean reaction time between conditions for detecting the target. CN = classroom noise; WN = white noise.

Figure 4.5. Mean reaction time for medicated and non-medicated children. CN = classroom noise; WN = white noise.
4.4 Discussion

The present study was designed to investigate the impact of concurrent white noise on vigilance and sustained attention in children with ADHD, using a CPT-X paradigm. The study examined the children’s performance on the CPT-X (i.e., omission errors, commission errors and RT for correct responses to the target stimuli) in the presence and absence of a white noise stimulus (rain) played via headphones.

Previous research has shown that concurrent white noise is beneficial for task performance in children with ADHD (see Söderlund, Sikström & Smart, 2007; Pelham et al., 2001). It was therefore hypothesized that children with ADHD would perform better on the CPT-X in the presence of white noise, compared to a background noise only condition. Our results provide partial support for this hypothesis.

Overall, children were more likely to detect and respond to the target (‘X’ or ‘7’) item in the presence of white noise. The absence of a condition x ISI interaction for omission error rate, suggests that this beneficial effect of white noise was not affected by increasing vigilance demands. The omission error pattern across the three ISI blocks was similar in the two conditions. It is possible that the addition of white noise improved the children’s ability to remain focused and maintain their attention on the task overall, rather than improving vigilance for the target. The pattern of omission errors within and between conditions would seem to suggest that the white noise had a positive impact on sustained attention, but had no impact on vigilance.

With increasing vigilance demands, the children were slower to respond to the target item, both in the classroom noise only and classroom noise + white noise conditions. The significant condition x ISI interaction indicates that there is a greater increase in mean reaction time at 4 second ISI in the presence of white noise. When this result is compared with the omission error pattern described above, what becomes apparent initially is a possible speed accuracy tradeoff (SATO). Although mean reaction
time increased at 4 second ISI in the presence of white noise, children continued to be more accurate under these conditions than in the classroom noise only condition. However, when these results were broken down further and the three-way interaction for mean reaction time was unpacked, a pattern emerged that is not consistent with a SATO.

For medicated children, mean RTs were comparable across ISIs and between conditions. Increasing vigilance demands did not influence the speed with which these children responded to a target item, regardless of condition. For non-medicated children, increasing vigilance demands had a bigger impact on their reaction time in the white noise + classroom noise condition. These children were slower to respond at 4 second ISI with the addition of white noise. Whether this reflects a speed accuracy tradeoff for these children, or indicates that white noise decreased vigilance is difficult to determine without comparing reaction with the three-way interaction for omission error rate. We must caution that we are reporting the pattern observed for omission error rates because it is important to consider this when interpreting the mean reaction time findings, however the three-way omission error rate pattern (i.e., condition x ISI x medication status interaction) was not statistically significant, and the condition x ISI interaction for medicated children only approached significance.

The omission error pattern suggests that medicated children were able to maintain accuracy and reaction time with increasing vigilance demands when white noise was present. Medicated children became less accurate at 4 second ISI in the absence of white noise, even though reaction time remained stable. This pattern suggests white noise may improve vigilance for children with ADHD who are on stimulant medication. For non-medicated children, the omission error pattern shows no difference in accuracy at 4 second ISI between conditions, suggesting the slower reaction time in the presence of white noise does not reflect a SATO. Rather, it suggests the white noise may be
having a negative impact on vigilance for these children. The omission error pattern for non-medicated children at 1 and 2 second ISI may be demonstrating that white noise helps these children to maintain focus on the task (i.e., better accuracy with addition of white noise when vigilance demands are low). However, given the non-medicated sample was small, further research is needed to clarify the impact of white noise on vigilance and sustained attention for non-medicated children with ADHD.

The absence of a main effect of ISI and condition x ISI interaction for commission error rate suggests increasing vigilance demands had no impact on participants impulsive responding. Given the low commission error rates overall, it is possible that there was simply insufficient variability in error rates to detect differences between conditions (i.e. a ceiling effect). It is possible that the effects of white noise (positive or negative) may become more evident with a more cognitively demanding task (e.g., CPT-AX or CPT-XX).

Researchers have proposed two theoretical frameworks that explain how concurrent noise could potentially improve cognitive performance in children with ADHD: the Optimal Stimulation Theory (Abikoff et al., 1996; Zentall & Zentall, 1983) and the Moderate Brain Arousal (MBA) model (Sikström & Söderlund, 2007). According to the Optimal Stimulation Theory of ADHD (Zentall & Zentall, 1983), the distractibility seen in these children results from a state of underarousal. Children with ADHD seek additional stimulus input from their surrounding environment in order to increase their arousal to more normal levels (Zentall & Zentall, 1983). It has been suggested that auditory distractors such as concurrent music or white noise could improve cognitive performance by increasing arousal to optimal levels and reducing stimulation-seeking behaviours that take a child’s attention and focus away from the primary task (Abikoff et al., 1996).
Sikström and Söderlund’s (2007) MBA model is based on the concept of Stochastic Resonance (SR). SR is when a signal that would have been below the detection threshold, becomes detectable with the addition of noise. ADHD has been shown to be associated with a hypofunctional dopamine system caused by low levels of extracellular dopamine (Solanto, 2002). The low level of extracellular dopamine leads to insufficient internal neural noise (Sikström & Söderlund, 2007). The MBA model proposes that concurrent white noise could compensate for lower levels of internal neural noise (low dopamine levels) in ADHD via the process of SR (Sikström & Söderlund, 2007; Söderlund et al., 2007).

The current research does not allow us to distinguish between these two theories, but rather, was an exploration of the nature of the effect. Subsequent research could be derived to attempt to address the underlying theoretical models. For example researchers could manipulate noise levels and examine the impact of different noise levels on children’s performance on a CPT. If the relationship between noise intensity and task performance produced an inverted U-shape curve, this would provide support for the MBA model (Sikström & Söderlund, 2007).

There are limitations in the current study that should be considered when interpreting the results. Normal controls were not included as a comparison group in the current study design because we were more interested in the nature of the impact of white noise on vigilance and sustained attention in children diagnosed with ADHD, than the differential impact of noise on normal controls versus children with ADHD. Without a normal control group however, we cannot comment as to whether the children with ADHD showed deficits on the CPT, compared to controls, before the addition of the concurrent white noise (i.e., were they performing below controls to start with?). Including a normal control group in future studies, would allow researchers to...
determine whether or not the white noise brings ADHD children’s vigilance/sustained attention up to the level of that of children without ADHD.

4.5 References


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Chapter 5

The Impact of Concurrent Noise on Executive Attention Processes in Children with ADHD

5.1 Introduction

The literature reviewed in Chapter One of this thesis, suggests that concurrent auditory noise has the potential to improve task performance in children with ADHD. Several studies have shown concurrent noise (music or white noise) to be beneficial for children with ADHD (Abikoff, Courtney, Szeibel, & Koplewicz, 1996; Cook, Bradley-Johnson, & Johnson, 2014; Pelham et al., 2011; Söderlund, Sikström, & Smart, 2007). These studies were however, not able to draw conclusions about what underlying cognitive processes were actually improving. The purpose of the current thesis was to address this research gap, and aimed to start to tease out which specific attentional processes, if any, may benefit from the presence of a concurrent auditory stimulus such as white noise. Chapter 3 found that white noise might improve the speed with which children with ADHD can accurately identify a visual target among task-irrelevant distractors, but this was the case for medicated children only, suggesting the potential for an additive effect between concurrent noise and medication. Chapter 4 revealed that – again - for medicated children, white noise improved vigilance, whereas for non-medicated children white noise had a negative impact on vigilance. So far, these results provide partial support for the hypothesis that white noise improves attention for children with ADHD.

As outlined in Chapter 2, Posner and Petersen (1990) viewed attention as comprising three networks: (a) the orienting network, which is responsible for the movement of visual attention in space and the selection of locations for further processing, (b) the vigilance network, which is responsible for maintaining a state of alertness, and (c) the executive attention network, which is responsible for monitoring
and resolving conflicts among alternative responses. As noted above, previous chapters investigated the impact of concurrent noise on selective attention, vigilance and sustained attention. What has not yet been examined is the effect that concurrent noise may have on higher-order functions such as attentional control (i.e., executive attention). This chapter is therefore focused on assessing the effects of white noise on executive attention, which has been shown to be weaker in children with ADHD (e.g., Homack & Riccio, 2004; Lansbergen, Kenemans, & Engeland, 2007; Mullane Corkum, Klein, & McLaughlin, 2009; Mullane Corkum, Klein, McLaughlin, & Lawrence, 2011).

### 5.1.1 Executive Attention

Executive attention refers to a supervisory attentional system that is responsible for monitoring and resolving conflict among thoughts, feelings and responses (Posner & Rothbart, 2007). It is important for planning and decision-making, error detection, and in overcoming habitual responses (Posner & Rothbart, 2007).

Two functions that have been associated with executive attention are *Inhibition* and *Conflict Resolution* (Reuda, Posner & Rothbart, 2005). Response inhibition refers to the suppression of a pre-planned or ongoing response (Barkley, 1997). Two of the most common measures of response inhibition are the Go/No-go task and the Stop-signal task (Castellanos, Sonuga-Barke, Milham, & Tannock, 2006). In both tasks, the go signal requires the subject to make a motor response (e.g., button press). The no-go or stop signal requires the subject to withhold the response. The frequency of go stimuli relative to no-go stimuli establishes a tendency to respond on every trial. Several studies have provided evidence of poorer response inhibition in ADHD using Go/No-go or Stop-Signal tasks (Nigg, 2001; Oosterlaan, Logan, & Sergeant, 1998; Pennington & Ozonoff, 1996; Rueda, Posner, & Rothbart, 2005; Schachar, Mota, Logan, Tannock, & Klim, 2000; Sergeant, Geurts, & Oosterlaan, 2002; Willcutt, Doyle, Nigg, Faraone & Pennington, 2005; Wodka et al., 2007).
Conflict resolution (or interference control) refers to the ability to filter out competing information that is irrelevant to the task being performed (Mullane et al., 2009). Brain areas thought to be part of the executive attention network have been shown to be active in tasks assessing conflict resolution (e.g., Stroop Colour-Word task, Flanker task, Simon task; Fan, Flombaum, McCandliss, Thomas, & Posner, 2003; Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Raz & Buhle, 2006). These tasks induce conflict by asking the participant for a response that is different to the one suggested by the stimulus presented (Reuda et al., 2005). For example, the Stroop task requires the participant to read the word ‘RED’ written in green ink. Similarly, the Simon task requires the participant to respond to an upward arrow presented below fixation, or a left pointing arrow presented to the right of fixation (Reuda et al., 2005).

Children’s performance on these ‘incongruent trials’ is compared to their performance on ‘congruent trials’ in which there is no stimulus-response conflict (e.g., read colour words written black ink or respond to a downward arrow presented below fixation).

The Stroop task has been the most commonly used task in this context; however there are mixed results in the literature regarding a deficit in conflict resolution in ADHD compared to controls, as measured by the Stroop Colour-Word task (Homack & Riccio, 2004; Lansbergen et al., 2007; Schwartz & Verhaeghen, 2008; Van Mourik et al., 2009; Van Mourik, Oosterlaan, & Sergeant, 2005). Some studies have found evidence for a deficit in conflict resolution (Homack & Riccio, 2004; Lansbergen et al., 2007), with greater differences in speed and accuracy on incongruent trials relative to congruent trials for children with ADHD compared to controls. Other studies have found no differences between groups (Van Mourik et al., 2005). Some of the inconsistency could be due to different administration formats (e.g., cards vs. computer-based) or different methods for calculating the Stroop interference score (Lansbergen et al., 2007). Van Mourik and colleagues (2005, 2009) concluded that the Stroop Colour-
Word task is not a good task to assess to conflict resolution in ADHD, due to possible confounding factors such as children’s reading ability, or rapid naming ability. Reading speed and reading ability have been shown to be poorer in children with ADHD.

Studies using other tasks such as the Flanker task or Simon task have more consistently demonstrated poor conflict resolution in children with ADHD (e.g., Johnson et al., 2008; Mullane et al., 2009; Mullane et al., 2011; Tsal, Shalev & Mevorach, 2005). For example, a meta-analysis of 12 studies using the Flanker or Simon task, found greater differences in speed and accuracy on incongruent trials relative to congruent trials for children with ADHD compared to controls, providing evidence for poorer conflict resolution in ADHD (Mullane et al., 2009). Using the Attention Network Test-Interaction (50% Flanker trials, 50% Simon trials), Mullane and colleagues (2011) found that the increase in Reaction Time (RT) on incongruent trials relative to congruent trials was significantly larger for children with ADHD than controls. Tsal and colleagues (2005) also found that children with ADHD demonstrated greater interference on a Simon task, when required to respond to stimulus direction. These tasks provide a means with which to test children’s conflict resolution, while eliminating the potential confounds of reading-related abilities noted on the Stroop task.

To our knowledge, there has only been one study that has looked at the effects of concurrent white noise on executive functioning. Helps, Bamford, Sonuga-Barke, and Söderlund (2014) examined the effects of different intensities of white noise on Go/No-go task performance in a non-clinical sample. Children with sub-attentive, normal-attentive, and super-attentive abilities, as rated by their teachers, each performed the Go/no-go task under three different levels of white noise – 65db, 75db and 85db. The sub-attentive group showed a significant improvement in performance (fewer omission errors) with a shift from low to moderate levels of white noise (Helps et al., 2015). Performance appeared to decrease for super-attentive children as the white noise
intensity increased. While these results indicate that white noise can improve executive functioning in children with sub-clinical attention problems, further research is needed to determine whether this effect can be replicated with a clinical sample of children diagnosed with ADHD.

The current study extends previous research by examining the impact of concurrent auditory noise on two functions linked to executive attention, inhibition and conflict resolution, in children with an ADHD diagnosis. Based on the results obtained by Helps and colleagues (2014), we predict that these children will perform better on the Go/No-go task in the presence of white noise. We further predict that the children will show better conflict resolution in the presence of white noise, as measured by a Simon task (adapted from Tsal et al., 2005).

5.2 Method

5.2.1 Participants

Participants were 33 children ($M_{age} = 9, SD = 1.97$; age range: 7-14 years) with a previous ADHD diagnosis given by a paediatrician, psychologist, or psychiatrist. Five participants were excluded due to a comorbid Pervasive Developmental Delay (PDD) diagnosis or failure to attend both testing sessions. The final sample consisted of 28 children aged 7-14 years (18 male, 10 female, $M_{age} = 9.07, SD = 1.89$). Of these, 18 children had an ADHD-combined type (ADHD-C) diagnosis and 10 had an ADHD-predominantly inattentive type (ADHD-PI) diagnosis. Professional diagnoses specifying ADHD subtype were used to classify children as ADHD-C or ADHD-PI for most children. However, if this information was not readily available, the Conners 3 Parent Rating Scale (Conners, 2008) was used to classify children. Seven children had a comorbid Learning Disorder diagnosis, five children had comorbid Oppositional Defiant Disorder or Conduct Disorder diagnoses, and five children had comorbid Mood or Anxiety Disorder diagnoses.
Twenty-one children were on stimulant medication such as Concerta, Ritalin or Dexamphetamine (or a combination of these) at the time they participated in the study. For ethical and practical reasons, these children continued their regular medication regime, and parents were asked not to make any changes to their child’s treatment for the duration of their involvement in the study. One medicated child, whose parents chose not to give him his ADHD medication on the days the child participated in the study, was included in the ‘non-medicated’ group. Twenty children were therefore classified as medicated and eight were classified as non-medicated.

Prior to testing, the first author conducted a screening interview with parents via telephone to ensure children met inclusion criteria for the study (ADHD diagnosis, absence of a comorbid Autism Spectrum Disorder or colour blindness). Parents completed the Conners 3 Parent Rating Scale (Conners, 2008) and the Child Behaviour Checklist (CBCL/6-18; Achenbach & Rescorla, 2001) and a questionnaire developed specifically for the present study requesting background information about the child’s ADHD diagnosis, comorbid diagnoses, current medication status and medication history, treatment history and home environment.

5.2.2 Materials and Stimuli

Visual stimuli were presented on a laptop using a Dell Precision 17 inch monitor with 60Hz refresh rate and screen resolution 1920 x 1080 pixels. Stimuli were programed using Inquisit 3.0.6.0 (Millisecond Software).

**Go/No-go Task.** The display area consisted of a white background (37.2° x 23.3°). Two versions of the task were created to reduce practice effects, differing only in target picture chosen. In version A, the target stimuli were a 10 x 10 cm (11.46° x 11.46°) cartoon lion coloured green (go target) or red (no-go target; see Figure 5.1). In version B, the target stimuli were a 12.5 x 12.5 cm (14.32° x 14.32°) cartoon dinosaur coloured green (go target) or red (no-go target). A single trial involved the following
sequence of events: (a) a blank white screen displayed for one of five stimulus onset asynchronies (SOAs = 100, 200, 300, 400 or 500 milliseconds); (b) a go or no-go target, which remained visible until a response occurred or 1000 milliseconds had elapsed; and (c) an inter-trial interval of 700 milliseconds.

The experiment consisted of two blocks of 80 trials, with a go/no-go ratio of 3:1 (75% go trials, 25% no-go trials). All participants completed eight practice trials prior to commencing the first test block. Participants were required to press the keyboard spacebar as quickly as possible when they saw a ‘go’ target (green lion or dinosaur) and to inhibit a response to the ‘no-go’ target (red lion or dinosaur).

*Figure 5.1.* Go/No-go task screen shots. (A) Version A – lion; (B) Version B – dinosaur.

**Simon Task.** The display area consisted of a white background (37.2° x 23.3°). Two versions of the task were again created to reduce practice effects, differing only in the orientation of the arrows. In version A, participants were presented with a 6 x 2.9 cm vertical black arrow (6.88° x 3.32 °). The arrow pointed either up or down and appeared either 3.3 cm above or below fixation (See Figure 5.2). In version B, participants were presented with a 2.9 x 6 cm horizontal black arrow (3.32° x 6.88 °) that pointed either left or right and appeared 8.3 cm to the left or right of fixation. A
trial involved the following sequence of events: (a) a fixation cross (+) for 100 milliseconds, (b) a blank white screen displayed for 700 milliseconds; (b) a target, which remained visible until a response occurred; and (c) one of five inter-trial intervals (ITIs = 600, 700, 800, 900, or 1000 milliseconds).

The experiment consisted of two blocks of 52 trials (104 trials in total). All participants completed eight practice trials prior to commencing each test block. Half of the trials in each block were congruent (e.g., an arrow above fixation, pointing upward) and half were incongruent (e.g., an arrow above fixation, pointing downward). There were two task conditions (direction and location), with congruent and incongruent trials randomly intermixed within each block. In the direction condition, participants responded to the direction the arrow was pointing, regardless of its location. In the location condition, the participants responded to the location of the arrow, regardless of its direction. The order of the task conditions was counterbalanced. Participants responded up by pressing the ‘8’ key, down by pressing the ‘2’ key, left by pressing the ‘4’ key and right by pressing the ‘6’ key on the number pad.

Figure 5.2. Simon task screen shots. (A) Version B congruent trial; (B) version B incongruent trial; (C) version A congruent trial; (D) version A incongruent trial.
Audio Stimuli. The white noise stimulus ‘Medium Rain’ was taken from an iPhone application titled ‘Sleep Machine’ (SleepSoft LLC, 2011). The white noise stimulus was presented using an iPhone 5 via Apple EarPods at medium volume, which all participants reported was a comfortable noise level. The background classroom noise audio consisted of a series of pre-recorded tracks of classroom noises downloaded from www.audiosparx.com, and linked together using GarageBand ’09 Version 5.1(398). The classroom noise audio was presented using an iPod Nano via speakers (Sony iPhone dock, Model ICF-C1iPMK2) during both experimental conditions. The classroom noise ranged from 36.0 – 59.2 dBA. Noise level was measured using a Digitech QM-1589 sound level meter.

5.2.2 Procedure

Participants completed the computer-based attention tasks individually, at a viewing distance of approximately 50cm. The Go/No-go task and Simon task were completed as part of a battery of attention tasks. Participants completed all the tasks on two occasions, under different noise conditions: classroom noise and classroom noise + white noise. Condition order was counterbalanced among participants, with half of the participants exposed to the white noise during the first testing session, and half during the second testing session. Testing sessions were scheduled 2-4 weeks apart to minimize learning and test-retest effects. Task order was randomized across participants but remained the same for each individual participant across conditions. During the classroom noise + white noise condition, participants were required to remove the Apple EarPod headphones (white noise stimulus) while the experimenter provided verbal instructions for each task.

5.3 Results

Multilevel modeling was used to analyze results in the two previous studies due to the unequal number of medicated and non-medicated children in the sample,
homogeneity of variance violations. Since no such violations were detected for the current Go/No-go task and Simon task data, multilevel modeling was not conducted.

5.3.1 Go/No-go Task

Several preliminary analyses were conducted on the Go/No-go data in order to ensure reliable and valid estimates of the response parameters derived from this task. For Go trials with very low RT (<100ms), the data were recorded as missing. Potential univariate outliers (z > 3.29, see Tabachnick & Fidell, 2007) within the mean RT raw data set were deleted prior to analysis.

Accuracy. A 2 (Condition: Classroom Noise vs. Classroom Noise + White Noise) x 2 (Medication Status: Yes vs. No) mixed ANOVA was conducted to assess No-go response accuracy (i.e., correctly withholding a response) across conditions, and between medicated and non-medicated children. There were no significant main or interaction effects (p <.05).

Two outliers (z > 3.29) were removed prior to analyzing Go response accuracy data due to significant negative skew. Even after removing these outliers, it was not possible to transform the percentage of correct Go responses to approach the normal distribution. Therefore, the percentage of correct responses to Go targets in the classroom noise + white noise and classroom noise conditions were compared with a non-parametric Wilcoxon Rank test. The Wilcoxon Signed Rank test revealed no significant difference in Go response accuracy between the two noise conditions, z = -1.147, p = .251.

Reaction time. A 2 (Condition) x 2 (Medication Status) mixed ANOVA was conducted to assess mean RT for correct response to ‘Go’ targets. There were no main or interaction effects, indicating no differences across conditions or between medicated and non-medicated children (p > .05).
**SDs.** A 2 (Condition) x 2 (Medication Status) mixed ANOVA was conducted to assess whether RT variability differed based on condition or medication status. There was a main effect of medication status (F(1, 26) = 6.275, \( p = .015, \eta^2 = .205 \)), with non-medicated children showing greater RT variability. The condition x medication status interaction was also significant (F(1, 26) = 5.115, \( p = .032, \eta^2 = .164 \)). RT variability was greater in the classroom noise condition than the classroom noise + white noise condition for non-medicated children, whereas for medicated children, variability was greater in the classroom noise + white noise condition.

**5.3.2 Simon task.**

RT and response accuracy difference scores were calculated for each task condition (direction and location blocks). To calculate the difference scores, the mean RT (or % correct) on congruent trials was subtracted from the mean RT (or % correct) on incongruent trials (e.g., Mullane et al., 2009). Larger scores are indicative of less efficient interference control. So as not to confuse noise condition with task condition, ‘dimension’ will be used in reference to the different direction and location trial blocks. Thus there were three main effects – condition (classroom noise + white noise vs. classroom noise), medication (medicated vs. non-medicated) and dimension (direction vs. location).

**Accuracy.** Prior to analyses, three outliers (z > 3.29) were removed from the data set. A 2 (condition) x 2 (dimension) within-subjects ANOVA was conducted to compare accuracy difference scores across conditions. The main effect of dimension approached significance \( F(1, 24) = 3.659, p = .068 \), with larger difference scores on the location block compared to the direction block. A 2 (condition) x 2 (dimension) x 2 (block: 1 vs. 2) mixed ANOVA was conducted to assess whether the effects of white noise were influenced by block order. There were no significant main or interaction effects for condition or block order (\( p > .05 \)).
A 2 (condition) x 2 (dimension) x 2 (medication status) mixed ANOVA was conducted to assess whether accuracy difference scores across conditions differed based on medication status. There were no significant main or interaction effects ($p > .05$).

**Reaction time.** Prior to analyses, four outliers ($z > 3.29$) were removed from the data set. A 2 (condition: classroom noise + white noise vs. classroom noise) x 2 (dimension: direction vs. location) within-subjects ANOVA was conducted to compare RT difference scores across conditions. There were no significant main or interactions effects ($p > .05$). A 2 (condition) x 2 (dimension) x 2 (block: 1 vs. 2) mixed ANOVA was conducted to assess whether the effects of white noise were influenced by block order. Again, all main effects and interactions were non-significant ($p > .05$).

A 2 (condition) x 2 (dimension) x 2 (medication status) mixed ANOVA was conducted to assess whether RT difference scores across conditions differed based on medication status. There was a significant interaction between dimension and medication status $F(1, 22) = 5.382, p = .030, \eta^2 = .197$, such that for medicated children, difference scores were higher on the location block, and for non-medicated children, difference scores were higher on the direction block. There were no significant condition interactions.

### 5.4 Discussion

The aim of this study was to assess the impact of concurrent white noise on executive attention in children with ADHD, in particular response inhibition and conflict resolution. The study assessed children’s performance a Go/No-go task and a Simon task in the presence and absence of a white noise stimulus played via headphones.

Previous studies that have demonstrated concurrent noise (e.g., white noise, music) to be beneficial for task performance in children with ADHD, and a recent study that found moderate levels of white noise improved executive functioning performance
in sub-attentive children (Helps et al., 2014). Based on these findings, it was predicted that participants would perform better on both the Go/No-go and Simon tasks in the presence of white noise. The findings did not support this hypothesis. Adding white noise neither improved nor disrupted performance on the Simon task. There was a small condition by medication status interaction for reaction time variability on the Go/No-go task, however the absence of a significant effect for RT or accuracy suggests that this interaction is likely negligible.

There was no difference between noise conditions for Go response accuracy (omission errors), No-go response accuracy (commission errors), or reaction time, suggesting that the concurrent white noise had no impact on response inhibition. This is at odds with the finding by Helps et al. (2014) that a moderate level of white noise was associated with fewer Go/No-go omission errors than low levels of noise. It is possible that methodological differences could account for these results. The Go/No-go task used by Helps et al. (2014) was more cognitively demanding – the go target was a left/right green arrow and the no-go target was a double-ended green arrow. These targets were likely harder to distinguish from one another than the green (go) and red (no-go) targets used in the current study. Go response accuracy (94-95%) and no-go response accuracy (85%) were both high across conditions, so it may be that there was not enough variability to identify a difference between noise conditions. Helps et al. (2014) did not report raw accuracy scores so it is not possible to comment on how our accuracy rates compares with those in their study. Another possibility is that with a different level of white noise, differences in Go/No-go task performance may become apparent. Helps et al. (2014) tested three different levels of white noise (65db, 75db and 85db). There may also be an interaction between noise intensity and task complexity; however, further research would be needed to explore this possibility. The absence of a significant difference between noise conditions for RT and accuracy difference scores on the
Simon task suggests that in the current study, the concurrent white noise had no impact on conflict resolution. As was the case for the Go/No-go task, accuracy was high for both congruent and incongruent trials, so it is possible that there was not enough variability to identify a difference between noise conditions for the Simon task.

There are limitations in the current study that should be considered when interpreting the results. Normal controls were not included as a comparison group in the current study design because we were more interested in the nature of the impact of white noise on executive attention processes in children diagnosed with ADHD, than the differential impact of noise on normal controls versus children with ADHD. Without a normal control group however, it is not possible to comment as to whether the children with ADHD showed deficits on the Go/No-go and Simon tasks, compared to controls, before the addition of the concurrent white noise (i.e., were they performing below controls to start with?). The absence of a control group was less important in previous studies (e.g., Help et al., 2014) that did demonstrate an effect for white noise, but becomes more important when no effect for white noise is found, as is the case in the current study.

Overall, the findings from the current study suggest that the beneficial effect of white noise for task performance observed in previous studies does not extend to an improvement in executive attention. Compared to the selective attention and sustained attention processes that were examined in previous chapters, executive attention is a higher order cognitive process. It may be that white noise does not affect different cognitive processes in the same way, or that different noise intensities are required for a beneficial effect. This could be a focus for future research.

5.5 References


Chapter 6

Discussion

6.1 Summary of Research Findings

The purpose of the current thesis was to investigate the effects of concurrent white noise on three different types of attention – selective attention, sustained attention/vigilance, and executive attention. The study in Chapter 3 found that white noise might improve the speed with which children with ADHD can accurately identify a visual target among task-irrelevant distractors, but this was the case for medicated children only, suggesting the potential for an additive effect between concurrent noise and medication. The study in Chapter 4 revealed that – again – for medicated children, white noise improved vigilance, whereas for non-medicated children white noise had a negative impact on vigilance. The study in Chapter 5 found that the addition of concurrent white noise neither improved nor disrupted performance on the Simon task. While there was a small condition x medication status interaction for reaction time variability on the Go/No-go task, the absence of a significant effect for RT or accuracy suggests that this interaction is likely negligible. The study in chapter 5 therefore found no meaningful effect of white noise on executive attention. A more detailed account of the findings is provided in sections 3.4, 4.4, and 5.4.

The current thesis set out to test whether or not the beneficial effect of white noise for children with ADHD observed in previous studies could reflect improvements in three core attentional processes. The overall outcome of experiments summarized above was more complex than this. The current chapter will therefore provide a discussion of the implications of this unexpected finding with regard to medication status.
6.2 Comparison with Previous Research

Multiple researchers have identified white noise as a potential intervention for children with ADHD (Cook, Johnson, & Bradley-Johnson, 2015; Söderlund, Sikström, & Smart, 2007). Given the need for strong evidence-based interventions in clinical practice, it is important to obtain empirical support regarding the types of tasks and circumstances under which children with ADHD may benefit from concurrent noise. Previous studies have demonstrated a beneficial effect of white noise on cognitive performance and off-task behaviours in children with ADHD (Söderlund et al., 2007; Cook, Bradley-Johnson, & Johnson, 2014; Cook et al., 2015), but the current thesis is the first to examine and compare the impact of white noise on specific attentional processes. Based on the current results, the beneficial effect of concurrent noise observed in previous studies are unlikely to be explained by improvements in executive attention. With respect to selective attention and vigilance, the results indicate that white noise may have a beneficial effect for some children with ADHD but not all. The current thesis complements and extends previous research in these areas.

Of particular interest, the results from the current thesis revealed that the nature of the effect of white noise may be dependent on children’s medication status. Consistent with our finding that white noise was beneficial for medicated children, two previous studies have shown that listening to white noise had a beneficial effect on assignment completion and off-task behaviours for children with ADHD on stimulant medication (Cook et al., 2014; Cook et al., 2015). Cook and colleagues (2014) found that for three children with ADHD who were on stimulant medication, listening to white noise reduced passive off-task behaviours in the classroom setting. A follow-up study by Cook and colleagues (2015) also demonstrated a combined effect of white noise and

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1 We again acknowledge that the concurrent auditory stimulus (rain) used in this series of experiments was not technically white noise, but was chosen as a more ‘child-friendly’ substitute.
stimulant medication. Their study compared the effects of white noise alone, medication alone, and combined white noise + medication on off-task behaviour and academic task performance (accuracy and amount produced) in the classroom for a single child with ADHD. Cook et al. (2015) found that a combination of white noise and stimulant medication was more beneficial than either of the two interventions alone, but that both medication and white noise were associated with a reduction in off-task behaviours compared to baseline.

6.3 Theoretical and Practical Implications of Findings

6.3.1 Evidence-based interventions for ADHD

Among the most common treatments for ADHD are prescription stimulant medications (NCCMH, 2009). The medications with the strongest evidence-based support are the stimulants methylphenidate and amphetamine (Greydanus, Nazeer, & Patel, 2009). Stimulants have been shown to effectively reduce inattention, hyperactivity and impulsivity in children and adolescents diagnosed with ADHD (Faraone & Buitelaar, 2010; Greydanus, Sloane, & Rappley, 2002; Sunohara et al., 1999). As a result, there has been a steady increase in stimulant use for ADHD over the last two decades (Prosser, Lambert, & Reid, 2015; Prosser & Reid, 2009; Zuvekas & Vitiello, 2012). However, there are several limitations to the exclusive use of medication in the treatment of ADHD. These include the fact that a significant number of children with ADHD are non-responsive to stimulant medication, the lack of evidence supporting to the long-term benefits of stimulant use, and the potential adverse effects of taking stimulants (Jensen et al., 2007; NCCMH, 2009). Common side effects include loss of appetite, weight loss, insomnia, abdominal pain and headaches (Graham & Cognhill, 2008; Graham et al., 2011; Greydanus et al., 2009). Thus research investigating non-pharmaceutical alternatives or possible adjuncts to medication will be important for clinicians and families of children with ADHD.
There is extensive research demonstrating that behavioural interventions improve outcomes for children with ADHD at home and in the school setting (Fabiano et al., 2009; Pelham & Fabiano, 2008). Behavioural interventions involve modifying environmental factors that contribute to (e.g., setting, structure) or reinforce (e.g., attention received from parents or teachers) problematic behaviours (Chronis, Jones, & Raggi, 2006). Several behavioural interventions have received empirical support, including behavioural parent training, classroom contingency management, academic interventions (e.g., task and instructional modifications), and social skills training (Chronis et al., 2006; Pelham & Fabiano, 2008; Van der Oord, Prins, Oosterlaan, & Emmelkamp, 2008). Research has shown than combining medication with behavioural interventions, may allow for a reduction in medication dosage (MTA Cooperative Group, 1999).

Based on previous research demonstrating a beneficial effect of concurrent noise for children with attention problems and ADHD, it has been proposed that white noise may offer an alternative to medication (Helps, Bamford, Sonuga-Barke, & Söderlund, 2014; Söderlund et al., 2007). However, rather than a replacement for medication, the results of the current thesis suggest that white noise – or additional auditory stimulation in general - may be helpful as an adjunct to stimulant medication for children with ADHD. It is important to also consider the likelihood of individual differences in children’s response to concurrent noise. It may be that concurrent noise is useful for some children but not all; or, it may be that there are individual differences in the level of noise that is found to be beneficial. A range of factors, including medication status, could contribute to potential individual differences in children’s response to concurrent noise.
6.3.2 U-shaped function of arousal

Multiple researchers have linked the idea of an optimal level of arousal to ADHD (e.g., Abikoff, Courtney, Szeibel & Koplewicz, 1996; Söderlund, Sikström & Smart, 2007; Zentall & Zentall, 1983). As outline previously, the Moderate Brain Arousal (MBA) model proposed by Sikström & Söderlund, (2007) is based on the phenomenon of stochastic resonance SR. When signal detection is plotted against noise intensity, the relationship produces an inverted U-curve (Moss, Ward, & Sannita, 2004). Söderlund and colleagues (2007, 2010) propose that the relationship between noise and cognitive performance follows a similar U-curve. That is, moderate levels of concurrent noise is beneficial for cognitive performance, while too much or too little noise hinders performance (Söderlund et al., 2007). The MBA model suggests that concurrent white noise can compensate for low levels of neural noise via SR (Sikström & Söderlund, 2007; Söderlund, Sikström, Loftesness, & Sonuga-Barke, 2010). The model predicts that when internal neural noise levels are low, high levels of concurrent white noise are needed to achieve SR, and when internal noise is high, less white noise is required (Sikström & Söderlund, 2007). It is thought that internal neural noise is linked to dopamine function, where low levels of dopamine are associated with low levels of neural noise (Söderlund et al., 2007). The MBA model proposes that for children with ADHD, which is associated with a hypofunctional dopamine system, a higher level of concurrent white noise is required to achieve peak cognitive performance than for children without ADHD (Sikström & Söderlund, 2007). That is, the position of the inverted U-curve differs for children with and without ADHD.

Stimulant medication acts on the dopamine system (Greydanus et al., 2009), increasing dopamine levels in the brain. It is possible then that medicated and non-medicated children with ADHD require different intensities of white noise for a beneficial effect to be observed. If this is the case, it may be that the noise used in the
current series of experiments was sufficient to improve performance for medicated children but was not sufficient to produce the same positive effect for non-medicated children.

6.4 Limitations and Future Directions

There are several limitations in the current studies. Firstly, it must be acknowledged that comorbidities were not included in the statistical analyses. It was decided that it would be statistically unreliable to collapse the different comorbidities, such that if each of the three categories of comorbidities had been analyzed separately there would have been insufficient statistical power. While the possibility that comorbidities may influence the effects of white noise cannot be ruled out without future research that addresses it directly, it is unlikely that comorbidities within the current sample accounts for the condition by medication status interaction observed on the visual search and continuous performance tasks. There was a similar proportion of comorbid learning, externalizing and internalizing disorders in the medicated groups as compared to the non-medicated group.

The use of a heterogeneous sample of ADHD children in the current series of studies reflects the true nature of the disorder. ADHD is a heterogeneous disorder, with children displaying different combinations of inattentive and hyperactive-impulsive symptoms. Moreover, research has shown that a large proportion of children with ADHD have difficulties that extend beyond the symptoms that characterize ADHD (Larson, Russ, Kahn, & Halfon, 2011; Root & Resnick, 2003). Children with ADHD have been shown to have a range of comorbid disorders, including learning disabilities, oppositional defiant disorder, conduct disorder, tic disorders, anxiety disorders, and mood disorders (Brown, 2009). As noted previously, one of the objectives of the current study was to investigate whether white noise is a viable and easily implementable everyday intervention for improving attention in children with ADHD. Given the high
degree of comorbidity in ADHD (Larson et al., 2011; Root & Resnick, 2003), including children with the above comorbid diagnoses in the current series of experiments, allowed us to assess this within a more ecologically valid sample as it represents the ‘real’ ADHD population.

Secondly, the studies in the current thesis did not set out to control for medication status, and thus do not allow for a comparison of the relative effects of white noise and medication. The unequal number of medicated and non-medicated children in the current sample is a notable limitation, reducing the statistical power. Nevertheless, demonstrating significant interactions between medication and noise, attests to the robustness of the finding, and warrants far more research in this area with larger and more tightly controlled samples. For example, further research is needed to explore the possible differential impact of noise on medicated versus non-medicated children with ADHD to explore the interaction between medication status and noise intensity. Examining the effects of different decibel levels of white noise for medicated and non-medicated children with ADHD, as well as different types of concurrent noise, could address this.

As discussed previously, the inclusion of a normal control group in future studies would allow researchers to confirm whether there were significant differences in task performance between groups to start with, which may be particularly useful in cases where no effect of noise is found. Assuming a beneficial effect is observed for children with ADHD, a normal control group comparison would allow researchers to assess whether or not the addition of white noise brings ADHD children’s task performance up to the level of that of children without ADHD. This would explore whether the concurrent noise is ‘normalizing’ the attentional engagement in ADHD children.
6.5 Conclusion

The current thesis extended previous research that has demonstrated a beneficial effect of white noise for children with ADHD, by examining the effect of concurrent white noise on three different types of attention – selective attention, vigilance and sustained attention, and executive attention. While no overall effect of white noise was observed for any of the three attentional processes, an interesting pattern emerged across the visual search continuous performance tasks. The current data suggests that the nature of the effect of white noise on attention may depend on children’s medication status, with white noise helpful as an adjunct to medication for children with ADHD.

6.6 References


Appendix A

Parental Consent Form

The Impact of a Concurrent Auditory Stimulus on Attention in Children with ADHD

Participation in the current study will involve:

• Completing three questionnaires about my child’s learning and behaviour at home, and their treatment history.
• My child will participate in 2 testing sessions each approximately 1 hr. My child will be asked to complete a series of computer-based attention tasks and a writing task. My child will complete these tasks in the presence and absence of a constant unvarying auditory stimulus.
• No changes will be made to the treatment(s) my child is receiving for the duration of their involvement in the current study.

I understand that participation in this study is voluntary and that my child or I can withdraw at any stage change. I have been advised that the results of the project may be published but that my child’s details will remain confidential. I have been advised that I will be sent a letter summarizing the overall results on completion of the study.

I ____________________________ have read the information above and give consent for my child ___________________________ to participate in the study ‘The Impact of a Concurrent Auditory Stimulus on Attention in Children with ADHD’.

Parent’s/Guardian’s Name: ______________ Signature: _____________ Date: ___/___/13
Appendix B

Participant Information Sheet

The Impact of a Concurrent Auditory Stimulus on Attention in Children with ADHD

Dear Parent/Guardian,

I am a student at the Australian National University studying towards a Doctorate of Clinical Psychology.

The purpose of this study is to investigate how the presence of a concurrent auditory stimulus affects basic attentional processes in children with ADHD. Recent research has suggested that such a stimulus may improve task performance in children with ADHD but further research is needed to identify which cognitive processes may benefit. This study will contribute to our understanding of attentional processes in children with ADHD and environments that may optimise task performance for these children.

The study comprises several components. First, there are two questionnaires for you to complete regarding your child’s learning and behaviour at home, and their treatment history. In addition, if your child participates, they will take part in 2 testing sessions each lasting approximately 1 hour. In these sessions your child will be asked to complete a series of computer-based attention tasks and a writing task. Your child will complete these tasks in the presence and absence of a constant unvarying auditory stimulus.

You will be sent a letter summarizing the overall results on completion of the study.

Data from each participant will be stored securely on a password-protected laptop and kept for five years from publication. All material will be treated in a strictly confidential manner as far as the law allows. Data from this study will form part of the researcher’s dissertation, and may be presented at professional conferences, and/or published in professional journals. However, no participant will be identifiable in these presentation formats.

Participation in this study is voluntary, and you or your child may withdraw at any time. If you choose to withdraw, your child’s data will be destroyed. If you agree for your child to participate in this study, please complete the consent form attached. If you have any queries or concerns, please do not hesitate to contact myself (6125 0788, Rosemary.Allen@anu.edu.au) or my supervisor, Dr Kristen Pammer (Kristen.Pammer@anu.edu.au).

The ethical aspects of this research have been approved by the ANU Human Research Ethics Committee (Protocol No. 2012/535). If you have any concerns or complaints about how this research has been conducted, please contact:

Ethics Manager
The ANU Human Research Ethics Committee
The Australian National University
I _____________________________ have read and understood the information above and give consent for my child _________________________________ to participate in the study ‘The Impact of a Concurrent Auditory Stimulus on Attention in Children with ADHD’. I understand that if I change my mind I am free to withdraw my child from this study at any stage. I have been advised that the results of the project may be published but that my child’s details will remain confidential.

Parent’s/Guardian’s Name:________________________ Signature: __________________________ Date: ___/___/13
Name of Researcher:________________________ Signature: __________________________ Date: ___/___/13
Appendix C

PARENT QUESTIONNAIRE

PART A: Demographic Information

Child’s Date of Birth: _____________
Country of Birth: ________________
If your child was not born in Australia, how long have they lived in Australia? ______
Are there languages spoken at home other than English? Yes ☐ No ☐
If yes, please specify ________________________________________________________

PART B: Educational Information

Name of School child is attending: _____________________________________________
Grade: _____________________
Has your child ever repeated a grade? Yes ☐ No ☐
Did you hold your child back from starting school? Yes ☐ No ☐

PART C: Clinical Information

Please indicate whether any of these diagnoses apply to your child by ticking the boxes (yes/no). If yes, please specify which professional(s) provided this diagnosis. This may have been a medical practitioner (e.g., GP, Paediatrician), school counsellor, or mental health professional (e.g., psychologist, psychiatrist, CAMHS worker, neuropsychologist).

ADHD/ADD
Yes ☐ No ☐
Diagnosed by: ☐ General Practitioner
☐ Paediatrician
☐ Psychiatrist
☐ Psychologist
☐ Neuropsychologist
☐ School Counsellor
☐ Other (please specify)
If possible please specify subtype: ☐ ADHD- Predominately Inattentive
☐ ADHD- Combined
Learning Disorder

Yes ☐ No ☐

Diagnosed by:
☐ General Practitioner
☐ Paediatrician
☐ Psychiatrist
☐ Psychologist
☐ Neuropsychologist
☐ School Counsellor
☐ Other (please specify) __________

Oppositional Defiant Disorder or Conduct Disorder

Yes ☐ No ☐

Diagnosed by:
☐ General Practitioner
☐ Paediatrician
☐ Psychiatrist
☐ Psychologist
☐ Neuropsychologist
☐ School Counsellor
☐ Other (please specify) __________

Auditory Processing Difficulties

Yes ☐ No ☐

Diagnosed by:
☐ General Practitioner
☐ Paediatrician
☐ Psychiatrist
☐ Psychologist
☐ Neuropsychologist
☐ School Counsellor
☐ Other (please specify) __________

Mood or Anxiety Disorder

Yes ☐ No ☐

Diagnosed by:
☐ General Practitioner
☐ Paediatrician
☐ Psychiatrist
☐ Psychologist
☐ Neuropsychologist
☐ School Counsellor
☐ Other (please specify) __________

Has your child ever undergone cognitive testing (e.g., Wechsler Preschool and Primary Scale of Intelligence-IV, Wechsler Intelligence Scale for Children-IV, Woodcock Johnson)?

Yes ☐ No ☐

If YES, please provide details:

Was your child’s IQ within the Average Range (90-109)?

Yes ☐ No ☐ Not Known ☐

Your child’s estimated IQ, based on the cognitive test(s) administered: _______
PART D: Treatment History

What interventions have you, your child, or their teacher(s) tried to implement (other than medication)?
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
Which strategies have been most effective for your child? Please give details
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
Are there strategies that have not been effective for your child? Please give details
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
Appendix D

Screen Shots from the Attention Tasks

Figure D1. Visual Search Task Screen Shots.
Figure D2. Continuous Performance Task Screen Scots
Figure D3. Go/No-go Task Screen Shots.
Figure D4. Simon Task Screen Shots.