

Age-Related Changes in Visual and Auditory Sustained Attention, Inhibition and
Working Memory in Preschool-Aged Children

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July, 2010

A thesis submitted to McGill University

In partial fulfillment of the requirements for the degree of

Masters of Science in Neuroscience

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Acknowledgements

I would like to express my sincerest thanks to my thesis supervisors, Drs.

Kim Cornish and Joseph Rochford, for their expertise, guidance and advice throughout the course of my master's project. My thanks also go to Julie Hanck and Armando Bertone, for their enthusiasm, kindness and encouragement, which have comforted me so much along the way. Last, but definitely not least, I am most thankful for the unwavering love and support of my parents who have always had faith in everything I do.

With great appreciation, I must also acknowledge all participating parents and children for the generous contribution of their time and for their keen sense of interest in research efforts like the present one.

Table of Contents

Acknowledgements.....	ii
List of Tables	3
List of Figures	4
Abstract	5
Résumé	6
General Introduction.....	7
Chapter 1	9
Introduction.....	9
Attention: A Divided Construct	9
The Typical Cognitive Profile of Attention: Age-Related Changes of Attention in Children	13
Sustained Attention	15
What is Sustained Attention?	15
Assessment of Sustained Attention.....	15
Recent Findings from use of CPTs with Typically Developing Children	16
Inhibition	18
What is Inhibition?.....	18
Assessment of Inhibition Control	18
An Association of Attention and Inhibition.....	20
Working Memory	21
What is Working Memory?	21
Assessment of Working Memory	22
An Association Between Attention and Working Memory	24
An Association Between Inhibition and Working Memory	25
Summary of Subcomponent-Related Findings	26
Biological Basis of Age Related Changes in Performance	26
A Cross-Modality Approach.....	28
Rationale for the Study	29
Specific Aims and Hypotheses	31
Aims	31
Hypotheses	32
Chapter 2	33
Method.....	33
Participants.....	33
Measures	34
Procedure	41
Chapter 3	43
Results	43

Sample Characteristics.....	44
Examination of Performance as a Function of Age	45
Age related Differences in Performances of Visual and Auditory Sustained Attention	46
Age related Differences in Performances of Visual and Auditory Inhibition.....	51
Age related Differences in Performances of Visual and Auditory Working Memory	54
Summary of Performance Accuracy Across Ages Groups	55
Contribution of Age to Performance Variability	57
Linear Regression Analyses for Variables of Sustained Attention	58
Comparison of Visual and Auditory Linear Regressions: Variables of Sustained Attention	61
Linear Regression Analyses for Variables of Inhibition	63
Figure 11a. Linear Regression for Age and Visual Correct Responses.....	64
Figure 12b. Linear Regression for Age and Auditory Correct Responses	65
Comparison of Visual and Auditory Linear Regressions: Variables of Inhibition ...	66
Correlations Between Visual and Auditory Tasks	67
Correlation Analyses of Accuracy Across Cognitive Measures of Sustained Attention, Inhibition and Working Memory	68
Correlations Among Ratings and Performances of Sustained Attention and Inhibition.....	69
Chapter 4	71
Discussion	71
Age-Related Differences in Sustained Attention	72
Age-Related Differences in Inhibition.....	74
Age-Related Differences in Working Memory.....	76
Association of Performance Accuracy Across Modalities.....	77
Association of Performance Accuracy Across Tasks	79
Association of Attention Ratings and Performance Accuracy in Sustained Attention and Inhibition	79
Limitations and Directions for Future Research	80
Conclusion	82
Bibliography.....	84
APPENDIX A	95
Mean Performance Accuracy Values in Visual and Auditory Sustained Attention, Inhibition and Working Memory	95

List of Tables

Table 1	. Participant Information, Estimated IQ Scores and Parent Rating Scale	45
Table 2	. Median Scores by Age Group for VISUAL Cognitive Measures	48
Table 3	. Median Scores by Age Group for AUDITORY Cognitive Measures	49
Table 4	. Correlations of Visual Performance Accuracy Between Cognitive Measures	68
Table 5	. Correlations of Auditory Performance Accuracy Between Cognitive Measures	69
Table 6	. Correlations Between Variables of Sustained Attention and Conner's Parent Rating Scale	70
Table 7	. Correlations Between Variables of Inhibition and Conner's Parent Rating Scale	70

List of Figures

Figure 1	. Hypothetical example of a picture plate in the PPVT-Third Edition.	35
Figure 2	. Stimuli included in the newly-adapted visual CPT and Dog-Cat Inhibition tasks	38
Figure 3	. Mean Reaction Times and SEM for the Target in the Visual CPT	50
Figure 4	. Mean Reaction Times and SEM for the Target in the Auditory CPT	51
Figure 5	. Reaction Times and SEM for Correct Responses in the Visual Dog-Cat Task	53
Figure 6	. Reaction Times and SEM for Correct Responses in the Auditory Dog-Cat Task	54
Figure 7	. Median Scores (25th and 75th percentile) Across Age Groups on Visual and Auditory Working Memory Tasks	55
Figure 8	. Summary of Performance Accuracy According to Age ($\geq 65\%$ Accuracy Rate)	57
Figure 9a	. Linear Regression for Age and Visual Mean Percent Hits	59
Figure 9b	. Linear Regression for Age and Auditory Mean Percent Hits	59
Figure 10a	. Linear Regression for Age and Visual Reaction Time	60
Figure 10b	. Linear Regression for Age and Auditory Reaction Time	60
Figure 11a	. Linear Regression for Age and Visual Correct Responses	64
Figure 11b	. Linear Regression for Age and Auditory Correct Responses	64
Figure 12a	. Linear Regression for Age and Visual Correct Responses	65
Figure 12b	. Linear Regression for Age and Visual Correct Responses	65

Abstract

To date, the differential development of the subcomponents of attention and executive function in preschool ages is not yet fully understood. Although there exists a large-body of research investigating the maturation of attention and executive function throughout the school-ages, little is known about the emergence of such skills among preschool-aged children. The importance of delineating age-related changes of attentional proficiencies and deficiencies rests largely in their utility for understanding atypical developmental trajectories; specifically in neurodevelopmental disorders that are characterized by attentional difficulties. Using adapted computerized paradigms, the present study examined age-related changes in visual and auditory sustained attention, inhibition and working memory in seventy typically-developing children aged 3 to 6 years. The results indicated that similar age-related gains in performance emerged across all three cognitive tasks and both visual and auditory modalities, which suggest that the adapted-measures used are sensitive enough to capture developmentally-associated variations in performance.

Résumé

Présentement, le développement différencié des sous-composantes de l'attention et des fonctions exécutives durant les âges préscolaires n'est pas entièrement compris. Bien qu'il existe un grand corps de recherche portant sur la maturation de l'attention et les fonctions exécutives dans les enfants d'âge scolaire, il reste encore beaucoup à apprendre concernant l'émergence de ces compétences chez les enfants d'âges préscolaires. Il est nécessaire de délimiter les compétences et les carences attentionnelles dans le développement typique pour qu'on puisse utiliser ces informations pour mieux comprendre et définir les trajectoires des habilités attentionnelles dans le développement atypique; précisément, dans les troubles du développement neurologique qui se caractérisent par des difficultés attentionnelles. En utilisant des paradigmes informatiques adaptés, la présente étude a examiné le développement de l'attention soutenue, l'inhibition et la mémoire de travail visuelle et auditive chez soixante-dix enfants au développement typique âgés de 3 à 6 ans. Les résultats montrent que des améliorations de performance liées à l'âge ont émergé à travers les trois tâches cognitives et les modalités visuelle et auditive, suggérant que les paradigmes adaptés utilisés sont suffisamment sensibles pour capturer des variations de performance associées aux changements développementaux.

General Introduction

Over the past ten years, the study of atypical and typical development has been facilitated by concurrent advancements in the areas of molecular genetics, neurobiology, neuroimaging, cognitive and developmental psychology.

Collectively, the contributions of these diverse fields have helped to develop the unified discipline of cognitive developmental neuroscience. The emergence of research in this field has stemmed from the recognition that cognitive domains, specifically the domain of attention, cannot be understood as unified constructs, but instead must be investigated as a complex entities broken down into their subcomponent parts (Cornish, Scerif et al. 2007). Situated within this field, the charting of domain-specific proficiencies and deficiencies has become important in identifying typical and atypical developmental trajectories. However, investigations to date have focused predominantly on one particular age group, specifically, school-aged children. Although findings from these studies have helped in developing a typical cognitive profile of attention, a large body of work remains, as investigations from infancy through early childhood are lacking. The delineation of early developmental milestones is critical not only to understand how atypical development converges and diverges from the typical profile, but also to develop clinical and pedagogical resources to maximize the potential of each child. Moreover, the frequent study of subcomponent processes in only one sensory modality, visual or auditory, fails to acknowledge modality-specific strengths and weaknesses. Therefore, to attain a comprehensive understanding of

age-related changes in attention and executive function, an analysis of subcomponent processes, as well as an examination across modalities, is necessary. It is only when the typical developmental profiles of attention and executive function are charted that the domain-specific proficiencies and deficiencies of atypical populations, such as Fragile X Syndrome and Williams Syndrome, can be understood.

With the use of newly adapted measures, the following study examines auditory and visual subcomponents of attention and working memory in typically developing preschool aged children in an attempt to chart subcomponent and modality specific age-related changes. Chapter 1 will provide a brief overview of the cognitive domains of attention, specifically, the subcomponents of sustained attention, inhibition and working memory. Each construct will be defined and then reviewed with specific reference to the existing literature investigating development across visual and auditory modalities in typically developing children. In addition, the premise and specific hypotheses for the experiment will be outlined. Chapter 2 will then detail the methodological framework from which the study was constructed. The research results obtained will be stated in chapter 3 and further articulated in the discussion sections of chapter 4.

Chapter 1

Introduction

Attention: A Divided Construct

To date, research in attention has produced several competing theories defining the construct of attention (see (Mirsky 2001; Posner and Rothbart 2007)). Despite the volume of research on attention, a universal and comprehensive theory of attention is lacking, as there is no clear consensus as to which subdivisions to include. However, the current literature concedes that attention is not unitary, but rather is conceptualized as a multifaceted construct comprised of specific sub-processes that interact across cognitive domains (Posner and Petersen 1990; Mirsky 2001). Although there is no clear delineation of its subcomponents, there is an agreement throughout much of the literature that attention can be broadly divided into four sub-domains: sustained attention, selective attention, divided attention, and attentional control (Posner and Petersen 1990; Mirsky 2001). Sustained attention requires the maintenance of attention over time, specifically, to remain on task for a substantive period of time where there are few triggers to the relevant behaviour. In contrast, selective attention requires the ability to focus on specific stimuli while simultaneously ignoring irrelevant information, for example to find salient and targeted task information among distracters. Divided attention requires the ability to simultaneously attend to multiple stimuli, for example concurrently coping with two or more tasks; and

attentional control or inhibition encompasses planning, manipulating and inhibiting prepotent responses to a specific stimulus.

Executive function, like attention, is a complex cognitive construct that encompasses higher-order processes such as inhibitory control and working memory, both of which will be defined in greater detail later in this section. Briefly, inhibitory control involves the inhibition of a prepotent response, whereas working memory refers to the temporary retention of information. These processes, typically associated with the prefrontal cortex, are said to underlie flexible goal-directed behaviour (Duncan 1986) .

Advances in research focusing specifically at the brain, cognitive and behavioural levels have helped to shape the understanding of the individual subcomponents of attention and executive function. At the level of the brain, the work of Posner and colleagues has provided compelling support for the division of attention into subcomponents. Posner's model includes three attentional systems (alerting, orienting and executive control) each controlled not by one brain area, but by a distinct network of brain regions (Posner and Petersen 1990; Posner and Dehaene 1994; Posner and Rothbart 2007). The alerting system is said to activate the vigilance network similar to the sustained attention subcomponent, while the orienting system requires the disengagement and shifting of focus akin to the selective attention subcomponent. Similar to the subcomponent of attentional control, the executive control system is involved in goal-directed behavior, target detection, error detection, conflict resolution and inhibition of automatic responses. Functional imaging studies investigating attention within Posner's proposed framework provide support for the model through their

identification of specific brain areas activated in response to individual subcomponent- targeted tasks. For example, investigations assessing sustained attention, a subcomponent of the vigilance or alerting system, with visual and auditory vigilance tasks reveal an increased activation of the right frontal-parietal system (Cohen, Semple et al. 1988; Pardo, Fox et al. 1991; Belin, McAdams et al. 1998) Studies focusing on the orienting system show activation in the right precentral gyrus of the frontal lobe and the right parietal lobe (Corbetta 1998; Rizzolatti 1998). The executive control system appears to require activation of the anterior cingulate gyrus, supplementary motor areas - Brodmann Area 6, the orbitofrontal cortex, the dorsolateral prefrontal cortex, and portions of the basal ganglia, specifically the caudate nucleus (Bush 1998; Posner 1998).

At the cognitive level, a refinement in testing paradigms has aided in understanding the complexities of individual attention subcomponents through highly specified and well-targeted assessments. Posner and colleagues developed a testing battery, the Attention Network Task (ANT; (Fan, McCandliss et al. 2005), to explicitly assess the three aforementioned networks. Use of the ANT has provided a wealth of information with respect to the functioning of these networks in adult populations. However, the development of an adapted ANT for children has also allowed for the investigation of attentional subcomponents in a broad range of ages in both typically (Mezzacappa 2004; Rueda, Fan et al. 2004) and atypically (Sobin, Kiley-Brabeck et al. 2004; Bish, Samantha et al. 2005) developing populations.

Like the ANT, another testing battery used to target individual subcomponents of attention is the Test of Everyday Attention (TEA) (Robertson,

Ward et al. 1994) and its child version, the Test of Everyday Attention for Children (TEA-Ch) (Manly 2001). Both versions are comprehensive testing batteries designed to measure subcomponents of selective attention, sustained attention, and attentional control. Although used in a large cohort of typically developing children, the TEA-Ch has been especially useful in documenting attentional impairments in a number of atypically developing populations, particularly in Attention Deficit Hyperactivity Disorder (ADHD) (Heaton, Reader et al. 2002; Hood, Baird et al. 2005).

The use of subcomponent-targeted testing batteries (ANT for children and the TEA-Ch) in ranges of typically developing children has started to reveal how processes of attention vary as a function of age. The strength of these two batteries, ANT for children and the TEA-Ch, relies mainly on the fact that they were designed specifically for children and were not simply abbreviated ‘adult’ tasks. Often, many tasks of attention used with children are simply shortened or revised versions of standardized adult measures, which are frequently inappropriate for the assessment of attention in young ages. Consequently, there are very few paradigms available to measure subcomponents of attention in children of 7 years and younger.

Since the domain of attention encompasses both behavioural and cognitive aspects, an understanding of each of these is necessary to comprehend the construct of attention and its corresponding subcomponents in full. Therefore, at the behavioural level, advancements in theories of Attention Deficit Hyperactivity Disorder (ADHD) have helped to define inattentive behaviours; particularly, difficulties in concentration, distractibility, impulsivity and hyperactivity.

Additionally, attention rating scales, such as the Conners' Parent Rating Scale-Revised (CPRS-R)(Conners 1997), the Strengths and Weakness of ADHD-symptoms and Normal-behaviour (SWAN) (Swanson 2005) and the Strengths and Difficulties Questionnaire (SDQ)(Goodman 1997), were developed to identify specific inattentive behaviours that differentiate typically developing children from those diagnosed with ADHD. More importantly, the use of rating scales to examine attention at the behavioural level has demonstrated that persistent inattentive behaviours throughout childhood may be linked to difficulties in cognitive functions, and poor academic outcomes (Tannock and Martinussen 2007). Although rating scales have a limited utility in identifying the underlying cognitive weaknesses associated with inattentive behaviours, they provide preliminary evidence for links between behavioural and cognitive components of attention. Further research is needed to understand how these components are related by mapping behavioural traits to cognitive functions.

The Typical Cognitive Profile of Attention: Age-Related Changes of Attention in Children

Although attention research has been conducted across a variety of age groups, distinct developmental trajectories of attention are lacking. The scarcity of clearly charted age-related changes stems primarily from the multi-faceted nature of attention, which presents difficulties in adequately and selectively assessing its sub-domains that are often overlapping. Following Posner's model of attention, Rueda et al. (Rueda, Fan et al. 2004) investigated the alerting, orienting and executive control systems in typically developing children aged 6 to 9 years,

using the ANT. The results reveal differential improvement on all three measures; specifically, consistent improvement on measures of alertness, stability on measures of orienting throughout all ages, and a plateau on measures of executive control at age 7 (Rueda, Fan et al. 2004). Manly et al. (Manly 2001) found comparable results using a similar differential subcomponent approach with the Test of Everyday Attention for Children (TEA-Ch), in typically developing children aged 6 to 16 years. Age-related improvements were found in all sub-tests of the TEA-Ch, with accuracy improving until 9 to 11 year old group and speed continuing to better in the 15 to 16 year old group. Results from another study examining neurocognitive development in children found that development occurred more rapidly in children ages 5 to 8 years as opposed to those between the ages of 9 to 12 years (Korkman 2001). Several additional studies have aimed to further define the different developmental sequences of attentional subcomponents in attempting to chart their developmental time points of maturity. Klenberg and colleagues (2001) reveal an initial clustering of components, followed by a differential development of components over time in children between the ages of 3 to 12 years of age. More specifically, it was found that the development of basic inhibition preceded the development of more complex processes of selective attention and other components of executive function (Klenberg 2001). Results from this study support the notion that certain elements of voluntary attention and executive function are formed in early childhood (Diamond 1985; Goldman-Rakic 1987), with rapid changes in performance on inhibition tasks occurring between the ages of 3 to 5 years. Although the subcomponents of attention are interrelated, the combined evidence from these

studies reveal the emergence of differential developmental sequences of attentional subcomponents throughout development, which thereby stress the importance of their future individual assessment.

Sustained Attention

What is Sustained Attention?

Sustained attention is defined as the ability to stay on-task and to inhibit distracting stimuli over a prolonged period of time. According to Posner's model, sustained attention forms a component of the vigilance network, and is assessed through tasks that require a participant to remain prepared to respond to an infrequent target over an extended time.

Assessment of Sustained Attention

Originally developed by Mirsky and colleagues (Rosvold, Mirsky et al. 1956) for the assessment of vigilance in patients suffering from brain injury, the Continuous Performance Test (CPT) is now one of the most commonly used paradigms to assess the maintenance of attention in school aged children. The CPT is delivered over a period of time and requires a response to one stimulus and no response to an alternative stimulus, which allows for the measurement of the maintenance of attention and inhibition. Among the CPTs suitable for preschool aged children are the CPT for Preschoolers (CPTP) (Corkum 1995), the Children's CPT (C-CPT) (Kerns and Rondeau 1998), the Conner's Kiddie CPT (K-CPT) (Conners 2001), the Zoo Runner tasks (Prather 1995), and the Auditory CPT (ACPT-P) (Mahone, Pillion et al. 2001).

Of the CPTs previously listed, particular interest is taken in the ACPT-P developed by Mahone and colleagues. The reasons for this are twofold; firstly, the ACPT-P is one of the few auditory CPTs, while all others are available solely in the visual format. The importance in addressing auditory attention in young children arises mainly from the need for appropriate hearing and speech discrimination, which is crucial for later academic performance. Secondly, the ACPT-P is suitable for a very young preschool population with successful completion of the task by children as young as 36 months (Mahone, Pillion et al. 2001).

Recent Findings from use of CPTs with Typically Developing Children

The examination of the performances of school-aged children on analogous auditory and visual CPTs has yielded quite consistent results, which support findings that auditory CPTs may be more difficult for school aged-children (Baker 1995; Prather 1995). Lewis and Greenberg (Lewis 1995) first reported poorer performance, longer response times and fewer correct responses, on an auditory CPT compared to a visual CPT matched for difficulty on all parameters. Similarly, moderate correlations between variables on the auditory and visual CPTs were reported by Aylward and colleagues (Aylward 2001), and performances on the auditory CPT revealed once again greater errors of omission (accuracy) and commission (false-alarms).

Studies investigating the performance of preschool-aged children on analogous auditory and visual CPTs have reported results consistent with those of school-aged children. A study by Prather et al. (Prather 1995) examined the

performances of preschool aged children (3 to 6 years) on the ZooRunner auditory and visual CPTs. It was found that across all age groups, more errors were made in the auditory test compared to the visual test. Another study by Kerns and Rondeau (Kerns and Rondeau 1998) using three variations of auditory, visual and audio-visually combined CPTs with children between the ages of 36 to 81 months revealed greater difficulties on the auditory CPT, as indicated by 90% omission errors in the 3 year old group. While their CPT was made more accessible to preschool children by virtue of a reduced testing time (5 minutes), the task failed to reveal a significant improvement in performance by the youngest age group, which underlined the importance of studying other task parameters such as the number of stimuli and interstimulus intervals.

In light of these findings, Mahone and colleagues conducted a study (Mahone, Pillion et al. 2001) using a novel CPT designed specifically to minimize the difficulties encountered by children of 3 years on previous preschool CPTs. Reductions in overall task duration and number of stimuli, along with an increase in response time were adopted to ensure that the youngest participants could successfully complete the task. Contrary to earlier findings, Hagelthorn et al. (Hagelthorn 2003) discovered that children of 3 years performed better on the ACPT-P when compared to a visual CPT with a much shorter response time (1350 ms versus 5000 ms) and a greater number of stimuli. These findings therefore highlight the importance of the specificity of task parameters in CPT design.

Inhibition

What is Inhibition?

As described in Posner's model of attention, the ability to exert effortful control to inhibit a dominant response and to hold relevant rules in working memory for suppression of a response form the foundation of the executive control system (Posner and Rothbart 2007). The development of inhibition throughout the preschool years is critical, as it acts as an important precursor for goal directed behaviours that are crucial for meeting the demands of the academic curricula of which children are faced in the school-aged years (Bull and Scerif 2001). Furthermore, a particular interest is taken in the investigation of the development of attentional control due to the remarkably rapid gains in inhibition from the ages of 2 to 5 years (Zelazo, Müller et al. 2003).

Assessment of Inhibition Control

Research on inhibition in preschool-aged children has primarily focused on the results from two widely used tasks: the Go-No/Go paradigm (Simpson and Riggs 2006; Simpson and Riggs 2007) and the Day-Night task (Gerstadt, Hong et al. 1994; Diamond, Kirkham et al. 2002). The former requires the ability to manually inhibit a prepotent response, whereas the latter requires verbal inhibition of a habitual response and initiation of a distinct learned response.

In the Day-Night task, the images of a sun and moon are substituted for the colour words and ink of the original task. The measure is further comprised of two trials: one of congruence and the other of incongruence. In the trial of

congruence the child is required to say “day” or “night” appropriately to the sun and moon, while they are asked to do the opposite by answering inappropriately (eg. say ‘night’ for the sun) in the incongruent trial. Children are therefore required to keep two rules online while performing both the congruent and incongruent trials. Inhibition, as measured by this task, involves the presentation of two salient but conflicting response options, whereby participants are required to choose the answer that is in direct opposition of the dominant response (Gerstadt, Hong et al. 1994; Diamond, Kirkham et al. 2002; Simpson and Riggs 2006). With the Day-Night task as its framework, Berger and colleagues created a task of ‘opposites’ to investigate both auditory and visual components of inhibition (Berger 2000). In using the sounds and images of a cat and dog in lieu of the sun and moon and eliminating the verbal component of the original task with a motor response, Berger and colleagues succeeded in developing a combined audio and visual task. Following the two trial format of the original task, administration of the task features the sound of a bark (dog) or meow (cat) after which the participant is required to touch the appropriate animal picture in the congruence trial, or the inappropriate image in the incongruence trial.

Developmental studies using the Day-Night task have found a significant improvement in accuracy and response times from the age of 3.5 years to 5 years (Gerstadt, Hong et al. 1994; Simpson and Riggs 2005). It was found that measures of accuracy reached ceiling at around the age of 5 years, whereas response times continued to decrease up to the age of 11 years (Simpson and Riggs 2005). Since children as young as 6 years have shown to perform at ceiling on the original task, other studies (Berlin and Bohlin 2002; Wåhlstedt, Thorell et al. 2008) have used

additional pairs of semantically related objects (eg. Boy-Girl, Large-Small, Up-Down) to increase its difficulty.

An Association of Attention and Inhibition

An emerging area of research involves the investigation of the association between attentional and inhibitory processes that are necessary for the completion of complex cognitive tasks. Early evidence from Kochanska and colleagues (Kochanska, Murray et al. 2000; Kochanska and Knaack 2003) is supportive of such an association and raises the question of whether the manipulation of attention in preschool-aged children would affect performances on tasks specifically targeted to measure response inhibition. Work conducted to date using the Day-Night task (Gerstadt, Hong et al. 1994; Diamond, Kirkham et al. 2002) has confirmed that the performance of preschool children improved on this task when a distraction, in the form of a song, was inserted in between the stimulus presentation and given response. Additionally, other studies examining children's performances on complex inhibition tasks have shown that participants who were able to redirect their attention from the rewarding aspects of the stimuli in childhood performed better on such tasks later in adolescence. Although subsequent research is necessary to confirm exactly how attention and inhibition interact, these preliminary findings are beginning to demonstrate that there is an association between these subcomponent processes.

Working Memory

What is Working Memory?

Working memory is best described as a short-term cognitive system that allows for the temporary storage of information for simultaneous processing or near-term reference (Baddeley 1986; Baddeley 2003). While there are several theoretical models of working memory (see (Miyake 1999) for a review), the Baddeley model (Baddeley 1986; Baddeley 2003) of working memory is one of the most influential for understanding the components of working memory. The model comprises four major components, the first of which is the “central executive,” which is responsible for a range of regulatory functions, predominantly attention, problem solving, cognitive control and manipulation of on-line information. The episodic buffer is another component that allows for the integration and binding of temporary multimodal information into a single representation. The remaining two subsystems of the model are the verbal (phonological loop) and visuospatial (visuospatial sketchpad) components that store and manipulate information with respect to their individual function: phonological and visual-spatial qualities, respectively. Support for this model of working memory is provided by neuroimaging studies that have identified specific brain areas supporting its subcomponents (Fletcher and Henson 2001). Specifically, evidence indicates that the central executive is associated with areas of the frontal and parietal lobes, the phonological loop with left inferior parietal

and anterior temporal frontal areas, and finally, the visuospatial sketchpad with the right occipital and inferior frontal lobes (Cabeza and Nyberg 2000).

Assessment of Working Memory

A wide range of tasks has been used in the assessment of working memory in children. Among these tasks are the commonly used measures of digit and word, and visual-spatial recall when examining the phonological loop and visual-spatial sketchpad, respectively. More complex tasks targeting the central executive require a manipulation process in addition to the storage component integral to the tasks previously mentioned. Of these measures, one of particular interest to this study is the “Noisy Book” task for the assessment of working memory in preschool-aged children. Originally based on the auditory sequencing subtest of the Goldman-Fristoe-Woodcock standard neuropsychological tests, the Noisy Book task has since been used in both school-aged (Dennis, Spiegler et al. 1991) and preschool-aged (Hughes 1998; Sonuga-Barke, Dalen et al. 2002) children. The engaging quality of this task rests largely on its use of a children’s storybook containing a vertical panel of picture buttons that emit sounds when pressed. Once familiarized with the pictures and sounds, children are required to memorize the location of the pictures and their corresponding sounds since cardboard panels conceal them in the testing phase. Furthermore, the child is required to find the appropriate buttons following a two, three or four-item list presented by the experimenter, which therefore requires the child to hold the order of this sequence online. More importantly, in varying the order of each sequence between trials, external resistance of distraction and interference from previous

trials is required, which therefore provides further support for the use of this task as a measure of working memory (Hughes 1998; Sonuga-Barke, Dalen et al. 2002; Sonuga-Barke, Dalen et al. 2003). Investigations of the development of working memory in preschool-aged children have indicated that the Noisy Book task is developmentally sensitive in measuring working memory, as shown by its dissociability from other domains of executive function such as inhibitory control and attentional flexibility (Hughes 1998).

Investigations of the development of working memory have focused primarily on the changes occurring in the individual components, as are defined by Baddeley's model. As a result, little is known of the general changes in organization of working memory throughout early and late childhood. Of the studies investigating the development of its components, it was found that both the phonological loop and visuospatial sketchpad were independent by the age of 5 years. Furthermore, it was also found that the central executive and the phonological loop, but not the visuospatial sketchpad were dissociable in a study of 6 and 7 year old children. The use of span tasks have revealed that memory span (the maximum number of items correctly recalled) significantly improves from only 2 or 3 items at the age of 4 years to a total of 6 items by the age of 12 years (see (Cowan 2001) and (Gathercole 1998) for reviews). A more recent study comparing the developmental trajectories of the subcomponents of working memory from the ages of 4 to 15 years found linear increases in performances from 4 years, with the emergence of the three individual subsystems as early as 6 years (Gathercole, Pickering et al. 2004).

An Association Between Attention and Working Memory

It is now well documented that both working memory and inhibition form two core domains of the frontal-lobe supported executive functions (Brocki, Randall et al. 2008). Moreover, it is also clear that as a child progresses through the preschool years, attentional capacity forms a foundation for the development of executive function (EF) abilities (see (Garon, Bryson et al. 2008) for a review). For these reasons, particular interest is taken in the important interplay between the development of attentional control and working memory (Davidson, Amso et al. 2006).

Preschool performances on tasks of attentional control have allowed for the differentiation of children into groups of high and low working memory spans (Epsy 2005). Furthermore, an investigation examining the link between working memory, interference and attention in typically developing school-aged children (Lui and Tannock 2007), found that poor performances on working memory predicted inattentive behaviour, as rated by parents on the Strengths and Difficulties (SDQ) (Goodman 1997) questionnaire and the Strengths and Weakness of ADHD-symptoms and Normal-behaviour (SWAN) (Swanson 2005) questionnaire (Lui and Tannock 2007).

Another compelling argument for the interaction between inhibition and working memory stems from the implication of their combined impairment in the neuropsychological profile of Attention Deficit Hyperactivity Disorder (ADHD) (see (Martinussen, Hayden et al. 2005) and (Willcutt, Doyle et al. 2005) for a review). ADHD is a disorder characterized by noradrenergic and dopaminergic

dysfunction in the prefrontal cortex and subcortical area, where regions responsible for supporting attention and working memory are located (see (Valera, Faraone et al. 2007) and (Lyon 1996)). Robust behavioural and neuroimaging evidence supporting these deficits has brought the interplay of working memory and attention to light (see (Castellanos, Sonuga-Barke et al. 2006)).

An Association Between Inhibition and Working Memory

Research to date suggests that there is an association between the processes of inhibition and working memory (see (Garon, Bryson et al. 2008)). It has been posited that there is a co-dependence of these processes, so much so, it is argued that the proficiency of working memory is dependent on response inhibition (Barkley 1997). Conversely, the importance of working memory in many tasks of inhibition, specifically those wherein children must remember and use a rule to control behaviour, have also been underlined (Diamond, Kirkham et al. 2002). Given that many of the tasks used in preschool populations involve both inhibition and working memory, it is difficult to determine whether these processes develop in a separate or joint fashion. The suspected co-dependence of these processes illustrates the importance of investigating these subcomponents in both an individual and mutual manner. However, it is important to note that although there is a small working memory component in the adapted Day-Night task (Gerstadt, Hong et al. 1994) of the present study, previous work conducted with the original version has confirmed that inhibition alone, and not working memory, has the greatest influence on the performance of preschoolers in this

particular task (Diamond, Kirkham et al. 2002; Simpson and Riggs 2005; Davidson, Amso et al. 2006).

Summary of Subcomponent-Related Findings

From the findings that have been discussed, it is apparent that there is no clear consensus with respect to the developmental trajectories of sustained attention, inhibition and working memory. Although studies have begun to chart when and how these subcomponent processes emerge in early childhood, the use of a variety of tasks has lead to many different conclusions. Accordingly, there is a need for reliable preschool appropriate measures that are sensitive yet accessible enough to assess attention in children as young as 3 years. It is only once new measures are developed and used in combination with other consistent measures that clearer and more consistent conclusions can be drawn with respect to the developmental trajectory of attention performance.

Biological Basis of Age Related Changes in Performance

As described, the results of studies examining the typical development of subcomponents of attention and working memory have shown that age-related changes and improvements in performance are present from early childhood onwards. The age-related changes in performance made by typically developing children are thought to correspond to periods of brain development and myelination. Although it is difficult to place the age-related changes in performance within a biological context, studies using cognitive measures and

imaging techniques have begun to identify how performance findings can be related to biological changes occurring in the brain.

From birth, the human brain undergoes a myriad of developmental changes both in terms of structure and function. These changes are largely the result of simultaneous progressive and regressive events, particularly synaptogenesis and synaptic pruning, in addition to the development of myelination (Casey, Tottenham et al. 2005). It is not until recently, with the advancement of imaging techniques, that changes in brain structure and function have been linked to cognitive development. Studies using techniques such as functional magnetic resonance imaging (fMRI) and diffusion tensor imaging (DTI) have highlighted the importance of the maturation of specific brain areas, namely the maturation of the frontostriatal and prefrontal-parietal connections, in the performance of inhibitory and working memory tasks, respectively (Olesen, Nagy et al. 2003; Liston, Watts et al. 2006). Explicitly, using Go-No/Go and Stroop-like tasks in conjunction with the aforementioned techniques, researchers have found that with age, brain regions which correlated with accuracy and speed performance became more fine-tuned showing an increase in activity. Conversely, regions that were uncorrelated with performance showed a decrease in activity, suggesting that the dynamic interplay activity may be reflective of age-related refinement of the projections to and from these specific brain regions (Casey, Giedd et al. 2000; Casey, Thomas et al. 2002). Additional work using DTI to examine the myelination of axons has also linked age-related increases in the myelination of major white matter tracts, particularly frontostriatal tracts, with cognitive test performance (Nagy, Westerberg et al. 2004).

Although the delayed maturation of areas mainly implicated in cognitive control, the prefrontal and parietal cortices, aid in explaining developmental improvements in performance, new findings in relation to functional networks are helping to improve our understanding of the underlying age-related variations of cognitive development. Specifically, network level findings are now emerging to further elaborate on how cognitive maturation, as evidenced through the use of performance-based measures, can be explained by the enhancement of functional connectivity and interactions between brain regions and not simply by the development of single brain structures alone. For example, it has been found that the weakening of short-range functional connections and the strengthening of longer-range connections within the frontoparietal and cingulate-lateral prefrontal networks may help to explain the age-related improvement in performances of cognitive control from childhood to adulthood (Fair, Cohen et al. 2009). Taken together, these findings provide a preliminary understanding of the links between developmental improvements in cognition, specifically in subcomponents of executive function and attention, and biological changes in structure and function occurring throughout early and late childhood.

A Cross-Modality Approach

To date, the majority of studies investigating attention throughout the school and preschool ages have adopted a single modality approach, examining the emergence of attentional skills in the visual modality alone. Consequently, very little is documented with respect to auditory attention in children ages 3 to 6 years. Recently, however, there has been a heightened interest in exploring early

auditory attention, since the bulk of the preschool literature has neglected to address whether responses to auditory cues are similar to those found with visual cues. Since many studies examining visual and auditory attention in school-aged children have found that there are generally poorer performances on auditory than visual tasks (Baker 1995; Lewis 1995; Aylward 2001), it is necessary to verify whether similar results will be found with preschool-aged participants. Furthermore, the discrepancies in visual and auditory performances of attention that can be identified with a cross-modal approach may provide a more holistic understanding of attention as a construct, which will ultimately help in characterizing whether there are similar developmental trends occurring across modalities. The information gained by investigations in typical development will undoubtedly help to better define attention proficiencies and deficiencies in atypical development, providing specific information with respect to whether certain syndrome-specific particularities in attention are unimodal or multimodal nature.

Rationale for the Study

The present work will complement and expand upon our existing knowledge of attention and executive function within a developmental context. The need for valid assessment of attention in typically developing children has grown substantially over the last few years in order to better characterize the ‘normal’ development of attention skills and to further assist clinicians in early identification and treatment of disorders characterized by attentional difficulties. The investigation of age-related changes will help to better define the role of

attention in shaping behaviour from early childhood onwards. It is imperative that the typical cognitive profile of attention be first charted to facilitate the subsequent understanding of how and when the atypical profile converges or diverges from that of typical development. Furthermore, the adaptation of measures in terms of difficulty and suitability for the assessment of preschool children is crucial since many of the commercially available measures have failed to yield useful data, as previously outlined.

The proposed tasks in this study were specifically selected to better understand subcomponent processes that have been previously identified as syndrome-specific weaknesses in past work. For example, there are now several studies that have documented sustained attention, inhibitory and working memory deficits in Fragile X Syndrome (Munir, Cornish et al. 2000; Cornish, Scerif et al. 2007; Scerif, Cornish et al. 2007; Ornstein, Schaaf et al. 2008; Lanfranchi, Cornoldi et al. 2009) and Williams Syndrome (Jarrold, Baddeley et al. 1999; Zhao, Shao et al. 2008). Although these deficits have been previously reported, the need to validate, replicate and better understand these syndrome specific particularities is imminent since it is often very difficult to attain reliable data using standardized and commercially available measures that are frequently difficult for atypically developing children to complete. Knowing this, it is only with the development of preschool- appropriate and easy-to-use tasks, which maximize a participant's potential to complete them, that we will refine our understanding of reported weaknesses in subcomponent processes in both typically and atypically developing children.

Specific Aims and Hypotheses

Aims

Acknowledging the importance of charting the typical developmental profile for sustained attention, the proposed study was driven by the following questions: 1) how does performance vary as a function of age on novel measures of sustained attention, inhibition and working memory? 2) is there a relationship in performances across visual and auditory modalities? and 3) is there a relationship in performance, as defined by percent (%) accuracy, across our measures of sustained attention, inhibition and working memory? Accordingly, the specific aim of the present study was four-fold. Firstly, to document any age-related changes in sustained attention, inhibition and working memory across the visual and auditory modalities in typically developing children ages of 3-6 years. Secondly, to document the developmental trends and relationship, as revealed by performance (accuracy and reaction time), between analogous visual and auditory paradigms. Thirdly, to assess the extent to which performance (i.e. accuracy) was correlated across all three cognitive measures. Fourthly, to examine the relationship between inattentive behaviours and cognitive performance, correlations between the scores of the standardized Conner's Parent Rating Scale-Revised (CPRS-R) of attention and the performance indices of the sustained attention and inhibition tasks were used to explore the validity of these adapted measures.

Hypotheses

In accordance with the four general aims of the study, there were four hypotheses. 1) It was hypothesized that age-related differences would emerge across developmental time and modality across all tasks. 2) In terms of modality, it was expected that similar developmental trends of performance accuracy and speed, as illustrated by similar slopes in linear regression analyses, would emerge between measures of visual and auditory sustained attention and inhibition. However, it was predicted that the values for accuracy and speed in the auditory tasks would be worse than those of the visual task, comparable to results from previous studies. Furthermore, it was projected that there would be a relatively strong relationship in performances between the visual and auditory tasks, as was evidenced in comparable studies (Aylward 2001; Hagelthorn 2003). 3) The examination of the relationship of performances across tasks was expected to yield positive and weak correlations due to the overlap of cognitive skills (attention, inhibition and working memory) required for each of the three tasks.

Chapter 2

Method

Participants

A total of seventy typically-developing children (36 boys, 34 girls) comprised four age-groups. All participants were recruited from the Montreal region using an established database from previous studies at the McGill Child Laboratory for Research in Education and Development Disorders, as well as an advertisement in the Montreal Families magazine (Date: June, July/August 2009). Participants were assessed individually under the supervision of Dr. Kim Cornish during one visit to the laboratory. All children spoke English or French as their first or second language. Exclusion criteria included any serious visual or hearing impairment, mental retardation, and previous diagnosis of Attention Deficit Disorder. Furthermore, participants taking psychotropic medication at the time of assessment were also excluded. In an effort to minimize the effects of fatigue, participants were tested preferentially in the morning from 9am to 12pm to reduce the likelihood of infringing upon afternoon nap time. Upon arrival at the lab, all caregivers provided written consent for their child(ren) to partake in the study. Testing commenced after ethics approval was granted by the research ethics committee of McGill University.

Measures

An experimental cognitive testing battery tapping visual and auditory sustained attention, inhibition and working memory was administered to all participants. In addition to the cognitive measures, a standardized behavioural rating scale of attention, the Conner's Parent Rating Scale-Revised (Short Form)(CPRS-R:S; (Conners 1997), was completed by parents or caregivers.

Measures of Verbal Function- Intellectual Screening

A standardized cognitive measure was first used for intellectual screening of each participant to ensure that their mental age was within a 'normal' range for their respective chronological age. For this assessment, the Peabody Picture Vocabulary Test (PPVT-III, Form L) (Dunn 1997) for English-speaking children or the Échelle de Vocabulaire en Images Peabody (EVIP, Forme A) (Dunn 1993) for French-Speaking children was administered prior to beginning the testing battery. The PPVT or EVIP uses 204 vocabulary items of increasing difficulty to assess a participant's breadth of receptive language and verbal ability. In this task, participants are presented with four pictures at a time and required to visually identify the spoken vocabulary word, as read by the experimenter, simply by pointing to the appropriate image on the 2×2 picture easel display. See Figure 1 for a hypothetical example of a test item presented in the PPVT. The participant is awarded a score of one for each correct response, and this score is then used to calculate a raw score. A standard score is then calculated from the total raw score using the norms for each age (in years and months) found in the examiner's manual. The PPVT was selected for its ease of use with very young children in

addition to its reported high overall reliability rating ($r=.95$), with reliability coefficients ranging from .92 to .98 (Dunn 1997). Furthermore, the PPVT is also found to correlate at .90 with Wechsler Intelligence Scale- Third Edition Full Scale IQ, which further justifies its use as a scale for abbreviated intellectual screening (Dunn 1997). The verbal mental age [MA] and standard scores [SS] of all participants fell well within norms for their age (3, mean [MA]= 3.309+/- 1.114, [SS]= 94.1 +/- 20.2); (4, mean [MA]= 4.432+/-1.526, [SS]=93.8 +/-14.3); (5, mean [MA]= 5.980 +/- 1.298, [SS]= 106.5+/- 13.8); (6, mean [MA]= 6.511 +/-1.15, [SS]=98.9 +/- 10.9). Children who failed to achieve a standard score within two standard deviations from the mean for their respective chronological age were excluded from the study.

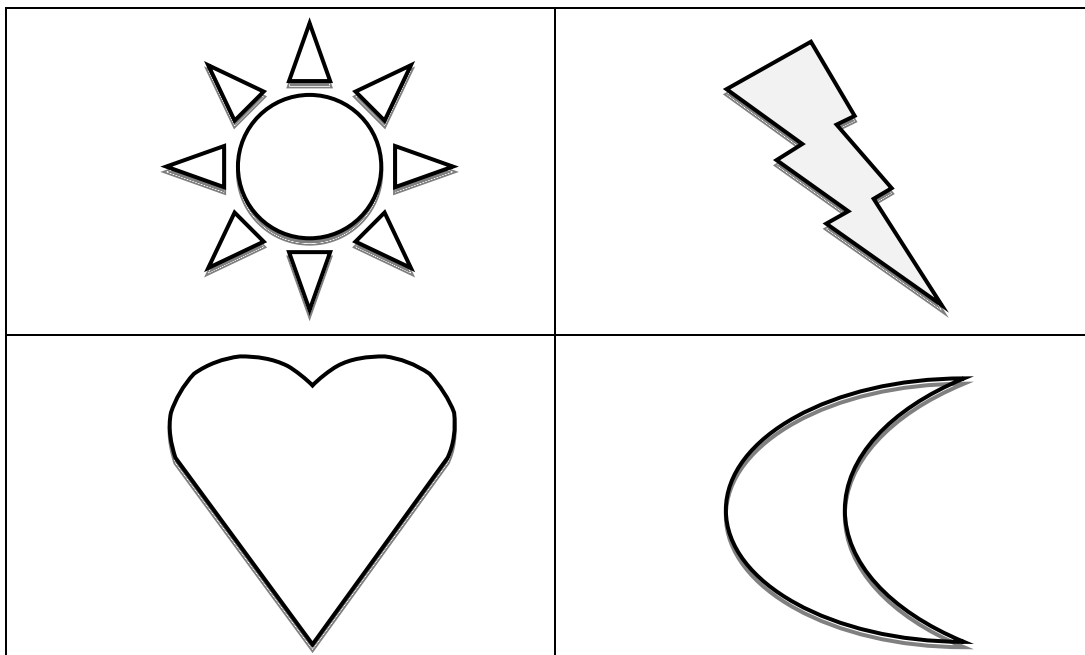


Figure 1. A hypothetical example of a picture plate in the PPVT-Third Edition. The participant is required to point to the vocabulary item (i.e. “sun”) presented verbally by the experimenter.

Parent's Ratings-Behavioural Questionnaire

Parents of participants were asked to complete a behavioural questionnaire, the Conners' Parent Rating Scale-Revised (Short Form)(CPRS-R:S; (Conners 1997), to assist in identifying any problem behaviours that would impact the results of the study. Particular interest was taken in the CPRS-R:S for screening of attention difficulties and ADHD symptomology , as rated by four behavioural indices: oppositional behaviour problems, hyperactivity, problems relating to cognition and inattention, and impulsivity. A 4-point Likert-scale, where 0= not at all true and 3=very much true, was used to rate the severity of behaviour on a total of 27 items. Once scored, a T score value exceeding 60 in the ADHD global index indicated that symptoms were indeed elevated within that index and therefore thought to negatively influence performance on the experimental attention paradigms. With the exception of one participant scoring 70 on the ADHD global index, no other participant was excluded based on this criteria.

Measures of Auditory and Visual Sustained Attention

Adapted Auditory and Visual Continuous Performance Tests (CPTs)

The Auditory Continuous Performance Test-Preschool (ACPT-P) developed by Mahone and colleagues (Mahone et al. 2001) provided the basis for the development of an adapted computerized auditory and visual continuous performance test (CPT) for use in this experiment. Similar to the original task, this adapted version was presented on a personal computer using the SuperlabTM (version 4.0) psychological stimulus presentation software. In the interest of

assessing performances across modalities, all parameters (presentation of stimulus, interstimulus interval, and participant response) were kept consistent to ensure that auditory and visual tasks were analogous in terms of format. First, in the auditory task, two familiar environmental sounds (dog barking and cat meowing) were extracted and edited from the Sound Effect Recognition Task (SERT) (Finitzo-Hieber 1980). The sounds were presented through headphones in a singular randomized fashion for 690 milliseconds(ms) with an interstimulus interval of 3000 ms. The participant was required to touch a rectangular response pad button for the target sound (dog barking) and to inhibit their response by abstaining from pushing the button for the non-target (cat meowing). The testing procedure commenced with a familiarization phase whereby the experimenter instructed and explained the testing protocol to the participant. This was followed by a practice phase which confirmed that the participant comprehended the task instructions and was capable of fulfilling its demands. The participant had to successfully complete two practice trials (one including the target and the other the non-target) to continue onto the testing phase. If participants were unable to complete the initial practice trials, they were granted two additional attempts to successfully complete the practice phase.

Similar to the auditory task, the visual CPT used picture displays of the dog and cat taken from the SERT (Finitzo-Hieber 1980). An analogous protocol was used in terms of administration, by which the participants were required to respond by pressing the button for the target (dog) and refraining for the non-target (cat) upon successful completion of the practice phase.

The testing phase in both the auditory and visual paradigms included 44 trials, each consisting of 22 distracters and 22 targets. The total time for the administration of each respective CPT was approximately 5 and a half minutes (two minutes orientation and practice, three and a half minutes testing). The main parameters included measures of correct responses (accuracy), omissions (accuracy), commissions (false-alarms), and reaction time (speed).

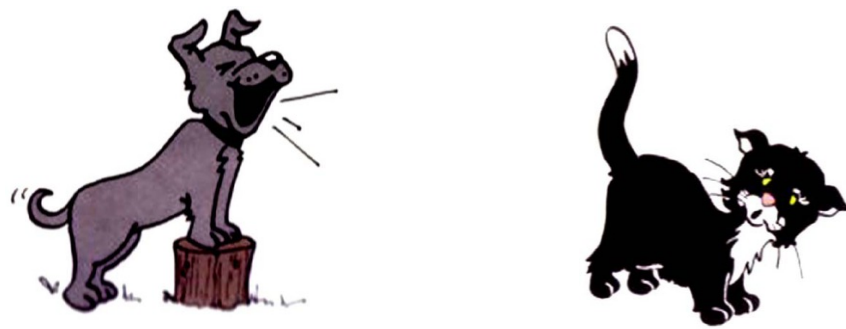


Figure 2. Stimuli included in the newly-adapted visual CPT and Dog-Cat Inhibition tasks.

Measures of Auditory and Visual Inhibition

Auditory and Visual Dog-Cat Tasks

A preschool-appropriate Stroop-like task developed first by Diamond et al. (Gerstadt, Hong et al. 1994) and by Berger et al. (Berger 2000) provided the framework for the design of an auditory and visual ‘opposites’ task using the sounds and images of a cat and dog. In the auditory task, the participant was presented with one of two sounds: a dog barking or a cat meowing. In the condition of congruence, the participant was required to verbally identify the corresponding animal to each sound heard through the headphones. Conversely, the participant was instructed to give the opposite verbal response to the sound heard in the condition of incongruence. For example, when the sound of a dog

was heard, the correct response required the participant to say “cat”. In the visual task, the sounds were replaced by the singular appearance of an image of a cat or dog, with all other parameters kept analogous to its auditory counterpart. In both the conditions of congruence and incongruence, there were 16 trials comprised of 8 cats and 8 dogs. Similar to the CPT, both the images and sounds for this task were taken from the SERT (Finitzo-Hieber 1980) and presented using Superlab™ (version 4.0).

Administration began with participants first oriented to the task in a familiarization phase involving four trials: two cats and two dogs. The experimenter would only precede to the practice trials once the participant demonstrated a clear understanding of the task in the initial familiarization stage. Upon successful completion of the practice trials, the participant was then permitted to advance to the testing phase.

The main parameters of investigation included three different types of errors: uncorrected errors (naming the picture instead of saying its opposite), self-corrected errors (naming the picture or starting to name the picture and correcting oneself), and errors of omission (no response). Reaction time, as measured by the time of the vocal response recorded from a voice key, was also examined.

Measures of Auditory and Visual Working Memory

Adapted Noisy Book Task

An adaptation of the noisy book task (Hughes 1998; Sonuga-Barke, Dalen et al. 2002) was used to study auditory and visual working memory using three individual trials: auditory, visual and audio-visual combined. Created through Microsoft Powerpoint (Office 2007), the paradigm was presented to participants

seated in front of a computer touch screen displaying a 3×3 matrix of various farm animal sounds, images or a combination of both- varying according to the nature of the trial. Children were required to not only recall the positions of the pictures or sounds within a matrix, but also to remember the sequence presented by the experimenter. Although the animals used throughout the task remained consistent, the order of presentation within the array was varied across the three trials.

The experimenter commenced each trial with a familiarization phase in which the location of the sounds or images were reviewed with each participant to ensure that a common term (i.e. dog or doggy) was established for each item presented. Additionally, the familiarization phase further allowed for adequate time for the participant to retain the positions of the items on the screen. A practice phase then followed the familiarization phase, where three single-item trials were given to ensure that the child remembered the locations of the sounds. Upon successful completion of the practice trials, a test phase consisting of three 2-item lists, 3-item lists and 4-item lists was presented in a fixed order. Progress from one level to the next required the successful completion of two of the three trials of the previous level. Accuracy was measured according to a scoring method coded as follows: 0 if none or one of the three two-items lists were performed successfully; 1 if at least two of the three two-item lists were recalled; 2 if at least two of the three-item lists were recalled; 3 if at least two of the three four-item lists were completed correctly (Sonuga-Barke, Dalen et al. 2002).

Procedure

Participants were assessed individually under the supervision of Dr. Kim Cornish during one visit to the McGill Child Laboratory for Research and Education in Developmental Disorders (Duggan House, 3724 McTavish Street). At the laboratory, parents were greeted by the applicant in the waiting room where they were issued a consent form. The consent form provided further background information and outlined the rationale and aims of the study, for which ethical approval had been secured. For the duration of the assessment, the applicant was administered the testing battery in a specially designed child-friendly testing room located adjacent to the waiting room. Upon completion of the testing session, participants and their families were offered monetary compensation (value: 20\$) for their participation, travel expenses and parking. Additionally, the children were awarded a small toy prize (value: 2\$) for their participation.

The testing battery was divided into approximately two half-hour blocks, beginning with the explanation of the protocol, consent procedures and verbal cognitive assessment, which was then followed by the computerized visual and auditory inhibition, sustained attention and working memory tasks. Based on results from the initial piloting of the paradigms, the dog-cat task (inhibition) was the first presented of the battery, as it required a verbal response from participants, which at times, was difficult to obtain from the youngest group. Following the presentation of the inhibition task, the working memory and sustained attention tasks were interspersed with the visual and auditory trials counterbalanced to limit the effect of learning. While testing was underway the

guardian of each participant was asked to complete the child's history questionnaire pertaining to vision and audition and the Conners' Parent Rating Scale-Revised (Short Form) (Conners 1997). The visit to the laboratory lasted approximately one hour and a half and included several breaks as dictated by the participant.

Chapter 3

Results

All data were examined using a series of statistical programs which included: [Predictive Analytics Software (PASW) version 17 (formerly known as the Statistical Package for the Social Sciences v.17.0)]. Since an assumption of normality is necessary for the use of parametric inferential statistics, the distribution of the data for all dependent variables was verified with the use of normal quantile plots as calculated by an in-house program (Rochford 1997). Results revealed that the accuracy data (percent correct responses and percent errors) for the visual and auditory sustained attention (CPT) and inhibition (Dog-Cat) tasks violated the normality assumption. Consequently, non-parametric analyses were conducted on these data. Furthermore, all analyses of the working memory data required the use of non-parametric tests, as accuracy measures from the task were ordinal measurements with values ranging from 0 to 3.

The results section is divided into five sections. The first section includes characteristics of the sample (age, gender) as well as the Peabody Picture Vocabulary Test standard scores. The second section examines the group differences in all three visual and auditory tasks, specifically detailing how performance varied as a function of age. The third section includes regression analyses to firstly explore the unique contribution made by age to performances of accuracy and reaction time, as well as to examine the developmental trends between visual and auditory trials of the respective sustained attention and inhibition tasks. Additionally, subsequent cross-modality correlation analyses were used to investigate the relationship in performances of accuracy and reaction

time between the visual and auditory trials of all three cognitive tasks. The fourth section provides modality-specific cross-task correlations in performance accuracy as defined by percent hits, correct responses and score in the sustained attention, inhibition and working memory tasks, respectively. The final section is comprised of correlations between parent ratings and the automated measures of sustained attention and inhibition.

Sample Characteristics

The participant information (gender, age), PPVT standard scores, and parent rating scale *t*-score results (for CPRS-R ADHD Index only) are provided in Table 1. The participant age-group breakdown was as follows: 17 three-year olds, 19 four-year olds, 19 five-year olds, and 15 six-year olds. The sample was largely of average attention rating, and of average to high ability based on the PPVT-3 verbal mental age assessment. All participants completed the entire testing battery, with the exception of two participants each aged 3 years and 3 months, who were unable to complete the full battery due to their inability to comprehend the Dog-Cat task of inhibition.

Table 1. Participant Information, Estimated IQ Scores and Parent Rating Scale

Age (Years)	3* n=17		4 n=19		5 n=19		6 n=15	
	M	SD	M	SD	M	SD	M	SD
% Male	59%		42%		47%		47%	
Mean Age (years, months)	3.53	0.27	4.49	0.29	5.40	0.24	6.37	0.29
PPVT Standard Score	98.4	15.6	98.8	11.5	107.5	13.4	99.7	11.0
Conners' Inattention Rating (T Score)	49	7	46	5	47	5	50	8
Conners' Hyperactivity Rating (T Score)	48	5	47	6	44	5	50	6
Conners' ADHD Index Rating (T Score)	49	6	47	6	45	5	51	7

* Incomplete data for two participants (3y, 3m) due to an inability to comprehend the Dog-Cat (inhibition) task

Examination of Performance as a Function of Age

To examine the group differences in performance as a function of age, both one-way Kruskal-Wallis tests and between subject ANOVAs were used, depending on the particular dependent variable included in the analysis. Specifically, percent hits and errors were examined with Kruskal-Wallis tests, whereas reaction times were measured with ANOVAs. Importantly, all analyses conducted using Kruskal-Wallis tests report on median, as opposed to mean, values. Although omitted in the results section, the mean values of performance

accuracy (percent hits and errors) are included for reference in Appendix A.

When required, post-hoc pairwise comparison tests were computed using the Mann-Whitney U test, and a Bonferroni correction was used to control the Type I error rate. Therefore, the results of all post hoc analyses meeting an alpha level less than or equal to .008 (.05/6) were considered statistically significant at the .05 level.

Age related Differences in Performances of Visual and Auditory Sustained Attention

As shown in Table 2, the median percent hits increased across ages with the 3 year old group being the least accurate, and the 6 year old group the most accurate. Non-parametric analyses using a Kruskal-Wallis test for the individual visual and auditory CPTs revealed a significant effect of age on percent hits, $H(3)=23.95$, $p<.0001$ and $H(3)=14.97$, $p<.01$, respectively. Subsequent two-tailed Mann-Whitney U pairwise comparison tests indicated that the percent median hits for the 5 and 6 year old groups were significantly higher than those of the 3 year old group in both CPTs, $p<.05$ (see Tables 2 and 3). Additionally, it was found that the 6 year old group had significantly greater median percent hits than the 4 year old group in the visual trial alone (see Table 1). No other pairwise contrasts were significant, $ps>.05$.

In addition to examining hits, individual analyses of the percent errors of omission (misses) and commission (false alarms) were completed to investigate performance as a function of age. Kruskal-Wallis tests performed on the median errors of omission revealed an overall significant effect for both the visual and auditory tasks, $H(3)=22.98$, $p<.0001$ and $H(3)=16.95$, respectively, $p<.001$.

Pairwise comparisons using two-tailed Mann-Whitney U tests revealed that the median percent visual omissions for the 3 year old group was greater than the medians of the 5 and 6 year old groups, $p < .05$, as shown in Table 1. Moreover, the 4 year old group made significantly greater percent median omissions than the 6 year old group, $p < .05$. Similar to the visual CPT, results from the auditory CPT indicated that the median omissions of the 3 year old group was significantly higher than the medians of the 5 and 6 year old groups, both, $p < .05$. Results from both CPTs indicated that errors of omission were decreasing, albeit not all significantly, with age.

Unlike the errors of omission, age did not significantly influence errors of commission in either the visual or auditory CPT, as no significant differences, $ps > .05$, or clear trend emerged between the medians of each age group.

Table 2. Median Scores (25th, 75th Percentile) by Age Group for **VISUAL** Cognitive Measures

		AGE (YRS)			
Task	Measure	3	4	5	6
		N=17*	N=19	N=19	N=15
		Median	Median	Median	Median
Visual CPT	Hits (%)	68.2 (59.1, 88.8)	86.4 (81.8, 95.5)	95.5 (90.9, 100)	95.5 (90.9, 100)
	Omission Errors (%)	27.3 (11.3, 40.9)	13.6 (4.5, 18.2)	4.5 (0, 9.1)	4.5 (0, 9.1)
	Commission Errors (%)	9.1 (0, 25.0)	4.5 (0, 13.6)	4.5 (0, 9.1)	0 (0, 9.1)
Visual Dog-Cat Task (Incongruence Trial)	Correct Responses (%)	59.4 (39.1, 81.3)	75.0 (68.8, 87.5)	87.5 (75.0, 93.8)	93.8 (87.5, 100)
	Non-Responses (%)	13.4 (6.3, 31.3)	12.5 (0, 12.5)	0 (0, 6.3)	0 (0, 6.3)
	Percent Incorrect (%)	18.8 (1.6, 31.3)	6.3 (0, 12.5)	6.3 (0, 12.5)	0 (0, 6.3)
Visual Working Memory	Mean Score/3	1.00 (0, 1.00)	1.00 (1.00, 2.00)	2.00 (1.00, 3.00)	3.00 (2.00, 3.00)

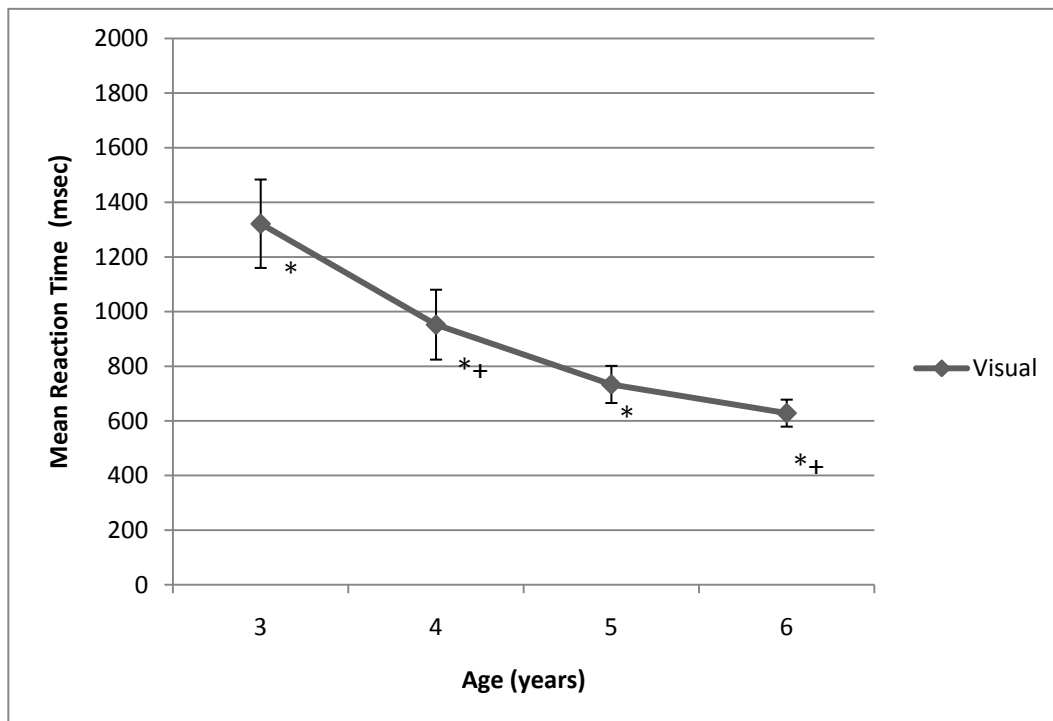
* N.B. N=16 for 3 year old group in Visual Dog-Cat Task

Table 3. Median Scores (25th, 75th Percentile) by Age Group for **AUDITORY** Cognitive Measures

		AGE (YRS)			
Task	Measure	3	4	5	6
		N=17*	N=19	N=19	N=15
		Median	Median	Median	Median
Auditory CPT	Hits (%)	77.3 (70.5, 95.5)	90.9 (81.8, 95.5)	100 (90.9, 100)	100 (90.9, 100)
	Omission Errors (%)	22.7 (4.5, 31.8)	4.5 (0, 18.2)	0 (0, 9.1)	0 (0, 9.1)
	Commission Errors (%)	9.1 (2.25, 18.2)	9.1 (0, 18.2)	9.1 (4.5, 18.2)	9.1 (9.1, 13.6)
	Correct Responses (%)	50.0 (37.5, 56.3)	75.0 (62.5, 81.3)	87.5 (75.0, 93.8)	87.5 (75.0, 93.8)
	Non-Responses (%)	37.5 (25.0, 50.0)	12.5 (6.3, 25.0)	6.3 (0, 18.8)	6.3 (0, 12.5)
Auditory Dog-Cat Task (Incongruence Trial)	Percent Incorrect (%)	12.5 (0, 25.0)	6.3 (0, 12.5)	0 (0, 6.25)	6.3 (0, 6.25)
	Mean Score/3	1.00 (0, 1.00)	1.00 (1.00, 1.00)	2.00 (1.00, 2.00)	2.00 (2.00, 3.00)
Auditory Working Memory					

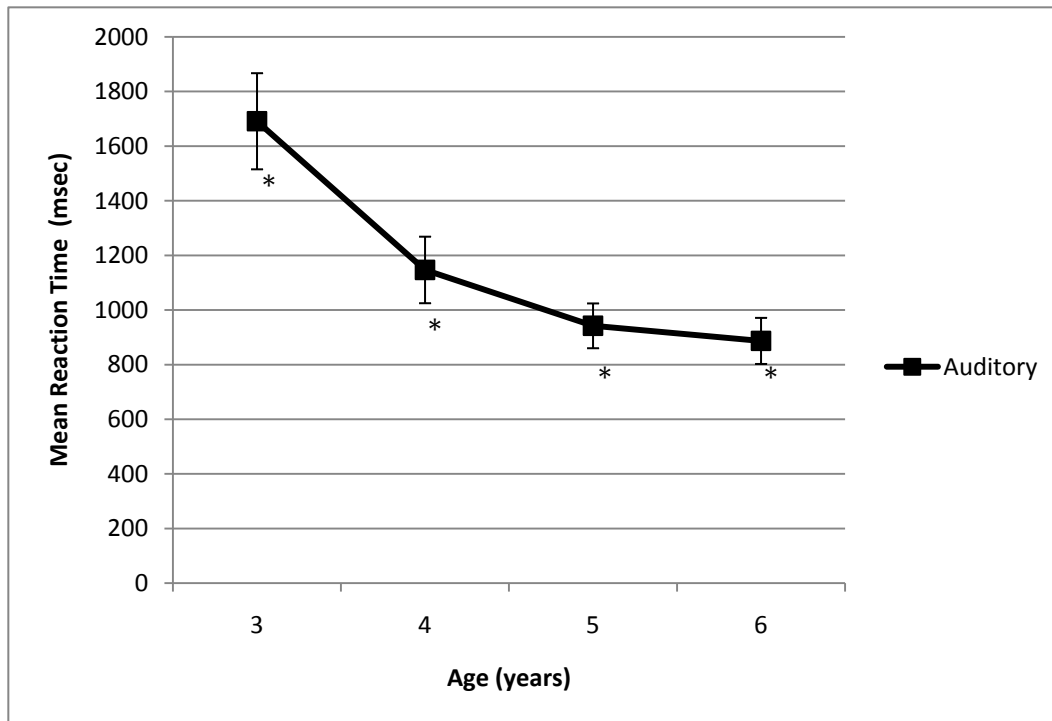
*N.B. N=15 for 3 year old group in Auditory Dog-Cat Task

The effects of age on mean reaction times in the visual and auditory CPT are displayed in Figure 3 and 4. As the reaction time data appeared to be normally distributed, one-way between subject ANOVAs were used to investigate the mean differences between age groups. An overall significant main effect was found for age in both visual and auditory CPTs, $F(3,66)=19.36$ and $F(3,66) = 19.73$, $p<.0001$, respectively. Post-Hoc analysis using the Tukey's Honestly Significant Differences test revealed significant pairwise comparisons between the 3 year old group and the 4, 5 and 6 year old groups for both CPTs, $p<.001$, which indicated that mean reaction times in these groups were significantly lower than those of the youngest participants (3 year old group). Another significant difference was also found between the 4 year and 6 year old groups in the visual CPT, $p<.05$.



* 6-, 5- and 4-yr.-olds < 3-yr.-olds ($p<.008$). +6-yr. olds < 3-yr.-olds ($p<.008$).

Figure 3. Mean Reaction Times and SEM for the Target in the Visual CPT



* 6-, 5- and 4-yr.-olds < 3-yr.-olds ($p < .008$). +6-yr. olds < 3-yr.-olds ($p < .008$).

Figure 4. Mean Reaction Times and SEM for the Target in the Visual CPT

Age related Differences in Performances of Visual and Auditory Inhibition

Kruskal- Wallis tests revealed an overall significant effect of age on the percent of correct responses in both the visual and auditory Dog-Cat tasks, $H(3)=21.05$ and $H(3)=27.22$, $ps < .0001$. As illustrated in Tables 1 and 2, the percent median hits improved from the ages of 3 to 6 years. The age-related improvement in performance on the visual task was confirmed through post-hoc analyses, indicating that the median percent hits of the 5 and 6 year old groups were significantly greater than that of the 3 year old group. Moreover, the median percent hits of the 6 year old group was found to be significantly greater than the median of the 4 year old group, $p < .05$. Similar improvements were recorded in the auditory trial, as Mann-Whitney U tests confirmed that the median percent hits of

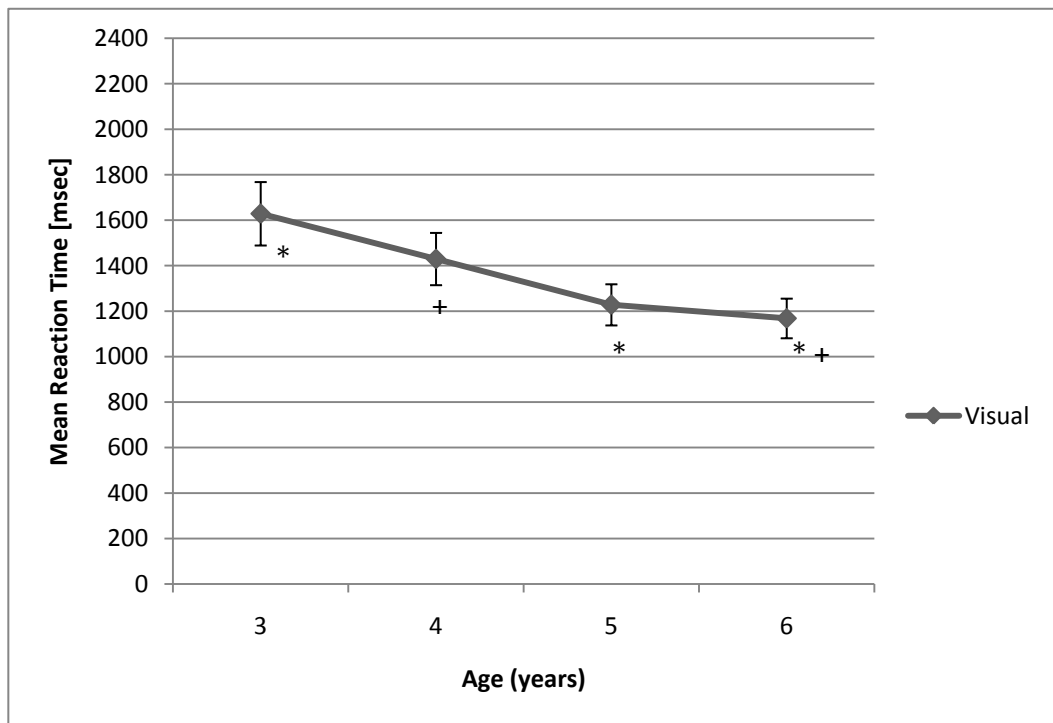
the 4, 5 and 6 year old groups were all significantly greater than that of 3 year old group, $p < .05$.

Overall significance was found in the Kruskal-Wallis tests for percent median non-responses and age in both the visual and auditory Dog-Cat tasks, $H(3)=16.99$ and $H(3)=23.40$, $ps < .001$. Post hoc analyses illustrated that the 3 year old group made significantly more non-response errors than the 5 and 6 year old groups in the visual task $p < .05$, as is displayed in Table 1. Additional significance was found between the 4 and 6 year old groups, with the 4 year old group producing more non-responses than the 6 year old group, $p < .05$. Similar results were found for the auditory task, with the exception of the comparison of the 3 and 4 year old groups, which were also significantly different, $p < .05$.

Unlike all other results reported on the task of inhibition, there was no age-related trend in terms of median percent incorrect responses in the visual or auditory Dog-Cat tasks. Although the overall significance of age on median percent incorrect responses was mildly significant in the visual Dog-Cat task, $p < .05$, there was only one significant pairwise comparison, confirming that the 6 year old group made significantly fewer incorrect responses than did the 3 year old group, $p < .05$. No other significant differences were found, $p > .05$.

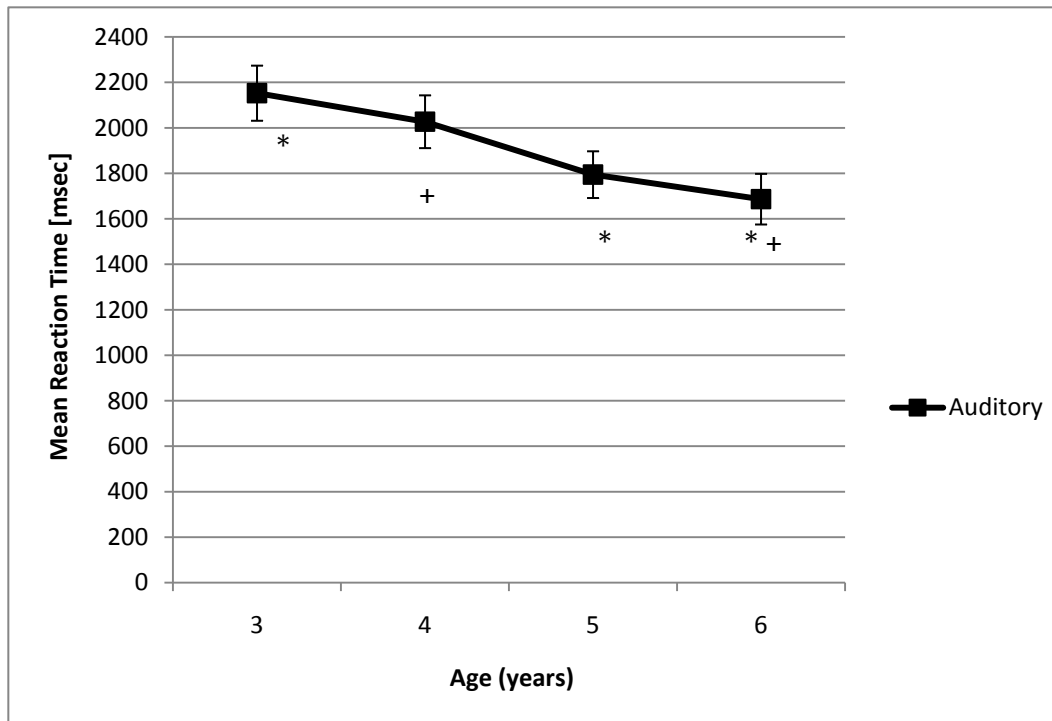
As was found with the CPT, the normal distribution of the reaction time data for the Dog-Cat tasks allowed for a parametric test to be used in the analysis of age group differences in reaction times. As shown in Figures 5 and 6, a similar trend to the one found with the CPT was also identified for the Dog-Cat task in that reaction times decreased from the ages of 3 to 6 years. One-way between

subject ANOVAs revealed an overall highly significant effect of age on reaction times in both the visual and auditory tasks, $F(3,65) = 9.76$, $p < .0001$, $F(3,64) = 7.85$, $p < .0001$, respectively. Post-Hoc analysis using the Tukey's Honestly Significant Differences tests revealed significant pairwise comparisons between the 3 year and the 5 and 6 year old groups, as well as between the 4 year and 6 year old groups, for both tasks, $p < .01$, which indicated that mean reaction times in these groups were significantly lower than those of the youngest participants (3 and 4 year old groups).



*5- and 6-yr.-olds < 3- yr.-olds ($p < .008$). + 6-yr.-olds < 4-yr.-olds ($p < .008$).

Figure 5. Reaction Times and SEM for Correct Responses in the Visual Dog-Cat Task



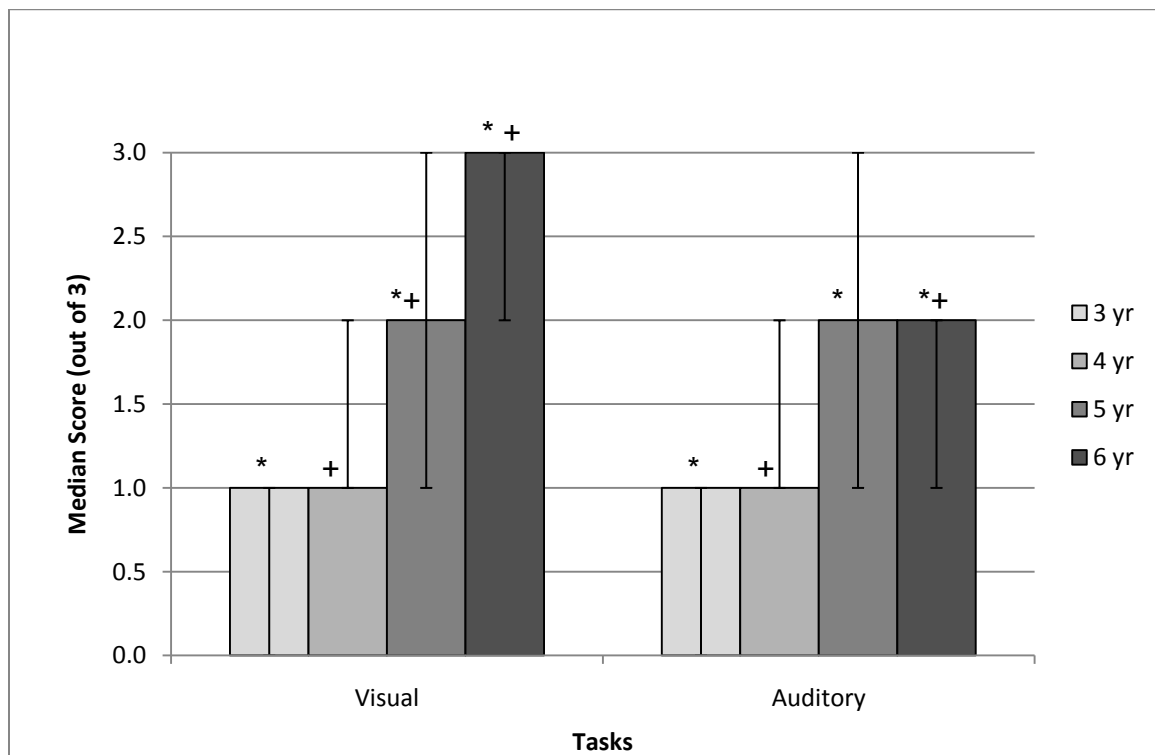
*5- and 6-yr.-olds < 3- yr.-olds ($p < .008$). + 6-yr.-olds < 4-yr.-olds ($p < .008$).

Figure 6. Reaction Times and SEM for Correct Responses in the Auditory Dog-Cat Task

Age related Differences in Performances of Visual and Auditory Working Memory

As mentioned, the variable of interest for the visual and auditory working memory tasks was reported as a score; an ordinal measurement defining the number of lists successfully completed by each participant. Use of this type of variable meant that a nonparametric analysis was required. Therefore, Kruskal-Wallis tests were used to analyze age group differences in scores. The results from these analyses confirmed that there was a highly significant effect of age on score in the respective visual and auditory tasks, $H(3) = 31.72$ and $H(3) = 21.38$, $ps < .0001$. As shown in Figure 7, median scores improved with age. The increase in scores indicated that the children in the 4 year old group successfully completed two of the three two-item lists, whereas children of the 5 year old

group completed at least two of the three three-item lists. Mann-Whitney U tests for the visual task revealed that the median scores of the 3 and 4 year old group were significantly lower than the scores of the 5 and 6 year groups, $p < .05$. Likewise, pairwise comparisons for the auditory task yielded identical results to those described for the visual trial, with the exception of a non-significant difference between the median scores of the 4 and 5 year old groups.



*5- and 6-yr.-olds > 3- yr.-olds ($p < .008$). + 6- and 5-yr.-olds < 4-yr.-olds ($p < .008$).

Figure 7. Median Scores (25th and 75th percentile) Across Age Groups on Visual and Auditory Working Memory Tasks

Summary of Performance Accuracy Across Ages Groups

In the aim of condensing the findings of the age-related changes in both visual and auditory sustained attention, inhibition and working memory, Figure 8, summarizes the age at which performance in each task reached a level

significantly better than chance ($\geq 65\%$). Depicted in this Figure are the percentages of the median performance accuracy rates for each individual task, specifically, the percent hits for the sustained attention tasks, the percent correct responses for the inhibition tasks, and the percent mean working memory scores. In summary, the findings revealed that while the youngest group (3 year old group) had difficulty in performing the tasks of inhibition and working memory, they were able to successfully attain a level of at least 65% accuracy in the task of sustained attention. Large gains in performance were achieved from the 3 year to the 4 year old group, as illustrated by an increase in performance ability in the inhibition task. In contrast, the results for the 5 and 6 year old groups revealed that the majority of the sample was able to complete all tasks at a level of accuracy equal to or greater than 65%.

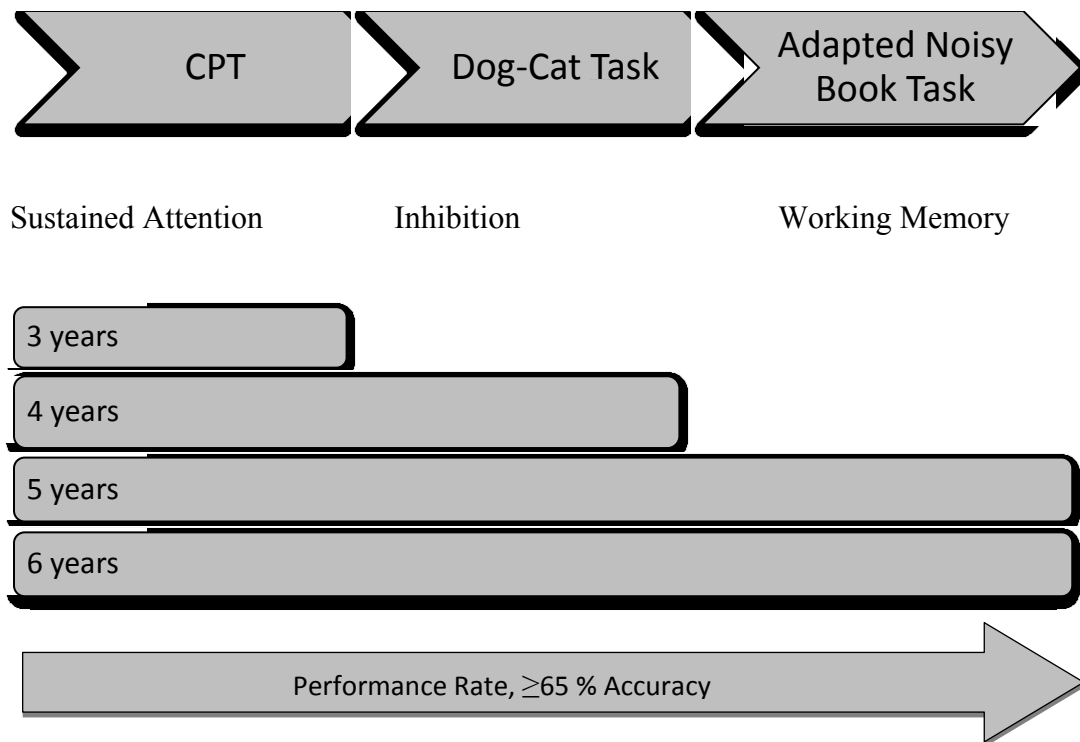


Figure 8. Summary of Performance Accuracy According to Age ($\geq 65\%$ Accuracy Rate)

Contribution of Age to Performance Variability

Firstly, to assess the amount of variance in accuracy (mean percent correct responses) and reaction time that was accounted for by age, a series of linear regression analyses were conducted for both the visual and auditory trials of the sustained attention and inhibition tasks. Secondly, to examine whether similar developmental trends existed between each visual and auditory task, specifically in terms of age-related changes in performance, the linear regressions for both accuracy and reaction times were statistically compared using the Regress program (Rochford 2000). This analysis was used to determine whether the trends were similar enough such that the data within tasks (visual and auditory) could be pooled and the developmental trend represented by only one regression line.

Linear Regression Analyses for Variables of Sustained Attention

As shown in Figures 9a and 9b, individual regression analyses examining the contribution of age to the variability in performance in terms of mean percent hits on the visual and auditory sustained attention tasks yielded significant Pearson correlation coefficients, $r = +0.645$ and $r = +0.522$, $p < .0001$, respectively. Similarly, as shown in Figures 10a and 10b, individual regression analysis investigating the effect of age in predicting reaction time of hits also revealed significant Pearson correlation coefficients, $r = -0.660$ and $r = -0.667$, $p < .01$, for the visual and auditory sustained attention tasks, respectively. Collectively, the relatively elevated correlation coefficients indicated that there was a strong correlation between age and percent hits as well as age and reaction time. The corrected Pearson correlation coefficients (r^2) confirmed that age contributed 42% and 27% of the variance in predicting visual and auditory percent hits, respectively. Similarly, age predicted 51% of the variance for mean reaction time in both visual and auditory trials.

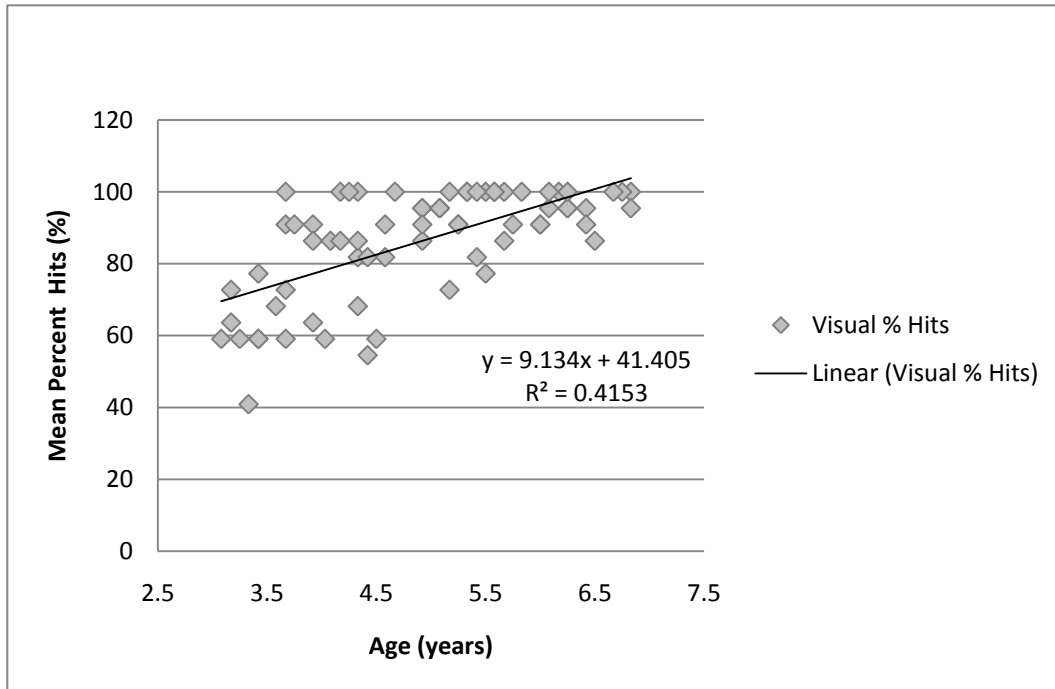


Figure 9a. Linear Regression for Age and Visual Mean Percent Hits

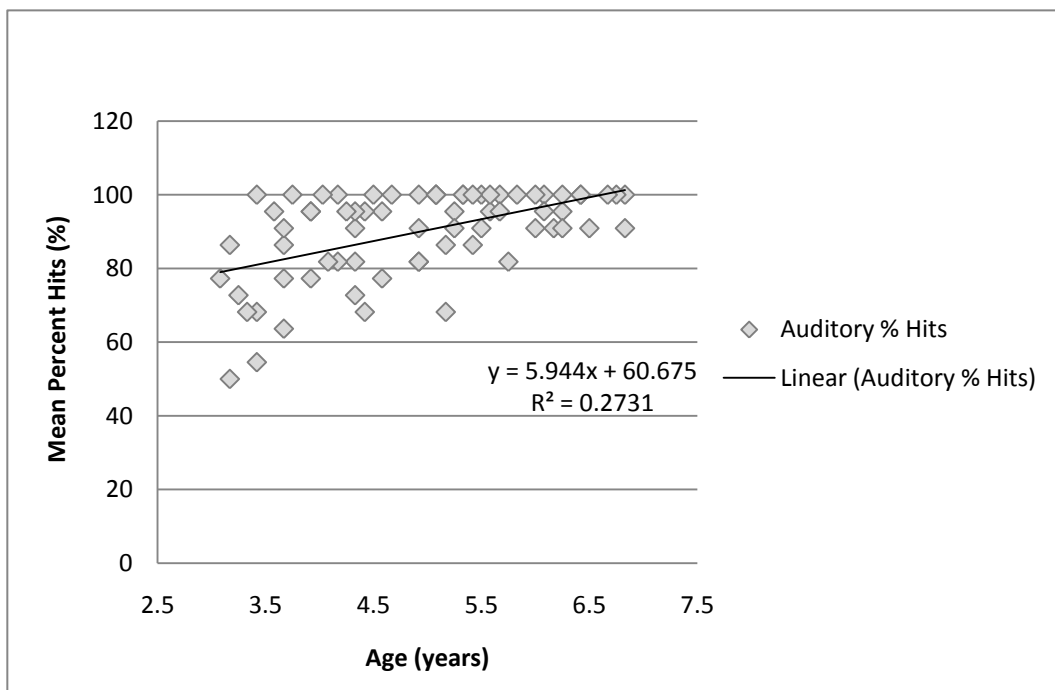


Figure 9b. Linear Regression for Age and Auditory Mean Percent Hits

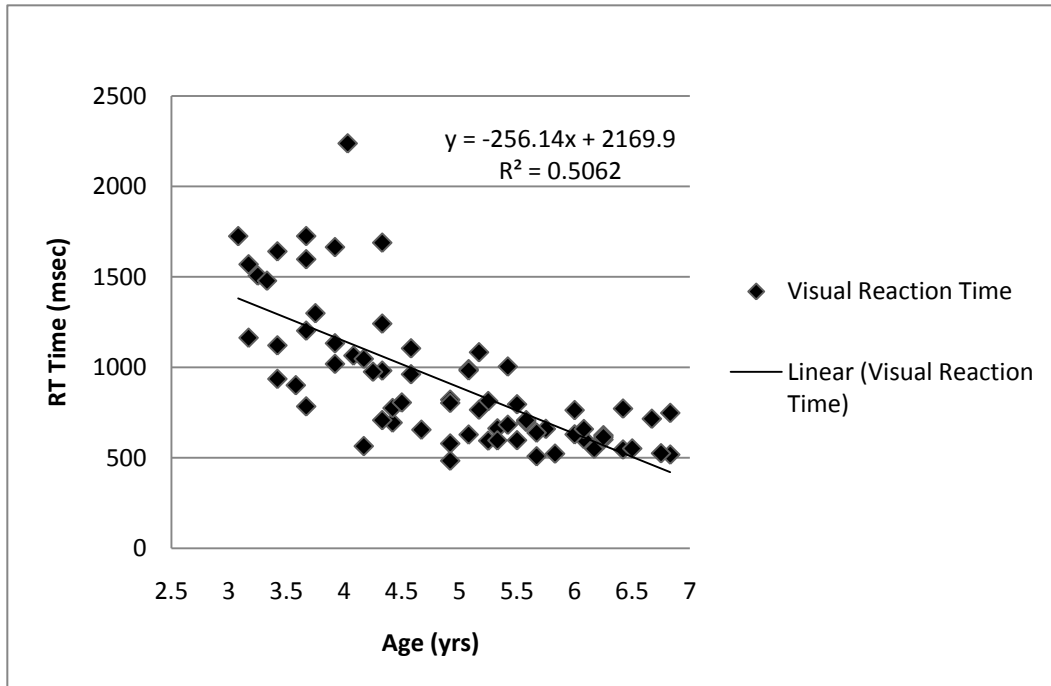


Figure 10a. Linear Regression for Age and Visual Reaction Time

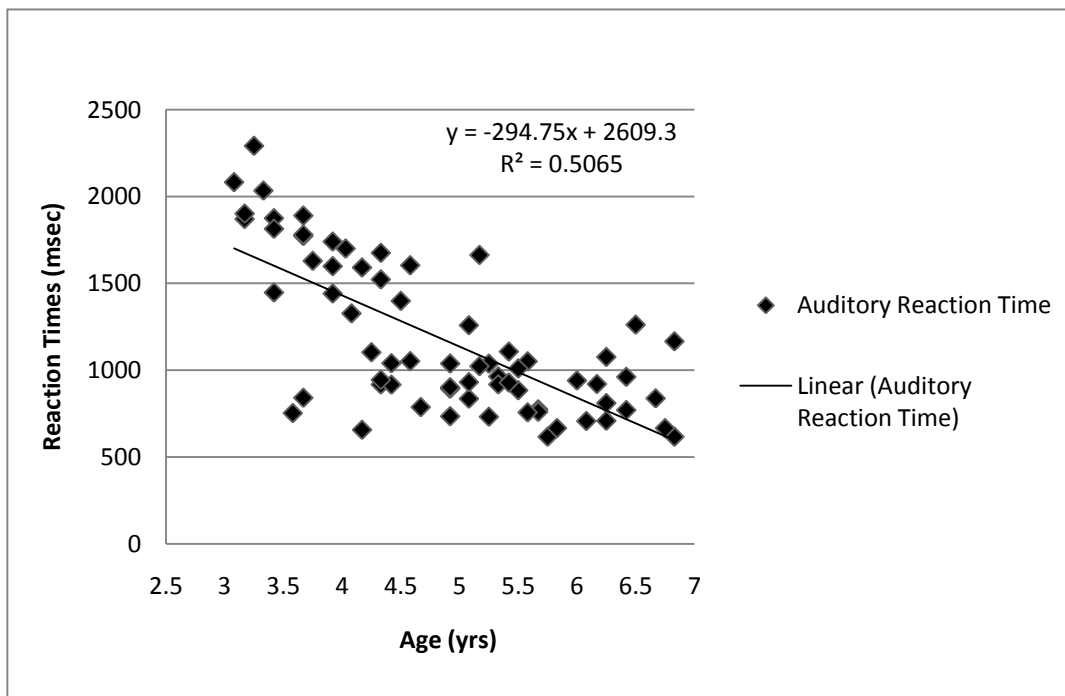


Figure 10b. Linear Regression for Age and Auditory Reaction Time

Comparison of Visual and Auditory Linear Regressions: Variables of Sustained Attention

Particular interest was taken in determining whether a similar increase in percent hits and decrease in reaction time was occurring for every one year increase in age across both modalities. The comparison of the visual and auditory regressions for mean percent hits and age revealed a significant result, $F(2, 136) = 3.56, p < .05$, rejecting the null hypothesis that the data could be best represented by a common line fit. Although the visual and auditory regressions appear to be quite comparable in terms of slope, the obtained result was likely explained by the difference in y-intercept values, with the auditory mean percent hits intercept value being significantly higher than the y-intercept value of the visual regression, $F(1, 136) = 108.32, p < .0001$. Generally, this result indicated that a greater number of hits were made throughout the ages of 3 to 6 years in the auditory task. Conversely, the comparison of the slopes of each regression revealed that the slope of the visual regression was significantly higher than that of the auditory regression, $F(1, 136) = 74.65, p < .0001$, as can be seen by the steeper slope in visual mean percent hits across all ages. However, a closer examination of the slopes pointed to the concentration of data points, particularly of the 5 and 6 year old groups, at the 100 percent accuracy mark. Knowing this, it was suspected that the high level of ceiling performance detected in both the visual and auditory tasks was likely adding to the variability between slopes of the regression lines; subsequently, contributing to the resultant rejection of a common line fit for all mean percent hit data in the tasks of sustained attention. Therefore, a second analysis, omitting the data of the 5 and 6 year old groups, was used to examine whether the visual and auditory mean percent hit data could be pooled.

The results provided by this second analysis indicated that the slopes, and thereby developmental trends in mean percent hit performance with age, were similar enough across visual and auditory tasks that the data could be pooled and represented by one common linear regression, $F(2, 68) = 2.61, p > .05$. This result suggests that although the y-intercepts were significantly different, the slopes of the visual and auditory regressions were actually quite similar once the influence of the ceiling performance data was removed.

Similar to the results obtained for the percent hits analysis, the F-value for the common line, slope and y-intercept for mean reaction times were all highly significant, $F(2, 136) = 13.78$, $F(1, 136) = 13.37$, and $F(1, 136) = 76.89, p < .001$. Individual assessment of the slope and y-intercepts revealed that both the values of the slope and y-intercept for the auditory regression were higher than those of the visual regression line, indicating that there was a sharper decrease in reaction time between ages, but generally slower response times throughout the auditory sustained attention task. Collectively, these results indicated, once more, that the slopes and y-intercepts of the two lines for the visual and auditory sustained attention tasks were significantly different from one another, suggesting that mean reaction times could not be represented by one regression line. The lack of statistical significance in grouping the data for mean reaction times may be a consequence of the stark difference in y-intercepts between the visual and auditory trials.

Linear Regression Analyses for Variables of Inhibition

Comparable to the results for the variables of sustained attention, the linear regressions of mean percent hits and reaction times with age showed that age contributed similarly to the variability in performances across visual and auditory inhibition tasks. Significant Pearson correlation coefficients were obtained for the mean percent hits ($r = +0.639$ and $r = +0.631$, $p < .0001$) and reaction time regressions ($r = -0.597$ and $r = -0.555$, $p < .0001$) for the visual and auditory inhibition tasks, respectively. Correspondingly, as shown by the corrected Pearson correlation coefficients in Figures 11a, 11b, 12a and 12b, age contributed similarly to the variability in performances in terms of mean percent correct responses and reaction times. Specifically, age contributed to approximately 41% of the variance in predicting mean percent correct responses and 34% of variance in predicting mean reaction times in both the visual and auditory inhibitory tasks.

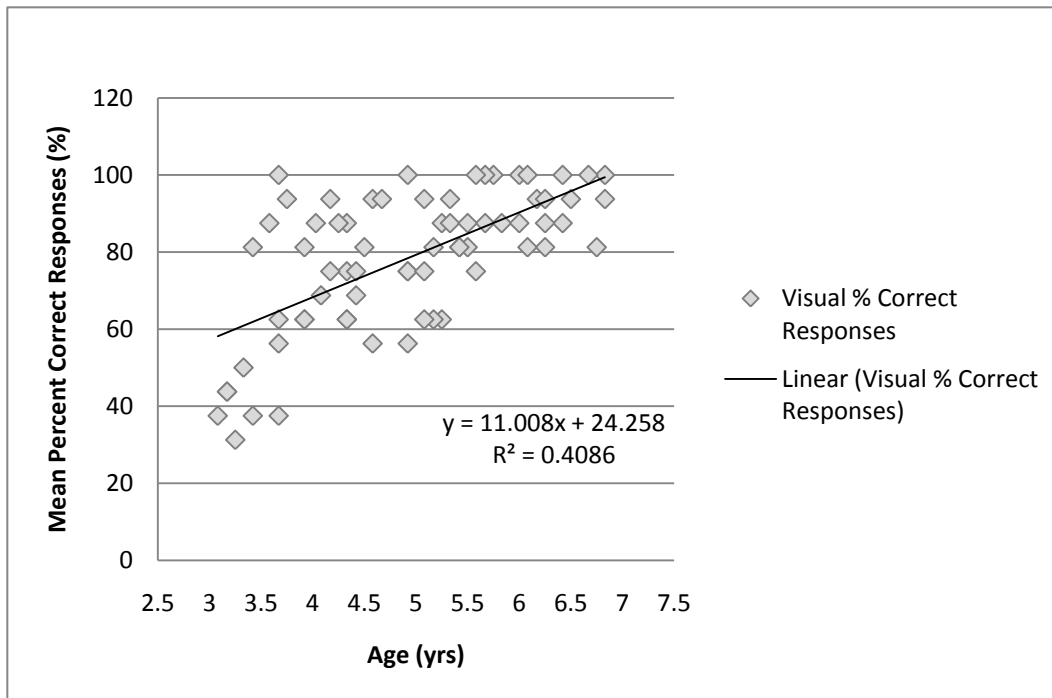


Figure 11a. Linear Regression for Age and Visual Correct Responses

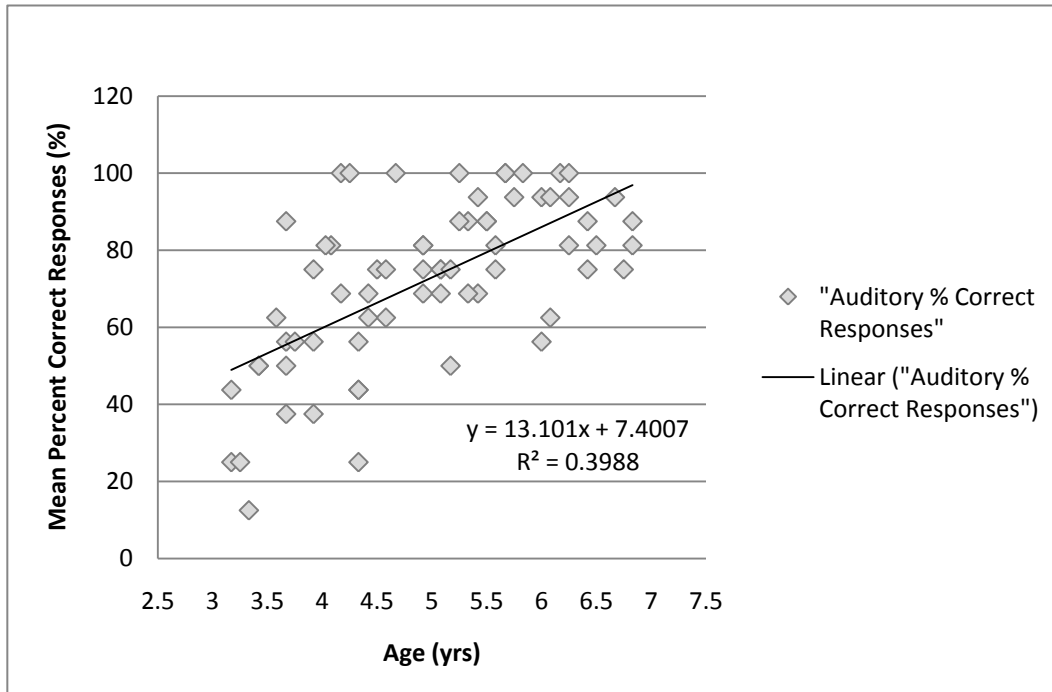


Figure 11b. Linear Regression for Age and Auditory Correct Responses

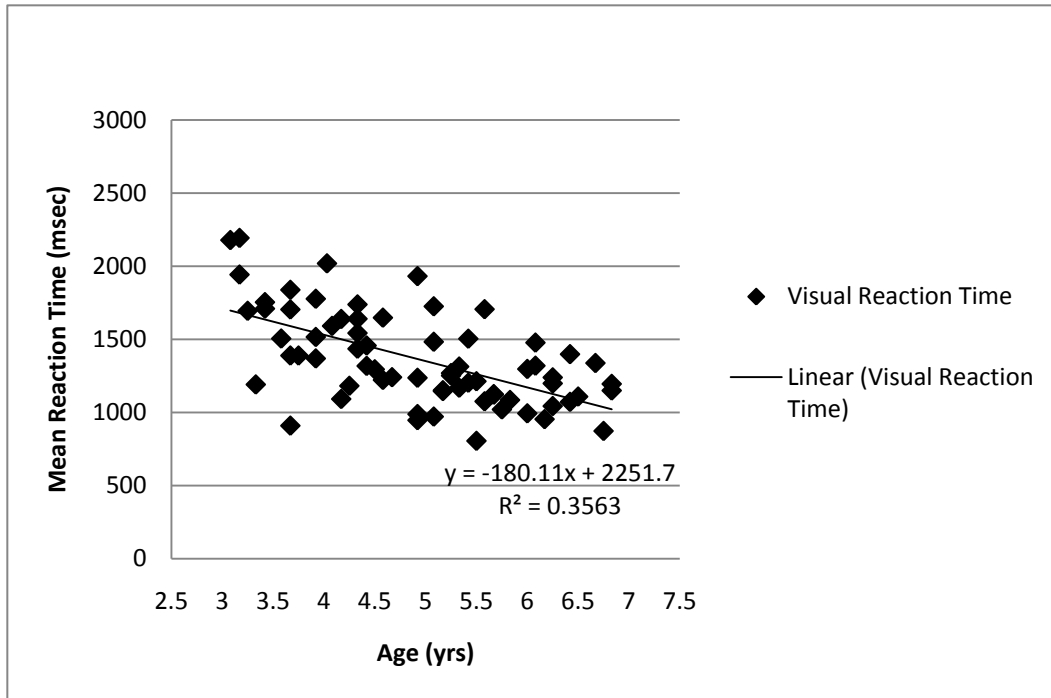


Figure 12a. Linear Regression for Age and Visual Correct Responses

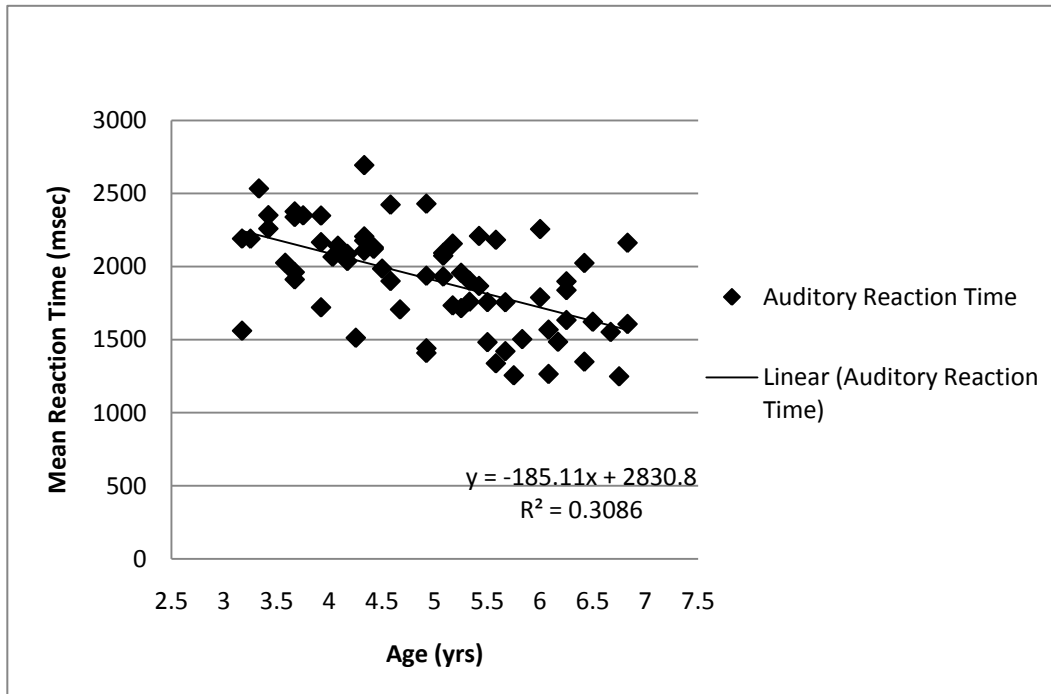


Figure 12b. Linear Regression for Age and Auditory Correct Responses

Comparison of Visual and Auditory Linear Regressions: Variables of Inhibition

As with the variables of sustained attention, the linear regressions for mean percent correct responses and reaction times for the variables of inhibition were also compared to see if the data could be pooled and represented by one regression line. This analysis yielded similar results to those found for the variables of sustained attention, in that a significant common line was found for the mean percent correct responses, $F(2,133) = 3.39$ and reaction times, $F(2,133) = 70.56$, $p < .05$, thereby rejecting the null hypothesis which stated that all data could be represented by one common regression line. However, it was suspected once again that the skewness of the data, as a consequence of an elevated level of ceiling performance in terms of percent correct responses by the 5 and 6 year old participants, was responsible for this result. Subsequently, the comparison analysis was performed for a second time for the variable accuracy (mean correct responses), specifically excluding the data for the 5 and 6 year old groups. As was thought, exclusion of the 5 and 6 year old data resulted in a non-significant common line, $F(2, 65) = 2.577$, $p > .05$, indicating that similar developmental trends for performance accuracy, particularly for the 3 and 4 year old groups, were emerging across modalities. Furthermore, it was suspected that the data for mean reaction times, as was the case for the sustained attention task, could not be pooled largely due to the pronounced difference in y-intercepts between the visual and auditory trials.

Correlations Between Visual and Auditory Tasks

To assess whether there was any relationship between measures of visual and auditory sustained attention and inhibition, a series of bivariate Spearman correlations were first conducted between the visual and auditory percent hits for the sustained attention tasks, percent correct responses for the inhibition tasks, and scores obtained from the working memory tasks. A second series of bivariate Pearson moment correlations were performed between the mean reaction time data of the visual and auditory sustained attention and inhibition tasks to further examine the relationship in performance across modalities. Since multiple correlations were computed, a conservative error rate, $\alpha=.01$, was used to identify any significant correlations.

The results from the Spearman correlation analyses for correct responses across modalities revealed significant, positive and moderate to strong correlations between the visual and auditory sustained attention($\rho=0.559$), inhibition ($\rho=0.847$), and working memory ($\rho=0.506$) tasks, $p<.01$. Additionally, the Pearson moment correlations used to examine the association between reaction times in the visual and auditory tasks indicated that there were significant, positive and moderate to strong correlations in reaction time performance across the sustained attention ($\rho= 0.812$, $p<.01$) and inhibition tasks ($\rho=0.525$, $p<.01$). Taken together, the results of the correlation analyses suggest that there are moderate to strong relationships in performance, as defined by percent correct responses and reaction time, across visual and auditory tasks.

Correlation Analyses of Accuracy Across Cognitive Measures of Sustained Attention, Inhibition and Working Memory

To evaluate the relationship in performance accuracy (percent hits, correct responses and scores) across all three measures targeting different subcomponents of attention and executive function, Spearman correlations were calculated for the respective visual and auditory trials of each task. As a result of the multiple comparisons, a conservative error rate, $\alpha=.01$, was used once again. The results of this analysis are summarized in Tables 4 and 5. Visual inspection of Tables 4 and 5 indicated that generally, the measures of sustained attention, inhibition and working memory were significant, positive and weakly to moderately correlated across all respective visual and auditory performances, suggesting that there was a weak to moderate relationship in performance accuracy between all three measures used in our testing battery.

Table 4. Correlations of Visual Performance Accuracy Between Cognitive Measures

Tasks	Visual CPT % hits	Visual Dog-Cat % hits
Visual Dog-Cat % hits	0.478**	-
Visual Working Memory Score	0.459**	0.477**

** $p<.01$, * $p<.05$

Table 5. Correlations of Auditory Performance Accuracy Between Cognitive Measures

Tasks	Auditory CPT % hits	Auditory Dog-Cat % hits
Auditory Dog-Cat % hits	0.340**	-
Auditory Working Memory Score	0.278*	0.433**

** p<.01, * p<.05

Correlations Among Ratings and Performances of Sustained Attention and Inhibition

A series of Spearman Correlations among the sustained attention and inhibition indices (percent hits/correct responses, percent omissions/ non-responses, percent commissions / incorrect responses and mean reaction times) and parent ratings on the Conner's Parent Rating Scale (Inattention, Hyperactivity, and ADHD Index scales) are presented in Tables 6 and 7. To control for multiple correlations, a level of $\alpha = .01$ was used to determine significance. Although no significant correlations were identified between the sustained attention indices and the CPRS-R, $p > .01$, the ratings of the Inattention and ADHD index scales were significantly, negatively and weakly to moderately correlated with the auditory percent correct responses, $p < .01$. Furthermore, the ADHD index ratings were significantly, positively and weakly to moderately correlated with visual percent incorrect responses of the inhibition task, $p < .01$. No significant bivariate Spearman correlations were found between the CPRS-R scales and reaction times in either the sustained attention or inhibition tasks.

Table 6. Correlations Between Variables of Sustained Attention and Conner's Parent Rating Scale

CPRS-R Scale	% Hits		% Omissions		% Commissions	
	Visual	Auditory	Visual	Auditory	Visual	Auditory
Inattention	-.128	-.012	.126	.048	.207	-.045
Hyperactivity	-.022	-.105	-.011	.131	.183	.251
ADHD Index	-.129	-.201	.127	.241	.199	.099

** p<.01

Table 7. Correlations Between Variables of Inhibition and Conner's Parent Rating Scale

CPRS-R Scale	% Correct Responses		% Non Responses		% Incorrect Responses	
	Visual	Auditory	Visual	Auditory	Visual	Auditory
Inattention	-.205	-.324**	.061	.279	.300	.129
Hyperactivity	-.189	-.276	.135	.199	.269	.233
ADHD Index	-.171	-.327**	.104	.259	.321**	.289

** p<.01

Chapter 4

Discussion

The first aim of the present study was to assess age-related changes in visual and auditory sustained attention, inhibition and working memory during the preschool-aged years (ages 3 to 6 years). This was accomplished using three preschool-appropriate computerized paradigms that tapped individual visual and auditory subcomponents of each of these cognitive abilities, specifically, sustained attention, inhibition and working memory. It was hypothesized that performance would increase across age groups on all three tasks. A second aim was to examine whether age contributed equally to the variability in performances across modalities and whether performances across modalities, as defined by accuracy and reaction times, were related. It was hypothesized that performance would be poorer in auditory than visual measures, but that correlations in performances would be found across modalities. A third aim was to assess whether there was a relationship in performance (% hits, correct responses and score) across the three newly-adapted measures that tap sustained attention, response inhibition and working memory. It was hypothesized that there would be a weak correlation between accuracy measures across all tasks. As a fourth and final aim, the performance indices of our sustained attention and inhibition tasks were correlated with scores from a standardized parent rating scale, the CPRS-R, to preliminarily examine the relationship between behavioural ratings and performances of attention.

With the exception of the results of accuracy in the sustained attention tasks (CPT), the findings from this study generally support our hypotheses and thereby contribute to our knowledge of age-related changes in subcomponents of attention and executive function in typically- developing preschool-aged children. The discussion of these findings will firstly elaborate the observed age group differences in performance across tasks, secondly detail the association of performances across modalities and measures, and thirdly briefly discuss the relationship of performance and behavioural ratings on the Conners' Parent Rating Scale-Revised (CPRS-R).

Age-Related Differences in Sustained Attention

The results from the visual and auditory sustained attention tasks (CPTs) demonstrated that the performance variables improved steadily across age groups; the ability to correctly identify the target increased, while the time to respond decreased with age. Although these differences were not significant between every age group, significance was always obtained between the 3 and 5 and 6 year old groups for percent hits, omissions and reaction times in both CPTs, which suggest that the period from 36 to 60 months is especially important in the development of sustained attention in terms of accuracy and motor response. The obtained results agree with those of other studies, which found that the largest gains in performance occurred between the 36 to 48 month groups (Corkum, Byrne et al. 1995; Prather 1995; Mahone, Pillion et al. 2001; Akshoomoff 2002). It is speculated that the changes in the ability of preschoolers to focus and sustain their attention in a formal testing environment may reflect the maturation of the orienting and anterior attention subsystems (Garon, Bryson et al. 2008). Future

investigations require the examination of performance as a function of age, defined in terms of months as opposed to years, particularly from 36 to 60 months, to better target the critical periods in preschool-aged development of sustained attention.

In terms of the level of accuracy, performances on the CPT remained elevated across all ages, with the youngest group attaining greater than 65% accuracy across both trials. These findings contradict those of other studies indicating that participant groups of 3 years of age require an interstimulus interval of at least 4000 milliseconds (Hagelthorn 2003). In the present study the interstimulus interval of 3690 milliseconds was sufficient for the 3 year-old participants to decide on and execute their responses. Future studies specifically investigating task parameters will help to determine the necessary minimum interstimulus interval to achieve maximal sensitivity and accessibility of CPT tasks to 3 year-old participant groups, especially since the importance of reaction time and mental age has recently been emphasized in the attention literature (Wilding and Cornish 2007).

Unlike the other performance variables that indicated age-related changes in performance and contrary to our prediction, the errors of commission in both the visual and auditory CPTs appeared to be age-independent. These findings are supported by other studies using visual and/or auditory CPTs in preschool-aged children, which also failed to observe a significant effect of age on commission error rate (Mahone, Pillion et al. 2001; Hagelthorn 2003). In contrast, a functional imaging study in children using a similar paradigm in a Go/No-Go type fashion found a trend for positive correlations between age and activation of the ventral

prefrontal cortex, an area that was also negatively correlated with accuracy (Casey, Trainor et al. 1997). These results suggest that at a certain period of developmental time, likely nearing adolescence, participants may be responding more quickly and impulsively, which is explained by the increase in activation of brain areas that are typically suppressed to successfully respond to the target and abstain from the non-target (Casey, Tottenham et al. 2005). It is therefore suggested that a period of increased impulsivity or greater errors of commissions is more likely to occur beyond the preschool years, which may aid in explaining why this did not occur in the present study.

Age-Related Differences in Inhibition

Similar to the results found for the sustained attention tasks, improvement in performance on the inhibition task (Dog-Cat task), as measured by correct responses, non-responses, and reaction time, occurred steadily across ages. With the exception of the percent hits in the auditory tasks, post-hoc analyses confirmed that significant differences existed between both the 3 and 5 and 3 and 6 year old groups, which underline the importance of the development of abilities of attentional control and inhibition during the period of 36 to 60 months. These results are in agreement with those of other studies using similar Stroop-like tasks, including the original Day-Night task and its adapted Grass-Snow task, which also demonstrated improved performance between the ages of 3 to 5 years (Gerstadt, Hong et al. 1994; Simpson and Riggs 2005) More importantly, our results also suggest that the improvement of inhibition may occur in somewhat of a non-linear fashion, as shown by the rapid increases in performance between the ages of 3 to 5 years and only modest improvement thereafter (Simpson and Riggs

2005). Future studies incorporating a larger range of ages will be necessary to confirm if a non-linear trend can be used to describe the development of inhibitory processes throughout the preschool- and school-aged years.

The success rate of performance on the task of inhibition was comparable to other findings, which have also evidenced particular difficulty in task completion for the youngest age group of 3 years. For example, using a task similar to the one of the present study, Carlson found that only 45% of the 3 year old group were able to meet the particular passing criteria of 75% accuracy (Carlson 2005). The results from the present study support these findings in that the median percent hits for both the visual and auditory tasks were less than 65%, indicating a relatively low level accuracy for this group. It is proposed that the high level of conflict incorporated in this task, specifically the semantic demand (i.e. Dog-Cat) in addition to the inhibition of a verbal and not a motor response, may be responsible for the low level of accuracy in the 3 year old group. Imaging studies suggest that the susceptibility to competing responses, like those in tasks of inhibition, may be explained by the coincident immaturity of the association cortex, specifically in the prefrontal and posterior parietal-related brain circuitry (see (Casey, Tottenham et al. 2005). Furthermore, the findings of developmental neuroimaging studies using Stroop-like tasks indicate that the susceptibility to interfering influences decreases, while the subsequent ability to filter information increases beyond the preschool and school years and carries on throughout the first two decades of life (Casey, Trainor et al. 1997; Adleman, Menon et al. 2002; Tamm, Menon et al. 2002). The maturational improvements occurring throughout childhood and into adolescence are illustrated by the refinement or fine-tuning of

performance related brain activity (i.e. reaction time and accuracy) and the attenuation of diffused activity in brain regions uncorrelated with task-specific functions (Casey, Tottenham et al. 2002). Simply, the functional neuroimaging evidence to date contends that as cognitive control (i.e. inhibition) continues to develop, there is a shift from generalized to focal activity, which may help to explain why enhanced performance in tasks of cognitive control are seen across developmental time (Durstun and Casey 2006).

Age-Related Differences in Working Memory

As expected, a developmental improvement in performance on both tasks of visual and auditory working memory occurred across the ages of 3 to 6 years. Similarly, the results of a longitudinal study also using the noisy-book task found improvement in performance between the ages of 3 to 4 years (Hughes 1998). Taken together, these results suggest that improved performance may reflect an increase in the ability to update and hold information in mind (Gathercole 1998), which ultimately points to an improvement in the visual-spatial sketchpad and phonological loop (Epsy 2005). Furthermore, the results of the present study suggest that performance in the adapted Noisy-Book task will continue to improve beyond the age of 6 years, since the median performance of the oldest age group did not reach a ceiling level. These findings complement those of other studies that also suggest a continued development of capacity and other more complex working memory abilities, such as updating and manipulating representations, throughout and beyond the preschool years (Gathercole 1998; Alloway, Gathercole et al. 2004). In the aim of better understanding the maturation of visual and auditory working memory in typical development, future

studies are needed to determine the age at which working memory performance on the Noisy-Book task reaches a developmental plateau.

Association of Performance Accuracy Across Modalities

In examining performance across modalities, regression analyses confirmed that age accounted for a large proportion of variance in the number of hits ($\approx 41\%$ visual and $\approx 27\%$ auditory) and response time ($\approx 50\%$) in both the visual and auditory sustained attention tasks. Similarly, individual regressions conducted for the visual and auditory inhibition tasks demonstrated that age accounted for a relatively large proportion of the variance in the number of correct responses ($\approx 40\%$) and response time ($\approx 36\%$ visual and 31% auditory). Although the developmental trends for both tasks and variables of interest were quite similar (i.e. performance improving from ages 3 to 6 years), the overall percent hits and reaction times across ages were different between visual and auditory tasks, as accuracy was at times better in the auditory task (i.e. sustained attention task), while at other times better in the visual task (i.e. inhibition task). Contrary to predictions, the percent hits regression analysis for the auditory sustained attention task revealed that auditory accuracy was higher across all ages in comparison to the visual sustained attention task. However, the reaction time regression line analysis for the auditory sustained attention task also confirmed the prediction that children were slower to respond in this task across all ages. One interpretation of this result can be that since children across all age groups took longer to respond to the target in this task, they had a higher success rate that is reflected by higher hit scores (an accuracy-speed trade-off). However, since both sustained attention tasks were as analogous as possible across task

parameters (i.e. stimuli, interstimulus interval, response time etc) these results bring into question the notion that auditory continuous performance tests are potentially more difficult than visual ones, as has been found in earlier studies (Baker 1995; Kerns and Rondeau 1998).

Despite the differences in reaction times between the visual and auditory trials of each the sustained attention and inhibition tasks, the comparable regression analyses suggest that similar developmental trends for performance, as defined by percent hits and reaction times, emerged across modalities.

In the interest of determining whether there was a relationship in performance across modalities, a series of correlations were conducted between the percent hits, correct responses and score of the respective visual and auditory sustained attention, inhibition and working memory tasks. Likewise another series of correlations were calculated between reaction times in the visual and auditory sustained attention and inhibition tasks. The analysis of performance in terms of accuracy and reaction times yielded moderate to strong correlations in performance, suggesting that there was a moderate to strong relationship in performance between visual and auditory accuracy in each of our three tasks. Knowing this, these findings suggest that performances on our selected tasks of sustained attention and executive functions may be generalized across modalities. Specifically, since the current paradigms are intended for future use in atypically developing populations, an auditory task, in lieu of a typically chosen visual task, may be more accessible depending on the specific proficiencies and deficiencies of the population in question. For example, the use of an auditory spatial working memory task, like the adapted auditory spatial sequencing noisy book task used in

the present study, could potentially yield useful information in a Williams Syndrome population, who have reported deficits in spatial tasks, but relatively good performances in auditory working memory (Levitin, Cole et al. 2005).

Association of Performance Accuracy Across Tasks

The examination of the relationship between performances across the three cognitive tasks within each respective modality revealed that there were significant weak to moderate correlations in visual and auditory performances across tasks, as defined by percent hits, correct responses and score. This finding provides preliminary evidence to support that our adapted tasks were assessing the desired subcomponents individually, since across task performance accuracy was not strongly, but only weakly to moderately correlated. Further support is offered to the suspected co-dependence of subcomponents of attention and executive function by the weak to moderate across task correlations. The significance of these correlations suggests that there may be an overlap of the attentional and executive functioning processes necessary to successfully complete each respective task, complimentary to findings of similar studies using comparable cognitive subcomponent-targeted tasks (Mahone, Pillion et al. 2001; Gomez-Perez and Ostrosky-Solvis 2006).

Association of Attention Ratings and Performance Accuracy in Sustained Attention and Inhibition

When performance variables of the sustained attention and inhibition tasks were compared with the scores of the Conners' standardized parent rating scale of attention, only the inhibition task (Dog-Cat task) demonstrated some initial association between performance and behavioural ratings. The negative

correlations between the auditory percent correct responses in the inhibition task and the indices of Inattention and ADHD simply suggest that strong performances of inhibition were related to lower (i.e. less impaired) ratings of inattentive and ADHD-like behaviour. Conversely, the positive correlation between the visual percent incorrect responses and the ADHD index rating suggests that higher parent ratings of ADHD-like behaviour were associated with a greater number of incorrect responses on the task of inhibition. The correlations evidenced may imply that our task of inhibition is valid in terms of detecting an association between behavioural manifestations of attention and cognitive performance. It will, however, be necessary to replicate these findings with a larger sample population to verify the reliability of the detected associations. Although no significant correlations were detected between attention ratings and the performance variables of the sustained attention task, this result is quite similar to what was found in studies using the original version of the task (Mahone, Pillion et al. 2001; Mahone, Pillion et al. 2005).

Limitations and Directions for Future Research

A number of considerations must be made with respect to this study: the limitations are threefold. First, the small sample size used in this study, 36 boys and 34 girls, limits the interpretation and generalization of the obtained results. Future studies will require larger sample sizes, which will provide a greater statistical power to better detect age related changes in cognitive subcomponents of attention and executive function. Additionally, future studies using a larger sample size will also help to replicate and subsequently validate the findings of the present study.

Second, the findings reveal an extremely high level of performance in terms of percent hits and correct responses in the visual and auditory CPTs and Dog-Cat tasks for the 5 and 6-year-old groups. The elevated levels of accuracy indicate that children of these age groups were approaching, if not reaching, ceiling level. This finding therefore suggests that these particular tasks may be too easy for children of 5 to 6 years of age. Subsequent use of these tasks would therefore be better suited for use in children with chronological and/or mental ages of 3 to 4 years.

Third, special consideration must be given to the relative contribution of intelligence to the variance in mean percent hits and reaction time scores in CPTs. Contrary to what has been found for school-aged children, the assumption that IQ is weakly related to scores of sustained attention, inhibition, and working memory cannot be extended to preschool-aged children since constructs such as intelligence, attention and executive function may not be as separable throughout the ages of 3-6 years (Hagelthorn 2003). As such, investigations like the present, may be strengthened primarily by the use of a full-scale intelligence test as a rigorous control and secondly by the incorporation of intelligence as a variable of interest. Still, investigation of the constructs of visual and auditory sustained attention, inhibition and working memory require the examination of performance as a function of age, defined in terms of months as opposed to years, to better target their critical periods in preschool-aged development of subcomponents of attention and executive function.

Fourth, a longitudinal design may help to better elucidate the significance of the individual development of visual and auditory attention before results can

be generalized to the neurotypical developmental profile of attention. Although a cross-sectional approach, like the one used in the present study, provides preliminary snapshots of changes in performance at different ages, it cannot provide the same developmental information that is offered by a longitudinal approach. Only with a longitudinal design will it be possible to delineate the developmental trajectories within the domains of attention and working memory, as age-related changes are reported from participants of the same cohort. It is with this type of information that researchers can begin to identify true developmental changes of attention.

Conclusion

The overarching aim of the present study was to identify and document the associated age-related changes in visual and auditory sustained attention, inhibition and working memory. Using a series of uniquely adapted preschool-appropriate measures tapping these individual subcomponents, improvements in performance were evidenced across all age groups, indicating that the newly-adapted measures used in this study were indeed sensitive enough to capture age-related differences across early-childhood. These findings, in combination with those from previous studies, provide a basis from which researchers can now better understand the acquisition of early cognitive skills, which will help in delineating the typical developmental progression of subcomponents of attention and executive function. In the eventual aim of defining syndrome-specific cognitive trajectories, it is anticipated that this study will incite future research

that will aid in identifying how and when the atypical and typical profiles converge and diverge.

Bibliography

Adleman, N. E., V. Menon, et al. (2002). "A Developmental fMRI Study of the Stroop Color-Word Task." NeuroImage **16**(1): 61-75.

Akshoomoff, N. (2002). "Selective Attention and Active Engagement in Young Children." Developmental Neuropsychology **22**(3): 625 - 642.

Alloway, T. P., S. E. Gathercole, et al. (2004). "A structural analysis of working memory and related cognitive skills in young children." Journal of Experimental Child Psychology **87**(2): 85-106.

Aylward, G. P., Brager, T., and Harper, D.C. (2001). "Comparison of visual and auditory continuous performance tests." The ADHD Report **9**: 5-8.

Baddeley, A. (1986). Working Memory. Oxford, England Oxford University Press.

Baddeley, A. (2003). "Working memory: looking back and looking forward." Nat Rev Neurosci **4**(10): 829-839.

Baker, D. B., Taylor, C., and Leyva, C.J. (1995). "Continuous performance tests: A comparison of modalities." Journal of Clinical Psychology **51**(4): 548-551.

Barkley, R. A. (1997). "Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD." Psychological Bulletin **121**(1): 65-94.

Belin, P., S. McAdams, et al. (1998). "The Functional Anatomy of Sound Intensity Discrimination." J. Neurosci. **18**(16): 6388-6394.

Berger, A., L Jones, MK Rothbart, MI Posner (2000). "Computerized games to study the development of attention in childhood." Behavior research methods, instruments, & computers **32**(2): 297-303.

- Berlin, L. and G. Bohlin (2002). "Response Inhibition, Hyperactivity, and Conduct Problems Among Preschool Children." Journal of Clinical Child & Adolescent Psychology **31**(2): 242 - 251.
- Bish, J. P., M. F. Samantha, et al. (2005). "Maladaptive conflict monitoring as evidence for executive dysfunction in children with chromosome 22q11.2 deletion syndrome." Developmental Science **8**(1): 36-43.
- Brocki, K. C., K. D. Randall, et al. (2008). "Working memory in school-aged children with attention-deficit/hyperactivity disorder combined type: Are deficits modality specific and are they independent of impaired inhibitory control?" Journal of Clinical and Experimental Neuropsychology **30**(7): 749 - 759.
- Bull, R. and G. Scerif (2001). "Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory." Developmental Neuropsychology **19**(3): 273-293.
- Bush, G., Paul, J. Whalen, Bruce, R. Rosen, Michael, A. Jenike, Sean, C. McInerney, Scott, L. Rauch (1998). "The counting stroop: An interference task specialized for functional neuroimaging - validation study with functional MRI." Human Brain Mapping **6**(4): 270-282.
- Cabeza, R. and L. Nyberg (2000). "Imaging Cognition II: An Empirical Review of 275 PET and fMRI Studies." Journal of Cognitive Neuroscience **12**(1): 1-47.
- Carlson, S. M. (2005). "Developmentally Sensitive Measures of Executive Function in Preschool Children." Developmental Neuropsychology **28**(2): 595-616.
- Casey, B. J., J. N. Giedd, et al. (2000). "Structural and functional brain development and its relation to cognitive development." Biological Psychology **54**(1-3): 241-257.
- Casey, B. J., K. M. Thomas, et al. (2002). "Dissociating Striatal and Hippocampal Function Developmentally with a Stimulus-Response Compatibility Task." J. Neurosci. **22**(19): 8647-8652.
- Casey, B. J., N. Tottenham, et al. (2002). "Clinical, imaging, lesion, and genetic approaches toward a model of cognitive control." Developmental Psychobiology **40**(3): 237-254.

Casey, B. J., N. Tottenham, et al. (2005). "Imaging the developing brain: what have we learned about cognitive development?" Trends in Cognitive Sciences **9**(3): 104-110.

Casey, B. J., R. J. Trainor, et al. (1997). "A Developmental Functional MRI Study of Prefrontal Activation during Performance of a Go-No-Go Task." Journal of Cognitive Neuroscience **9**(6): 835-847.

Castellanos, F. X., E. J. S. Sonuga-Barke, et al. (2006). "Characterizing cognition in ADHD: beyond executive dysfunction." Trends in Cognitive Sciences **10**(3): 117-123.

Cohen, J. D. (1988). Statistical power analysis for the behavioural sciences Hillsdale, NJ, Lawrence Erlbaum Associates.

Cohen, R. M., W. E. Semple, et al. (1988). "Functional localization of sustained attention: Comparison to sensory stimulation in the absence of instruction." Neuropsychiatry, Neuropsychology, & Behavioral Neurology **1**(1): 3-20.

Conners, C. (2001). Conners' Kiddie Continuous Performance Test. Toronto, Multi-Health Systems.

Conners, C. K. (1997). Conners Rating Scales Revised. Niagara Falls, NY, Multi-Health Systems.

Corbetta, M. (1998). "Frontoparietal cortical networks for directing attention and the eye to visual locations: Identical, independent, or overlapping neural systems?" Proceedings of the National Academy of Sciences of the United States of America **95**(3): 831-838.

Corkum, V., J. M. Byrne, et al. (1995). "Clinical assessment of sustained attention in preschoolers." Child Neuropsychology **1**(1): 3 - 18.

Corkum, V., Joseph M Byrne, Christine Ellsworth (1995). "Clinical Assessment of Sustained Attention in Preschoolers " Child Neuropsychology **1**(1): 16.

Cornish, K., G. Scerif, et al. (2007). "Tracing Syndrome-Specific Trajectories of Attention Across the Lifespan." Cortex **43**(6): 672-685.

Cowan, N. (2001). "The magical number 4 in short-term memory: A reconsideration of mental storage capacity." Behavioral and Brain Sciences **24**(1): 87-185.

Davidson, M. C., D. Amso, et al. (2006). "Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching." Neuropsychologia **44**(11): 2037-2078.

Dennis, M., B. J. Spiegler, et al. (1991). "Brain tumors in children and adolescents--I. Effects on working, associative and serial-order memory of IQ, age at tumor onset and age of tumor." Neuropsychologia **29**(9): 813-827.

Diamond, A. (1985). "Development of the ability to use recall to guide action, as indicated by infants' performance on AB." Child Development **56**: 868-883.

Diamond, A., N. Kirkham, et al. (2002). "Conditions under which young children can hold two rules in mind and inhibit a prepotent response." Developmental Psychology **38**(3): 352-362.

Duncan, J. (1986). "Disorganisation of behaviour after frontal lobe damage " Cognitive Neuropsychology **3**: 271-290.

Dunn, L., Dunn, L.M. (1997). Peabody Picture Vocabulary Test- Third Edition. Circle Pines, MN, American Guidance Service.

Dunn, L. M., Thériault-Whalen, C. M., & Dunn, L. M (1993). Échelle de vocabulaire en images Peabody (EVIP). Circle Pines, MN, American Guidance Services.

Durston, S. and B. J. Casey (2006). "What have we learned about cognitive development from neuroimaging?" Neuropsychologia **44**(11): 2149-2157.

Epsy, K. A. B., R. (2005). "Inhibitory Processes in Young Children and Individual Variation in Short-Term Memory." Dev Neuropsychol **28**(2): 669-688.

Fair, D. A., A. L. Cohen, et al. (2009). "Functional Brain Networks Develop from a Local to Distributed Organization." PLoS Comput Biol **5**(5): e1000381.

Fan, J., B. D. McCandliss, et al. (2005). "The activation of attentional networks." NeuroImage **26**(2): 471-479.

Finitzo-Hieber, T., Irvin J. Gerling, Noel D. Matkin, and Evelyn Cherow-Skalka (1980). "A Sound Effects Recognition Test for the Pediatric Audiological Evaluation." EAR AND HEARING **1**(5): 271-276.

Fletcher, P. C. and R. N. A. Henson (2001). "Frontal lobes and human memory: Insights from functional neuroimaging." Brain **124**(5): 849-881.

Garon, N., S. E. Bryson, et al. (2008). "Executive function in preschoolers: A review using an integrative framework." Psychological Bulletin **134**(1): 31-60.

Gathercole, S. E. (1998). "The Development of Memory." The Journal of Child Psychology and Psychiatry and Allied Disciplines **39**(01): 3-27.

Gathercole, S. E., S. J. Pickering, et al. (2004). "The Structure of Working Memory From 4 to 15 Years of Age." Developmental Psychology **40**(2): 177-190.

Gerstadt, C. L., Y. J. Hong, et al. (1994). "The relationship between cognition and action: performance of children -7 years old on a stroop- like day-night test." Cognition **53**(2): 129-153.

Goldman-Rakic, P. S. (1987). Circuitry of primate prefrontal cortex and regulation of behavior by representational knowledge. Handbook of physiology. F. P. V. Mountcastle. **5**: 373--417.

Gomez-Perez, E. and F. Ostrosky-Solvis (2006). "Attention and Memory Evaluation Across the Life Span: Heterogeneous Effects of Age and Education." Journal of Clinical and Experimental Neuropsychology **28**(4): 477 - 494.

Goodman, R. (1997). "The Strengths and Difficulties Questionnaire: A Research Note." Journal of Child Psychology and Psychiatry **38**(5): 581-586.

Hagelthorn, K., Hiemenz, J, Pillion, J, et al. (2003). "Age and Task Parameters in Continuous Performance Tests for Preschoolers." Percept Motor Skills **96**: 975-989.

- Heaton, S. C., S. K. Reader, et al. (2002). "The Test of Everyday Attention for Children (TEA-Ch): Patterns of Performance in Children With ADHD and Clinical Controls." Child Neuropsychology 7(4): 251 - 264.
- Hood, J., G. Baird, et al. (2005). "Immediate effects of methylphenidate on cognitive attention skills of children with attention-deficit–hyperactivity disorder." Developmental Medicine & Child Neurology 47(06): 408-414.
- Hughes, C. (1998). "Executive Function in Preschooler: Links with Theory of Mind and Verbal Ability." British Journal of Developmental Psychology 16: 233-253.
- Jarrold, C., A. d. Baddeley, et al. (1999). "Genetically dissociated components of working memory: evidence from Downs and Williams syndrome." Neuropsychologia 37(6): 637-651.
- Kerns, K. A. and L. A. Rondeau (1998). "Development of a continuous performance test for preschool children." J Atten Disord 2(4): 229-238.
- Klenberg, L., Korkman, M., Lahti-Nuuttila, P. (2001). "Differential development of attention and executive functions in 3-to 12-year-old Finnish children." Developmental Neuropsychology 20(1): 407-428.
- Kochanska, G. and A. Knaack (2003). "Effortful Control as a Personality Characteristic of Young Children: Antecedents, Correlates, and Consequences." Journal of Personality 71(6): 1087-1112.
- Kochanska, G., K. T. Murray, et al. (2000). "Effortful control in early childhood: Continuity and change, antecedents, and implications for social development." Developmental Psychology 36(2): 220-232.
- Korkman, M., Kemp, S.L., Kirk, U. (2001). "Effects of age on neurocognitive measures of children ages 5 to 12: a cross-sectional study on 800 children from the United States." Dev Neuropsychol 20(1): 331-354.
- Lanfranchi, S., C. Cornoldi, et al. (2009). "Working Memory In Individuals With Fragile X Syndrome." Child Neuropsychology 15(2): 105 - 119.

Levitin, D. J., K. Cole, et al. (2005). "Aversion, awareness, and attraction: investigating claims of hyperacusis in the Williams syndrome phenotype." Journal of Child Psychology and Psychiatry **46**(5): 514-523.

Lewis, T. M., & Greenberg, G. D. (1995). "ADHD children's performance on visual and auditory continuous performance tests." ADHD/Hyperactivity Newsletter **22**: 5-6.

Liston, C., R. Watts, et al. (2006). "Frontostriatal Microstructure Modulates Efficient Recruitment of Cognitive Control." Cereb. Cortex **16**(4): 553-560.

Lui, M. and R. Tannock (2007). "Working memory and inattentive behaviour in a community sample of children." Behavioral and Brain Functions **3**(1): 12.

Lyon, G. R. a. K., N.A., (1996). Attention, Memory, and Executive Function, Paul H. Brookes Publishing.

Mahone, E. M., J. P. Pillion, et al. (2001). "initial development of an auditory continuous performance test for preschoolers." J Atten Disord **5**(2): 93-106.

Mahone, E. M., J. P. Pillion, et al. (2005). "Construct Validity of the Auditory Continuous Performance Test for Preschoolers." Developmental Neuropsychology **27**(1): 11 - 33.

Manly, T., Anderson, V., Nimmo-Smith, I., Turner, A., Watson, P., Robertson, I.H. (2001). "The Differential Assessment of Children's Attention: The Test of Everyday Attention for Children (TEA-Ch), Normative Sample and ADHD Performance." Journal of Child Psychology and Psychiatry **42**(8): 1065-1081.

Martinussen, R., J. Hayden, et al. (2005). "A Meta-Analysis of Working Memory Impairments in Children With Attention-Deficit/Hyperactivity Disorder." Journal of Amer Academy of Child & Adolescent Psychiatry **44**(4): 377-384
310.1097/1001.chi.0000153228.0000172591.0000153273.

Mezzacappa, E. (2004). "Alerting, Orienting, and Executive Attention: Developmental Properties and Sociodemographic Correlates in an Epidemiological Sample of Young, Urban Children." Child Development **75**(5): 1373-1386.

- Mirsky, A. F., Duncan, Connie C. (2001). "A Nosology of Disorders of Attention." Annals of the New York Academy of Sciences **931**(ADULT ATTENTION DEFICIT DISORDER: BRAIN MECHANISMS AND LIFE OUTCOMES): 17-32.
- Miyake, A., Shah, P. (1999). Models of Working Memory: Mechanisms of Active Maintenance and Executive Control. New York, Cambridge University Press.
- Munir, F., K. M. Cornish, et al. (2000). "Nature of the Working Memory Deficit in Fragile-X Syndrome." Brain and Cognition **44**(3): 387-401.
- Nagy, Z., H. Westerberg, et al. (2004). "Maturation of White Matter is Associated with the Development of Cognitive Functions during Childhood." Journal of Cognitive Neuroscience **16**(7): 1227-1233.
- Olesen, P. J., Z. Nagy, et al. (2003). "Combined analysis of DTI and fMRI data reveals a joint maturation of white and grey matter in a fronto-parietal network." Cognitive Brain Research **18**(1): 48-57.
- Ornstein, P., J. Schaaf, et al. (2008). "Memory skills of boys with fragile X syndrome." Am J Ment Retard **113**(6): 453-465.
- Pardo, J. V., P. T. Fox, et al. (1991). "Localization of a human system for sustained attention by positron emission tomography." Nature **349**(6304): 61-64.
- Pickering, S. J. (2001). "The development of visuo-spatial working memory." Memory **9**(4): 423 - 432.
- Posner, M. I., & DiGirolamo, G. J. (1998). Executive attention: Conflict, target detection, and cognitive control. The attentive brain. R. Parasuraman. Cambridge, MA, MIT Press: 401-423.
- Posner, M. I. and S. Dehaene (1994). "Attentional networks." Trends in Neurosciences **17**(2): 75-79.
- Posner, M. I. and S. E. Petersen (1990). "The attention system of the human brain." Annual Review of Neuroscience **13**: 25-42.

Posner, M. I. and M. K. Rothbart (2007). "Research on Attention Networks as a Model for the Integration of Psychological Science." Annual Review of Psychology **58**(1): 1-23.

Prather, P., Sarmiento, N., Alexander, A. (1995). "Development of vigilance in preschoolers." Journal of the International Neuropsychological Society **1**(153).

Rizzolatti, G., & Craighero, L. (1998). Spatial attention: Mechanisms and theories. Advances in psychological science. F. C. M. Sabourin, & M. Robert. East Sussex, England Psychology Press. **2: Biological and Cognitive Aspects:** 171-198

Robertson, I. H., T. Ward, et al. (1994). Test of Everyday Attention. Flenpton, Thames Valley Test Company.

Rochford, J. (1997). Normcheck. Montreal.

Rochford, J. (2000). Regress. Montreal.

Rosvold, H. E., A. F. Mirsky, et al. (1956). "A continuous performance test of brain damage." Journal of Consulting Psychology **20**(5): 343-350.

Rueda, M. R., J. Fan, et al. (2004). "Development of attentional networks in childhood." Neuropsychologia **42**(8): 1029-1040.

Scerif, G., K. Cornish, et al. (2007). "Delineation of early attentional control difficulties in fragile X syndrome: Focus on neurocomputational changes." Neuropsychologia **45**(8): 1889-1898.

Simpson, A. and K. J. Riggs (2005). "Inhibitory and working memory demands of the day-night task in children." British Journal of Developmental Psychology **23**(3): 471-486.

Simpson, A. and K. J. Riggs (2006). "Conditions under which children experience inhibitory difficulty with a "button-press" go/no-go task." Journal of Experimental Child Psychology **94**(1): 18-26.

Simpson, A. and K. J. Riggs (2007). "Under what conditions do young children have difficulty inhibiting manual actions?" Developmental Psychology **43**(2): 417-428.

Sobin, C., K. Kiley-Brabeck, et al. (2004). "Networks of Attention in Children With the 22q11 Deletion Syndrome." Developmental Neuropsychology **26**(2): 611-626.

Sonuga-Barke, E. J. S., L. Dalen, et al. (2002). "Are Planning, Working Memory, and Inhibition Associated With Individual Differences in Preschool ADHD Symptoms?" Developmental Neuropsychology **21**(3): 255 - 272.

Sonuga-Barke, E. J. S., L. Dalen, et al. (2003). "Do executive deficits and delay aversion make independent contributions to preschool attention-deficit/hyperactivity disorder symptoms?" Journal of the American Academy of Child & Adolescent Psychiatry **42**(11): 1335-1342.

Swanson, J. M. (2005). The SWAN Rating Scale. Irvine, CA, University of California.

Tamm, L., V. Menon, et al. (2002). "Maturation of Brain Function Associated With Response Inhibition." Journal of the American Academy of Child & Adolescent Psychiatry **41**(10): 1231-1238.

Tannock, R. and R. Martinussen (2007). "Promising Practices in Education for Students with ADHD." Orbit **37**(1): 32-35.

Valera, E. M., S. V. Faraone, et al. (2007). "Meta-Analysis of Structural Imaging Findings in Attention-Deficit/Hyperactivity Disorder." Biological Psychiatry **61**(12): 1361-1369.

Wåhlstedt, C., L. B. Thorell, et al. (2008). "ADHD Symptoms and Executive Function Impairment: Early Predictors of Later Behavioral Problems." Developmental Neuropsychology **33**(2): 160 - 178.

Wilding, J. and K. Cornish (2007). "Independence of Speed and Accuracy in Visual Search: Evidence for Separate Mechanisms." Child Neuropsychology **13**(6): 510 - 521.

Willcutt, E. G., A. E. Doyle, et al. (2005). "Validity of the Executive Function Theory of Attention-Deficit/Hyperactivity Disorder: A Meta-Analytic Review." Biological Psychiatry **57**(11): 1336-1346.

Zelazo, P. D., U. Müller, et al. (2003). "The Development of Executive Function in Early Childhood." Monographs of the Society for Research in Child Development **68**(3): i-151.

Zhao, Z.-Y., J. Shao, et al. (2008). "VISUAL SEARCH ATTENTION AND EXECUTIVE FUNCTION IN CHINESE CHILDREN WITH WILLIAMS SYNDROME." Pediatrics **121**(Supplement_2 %U http://pediatrics.aappublications.org/cgi/content/abstract/121/Supplement_2/S148-a %8 January 1, 2008): S148-a-.

APPENDIX A

Mean Performance Accuracy Values in Visual and Auditory Sustained Attention, Inhibition and Working Memory

Table 1. Mean scores for **VISUAL** measures by age group (SD)

		AGE (YRS)			
		3	4	5	6
Task	Measure	N=17	N=19	N=19	N=15
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Visual CPT	Percent Hits (%)	71.4 (15.9)	84.5 (14.5)	93.5 (8.5)	95.8 (4.3)
	Mean RT Per Hit (msec)	1321.7 (667.41)	952.1 (557.77)	733.3 (296.25)	628.2 (191.46)
	Percent Omission Errors (%)	27.0 (15.9)	15.5 (14.5)	6.5 (8.5)	4.2 (4.4)
	Percent Commission Errors (%)	13.4 (14.3)	7.4 (8.5)	7.2 (7.5)	3.6 (4.6)
Visual Dog-Cat Task	Percent Correct Responses (%)	60.6 (22.2)	77.6 (13.2)	83.5 (12.0)	92.1 (7.3)
	Mean RT (msec)	83.84 (27.01)	105.71 (34.36)	164.54 (32.84)	126.39 (42.43)
	Percent Non-Responses (%)	18.0 (15.6)	9.5 (9.2)	5.3 (7.8)	4.2 (5.1)
	Percent Incorrect Responses (%)	18.0 (14.6)	9.5 (9.1)	5.3 (6.0)	4.2 (5.1)
Visual Working Memory	Mean Score				
	(/ 3)	0.59 (0.62)	1.16 (0.76)	2.11 (0.81)	2.40 (0.74)

* N.B. N=16 for 3 year old group in Visual Dog-Cat Task

Table 2. Mean scores for **AUDITORY** measures by age group (SD)

		AGE (YRS)			
		3	4	5	6
Task	Measure	N=17**	N=19	N=19	N=15
		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Auditory CPT	Percent Hits (%)	80.0 (15.6)	89.0 (10.2)	94.3 (8.6)	96.4 (4.3)
	Mean RT for Hits (msec)	1691.6 (725.55)	1146.9 (531.00)	942.3 (357.33)	888.7 (326.58)
	Percent Omission Errors (%)	19.8 (15.8)	10.3 (10.2)	4.1 (5.4)	3.0 (4.1)
	Percent Commission Errors (%)	13.1 (15.0)	10.3 (10.2)	12.7 (11.5)	10.6 (6.3)
Auditory Dog-Cat Task	Percent Correct Responses (%)	48.3 (19.4)	71.0 (19.7)	82.9 (13.8)	87.1 (10.9)
	Mean RT for Hits (msec)	2152.55 (469.40)	2027.05 (505.88)	1794.39 (447.67)	1686.56 (431.16)
	Percent Non-Responses (%)	37.1 (17.8)	16.8 (13.5)	6.3 (10.9)	6.3 (9.6)
	Percent Incorrect Responses (%)	12.5 (13.2)	7.9 (8.0)	4.3 (7.5)	4.6 (5.0)
Auditory Working Memory	Mean Score (/ 3)	0.71 (0.47)	1.00 (0.67)	1.74 (0.93)	2.00 (0.85)

*N.B. N=15 for 3 year old group in Auditory Dog-Cat Task