THE INFLUENCE OF ADHD AND EXPERIMENTAL CONTEXT ON COMPONENTS OF ATTENTION IN CHILDREN

by

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Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy

at

Dalhousie University
Halifax, Nova Scotia
August 2006

Your file Votre référence
ISBN: 978-0-494-19609-0
Our file Notre référence
ISBN: 978-0-494-19609-0

DALHOUSIE UNIVERSITY

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Dedication

The journey of a thousand miles begins with a single step.

- Lao Tzu (604 BC – 531 BC)

I dedicate this dissertation to future graduate students who will lament for long hours about the endless nature of their dissertations but, at the very end of the journey, will say: "Given the chance, I'd do it all over again." Such, I have learned, is the quest for knowledge.

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Abstract

An abundance of literature in both clinical and cognitive psychology suggests that children with Attention-Deficit/Hyperactivity Disorder (ADHD) show improved attentiveness and decreased hyperactivity in situations wherein positive behaviours are immediately rewarded. An application of the optimal stimulation theory further suggests that children with ADHD need higher levels of stimulation and excitement, relative to controls, in order to function well in their environments. Little research, however, has focused on the specific influence of rewards and excitement on the different components of attention in children. The current study did so by comparing task performance on a computerized attention battery in each of two conditions (traditional/boring and video game/exciting) for 45 children (19 ADHD, 26 control) aged 7 through 11 years. The five tasks used in the battery - Simon, flanker, stop-signal, blink, and continuous performance – provided measures of the following components of attention: expectancy, encoding capacity, sustained attention, focusing, filtering, and interference control. The traditional attention battery employed plain-color computer screens with no non-task related stimuli whereas the video game battery employed a storyline and prizes. An initial study completed with 60 university students demonstrated the expected task effects. Task reliability was also established among the sample of control children. Neither the ADHD nor the control group's attentional abilities were consistently facilitated by the enhanced video game context, perhaps because the increased stimulation and related memory demands unintentionally overloaded the children's cognitive capacities.

Acknowledgements

I was 16 years old when I decided I would become a child psychologist. At the time, I had a general understanding of what a career in psychology entailed. I had a sense of the educational credentials required and knew that a fancy combination of letters would ultimately be tacked onto my name. I was well grounded and prepared for the road ahead – or so I thought. How naïve I was. If, all those years ago, someone had sat me down and told me exactly what the process of becoming a psychologist involved, I might easily have run the other way. In retrospect, I am glad no one did. I have been, and continue to be, impressed by my lessons in the normal and abnormal functioning of the human mind. My journey has been led by the support, guidance, and knowledge of many fine people. It is with sincere gratitude that I thank just a few of them now.

Dr. Raymond Klein, my supervisor and one of the greatest intellectuals I know, went above and beyond the call of duty to facilitate my dissertation and progress throughout graduate school. By means of late night emails, side-by-side chats on the lab couch, and much sound advice, I learned more from Ray over the last several years than my long-held schema for supervision would ever suggest. Thank you Ray for helping to make my graduate student experience all that it has been. As a relative "newbie" in the field of reaction time work, I was fortunate to have Dr. Tracy Taylor-Helmick on my dissertation committee who, by means of her expertise in the same, helped me to bridge the divide between clinical and cognitive research on ADHD. Thank you to Dr. Penny Corkum, who also served on my committee; her commitment to children's mental health and support for graduate students learning the same is inspiring. Additionally, thank you to Dr. Sherry Stewart for suggestions and guidance in the early stages of this project.

A strong team of enthusiastic players often builds the foundation to solid research and was definitely important in the development and completion of this dissertation. First and foremost, I extend my gratitude to Patti Devlin, the lab manager. Her skills for organization and efficiency are top notch. Were I ever to have a research lab, I would want Patti to manage it. Similarly, Pam (Loba) Collins manages the Stewart lab with congeniality, grace, and humour. I remember all of our trips going up and down the stairs between the Klein and Stewart labs in pursuit of the most rudimentary understanding of how to make the attention tasks work on a Macintosh computer. I doubt those early days would have been as much fun with anyone but Pam as a sidekick. John Christie, a former student in the lab and a Macintosh guru, was also pivotal to my progress throughout the completion of my research. He consistently bailed me out of computer quandaries and inspired me with his aptitude for attention research and statistical analyses.

Many research assistants were pivotal to completion of this project. Thank you to Katherine Rogers who, in addition to being naturally pleasant and fun to be around, is a superb tester! Thank you also to Cathy Mackay whose initiative for recruiting children allowed me to collect more data than I initially planned, and to Melissa Hargrove whose commitment to doing the job right and doing it well was always evident. Additionally, I extend sincere gratitude to the computer science folks who programmed the attention batteries I used in this project. These include Joe MacInnes, Keith Slade, Micah McCurdy, and Edgar Ellis. Special kudos goes to Edgar who could make graphics and animations appear on the computer screen that fit exactly with the images I saw in my mind's eye. Finally, a sincere thank you to Laura Allen who would be the envy of any graduate student looking to update their reference library.

My sincerest appreciation goes to all the children and families who took part in my study as participants/informants. I feel very fortunate to have had much success with participant recruitment and testing, and to have met so many wonderful people along the way. I had a lot of fun at the lab during my "testing summer." It is always a treat to meet families who are interested in research and willing to offer their time and expertise in the name of advancing science.

Graduate school is an expensive proposition. I am indeed thankful for the funding I received to complete this dissertation and my PhD as a whole. Specifically, I am grateful for a grant from the Nova Scotia Gaming Foundation that was used in the developmental phase of this project for the computer tasks to be programmed and piloted. Additionally, I extend thanks to the National Science and Engineering Research Council (NSERC) for a Postgraduate Scholarship A (PGS A) during my first two years of graduate school and to the Killam Trusts for "topping up" that funding and then granting me a full Izaak Walton Killam Memorial Scholarship in my third year. I am also very appreciative of the Student Research Award I received from the Nova Scotia Health Research Foundation (NSHRF) in my fourth and fifth years of school.

In addition to "hands-on" help from many individuals and financial assistance from the listed agencies, were several "behind the scenes" friends and family members who provided support in equally important ways. I am especially thankful for the friends that I have made throughout the many years of my post-secondary education. I extend gratitude to Sean Best whose spunk, attitude and sense of humour kept me laughing in the final years of my undergraduate degree and early years of graduate school. My second year of graduate school would never have ended if it weren't for my regular 2 AM debriefings over the phone with Sean. I daily recounted my woes as the bottom rung in ladders built by power differentials that, fortunately, I have since learned are rare in graduate level education. True to form, Sean would one-up each of my play-by-plays with a story that ultimately confirmed the futility of higher education – or so it seemed to both of us at the time.

Thank you to Kelly Murrin who, since the day we first met in residence back in 1995, has been someone I can count on regardless of the number of miles between us. Thank you to Kris Devoulyte, whose addiction to MSN instant messaging parallels my own; she kept me connected to home throughout my internship year in Albuquerque, New Mexico. I also acknowledge my closest friends from Dalhousie (who, in addition to Kris, include Celeste Lefebvre, Denise Bernier, Jen Klages, Kris Peace, and Ann Penny) and all the times that, despite our best efforts to do otherwise, we inevitably returned to talking about psychology and "the Department." Medicine does indeed come in many forms, and "a good laugh with the girls" ranks among the very best.

Thank you to my parents, Stan and Judy Sparkes, for instilling within me an appreciation for education and a deep love for children. Thank you to my adorable nephew (Andrew Greek) and precious two nieces (Karen Greek and Emily Shaw) for providing excellent reasons to take breaks from my work. Phone calls and visits with my cutie pies are the best! I am very excited about having a fourth little cutie pie in the new year. I also extend great appreciation toward my aunt, Lillian Martin. It would be difficult to indicate all that Lillian has done for me throughout my undergraduate and graduate degrees but perhaps fair to say that it remains unparalleled.

I have many fond memories from my time in graduate school. Some of my favourite are from just recently, on the day of my defense. Thank you to Dr. Darlene Brodeur for being the external examiner and Dr. Dennis Phillips for being the departmental representative. I am sincerely grateful for the friends and family members who took the time and arranged their schedules to be a part of my audience. I especially acknowledge my parents, Aunt Lil, and my sister (Joanne Sparkes) for flying from Newfoundland to attend the event. Thank you to Charles O'Dale for capturing the day with beautiful pictures. You're a very patient friend Charles! I also extend tremendous thanks to my sister (Susan Sparkes) and partner (Adrian Cook) for throwing the best party ever in celebration of the event. The Timberlea Chase was awesome! Do you think a clue word is still taped to the back of that stop sign?!

My final acknowledgements go to Suz and Adrian: I know no words that can express the depth of my gratitude for your unwavering support throughout this PhD endeavour. There are many things in life that can threaten even the tightest of social bonds and I suspect that the demands of graduate school are among them. There were days, especially in these last six months, when I devoted virtually all of my attention to this dissertation. I can only imagine how justified each of you would have been to ask for more of my time; at the very least, it would have been fair for you both to have completely ignored me. Neither of you did these things. Rather, you both gave words of encouragement, surprised me with treats, and even did my chores to give me more time for work. I am tremendously grateful for having each of you in my life, and very happy

to now have time to do all the things I promised we'd do "after I defend." Let the good times begin!

I have always been, and expect I always will be, fascinated by humans. I am especially intrigued by youth's innocence and awed by the resiliency that I have seen borne from its tragic loss. I am fortunate to be on the cusp of receiving my doctorate in clinical psychology and look forward to a career effecting change, through research and practice, in individuals whose lives are challenged by behavioural, cognitive, and social difficulties. To all those who have been, and will be, at this very same threshold: I wish you the very best. May the world always know the benefits of our work.

Chapter 1: Introduction

This project is primarily about attention in 7- to 11-year-old children with ADHD relative to that of their same-aged, typically developing peers. Attention is assessed as a multi-component construct using a series of computerized attention tasks in each of two contexts. The tasks parallel traditional lab paradigms in the control context and are enhanced with visual stimulation, a story line, and prizes in the experimental context. Each task was customized for use in this project and employed parameters that are typical of those used in cognitive research. An initial experiment was completed with university students to ensure that the tasks were reliable (in that they reproduced the effects most commonly reported in the literature for the same). The project's main goals are to highlight the multi-component nature of attention and to bring awareness to the differential influence that environmental factors can have on the various components of attention. The following overview of this manuscript will orient readers to the structure and organization of the literature review, methodology, results, and conclusions that are written herein.

Chapter 2 provides an introduction to this project. It addresses the rationale for the combined study of attention and environmental context, and then outlines the main queries of the project. Chapter 2 also provides an outline of two models of attention and then places the eight components that they collectively identify into the context of a comprehensive, neural-network-based framework of attention. This serves to relate the eight components of attention to each other and also to the construct of attention as a whole. The framework also adds neurological relevance to the project – which, when considered with the neuroanatomical abnormalities, neurotransmitter dysfunction, and genetic patterns that have been repeatedly implicated in ADHD, increases confidence in hypothesis generation. The final section of Chapter 2 addresses the components of attention that are studied in this project and the tasks that were used to study them. The reader's attention is therein directed to the appendix, which includes - for each task - a visual depiction of at least one sample trial, details regarding trial timing, and participant instructions.

Chapter 3 provides a summary of the etiological factors that have been implicated in ADHD. The greatest focus is given to the biological abnormalities, especially the atypical neuroanatomy and neurophysiology, which have been found most consistently in children with the disorder. Not surprisingly, the brain regions and chemicals that have been repeatedly implicated in ADHD are those that have been linked to processes of attention as they occur in typically developing individuals. By connecting ADHD with dysfunction in attention components at a neurological level, this chapter lays the foundation for the hypotheses in this project. In particular, impairments in focused and sustained attention, in addition to a reduced capacity for rapidly presented visually patterned stimuli, are conjectured for the children with ADHD.

Chapter 4 provides an overview of three theories[1] of ADHD. The three theories are a mere sampling of the many that have been proposed to explain ADHD; they were chosen on the basis of relevance to the current project and popularity within the field. Zentall's (1975) understimulation theory of ADHD is first reviewed, followed by Douglas' (1983, 1988, 2005) model of impaired self-regulation, and, finally, Barkley's (1997a, 1997b) theory of behavioural disinhibition. The summary section of Chapter 4 provides, on the basis of these three theories, hypotheses for the project regarding the deficits in task performance that can be expected from the children with ADHD – and, to a lesser extent – hypotheses regarding the influence that the contextual manipulation of the attention battery will have on the same. Notably, the hypothesized deficiencies in attention components for the children with ADHD generally map onto those predicted by the research reviewed in Chapter 3.

A shift in focus is made from Chapter 4 to Chapter 5. The latter provides a discussion of the five attention tasks used in this project. A brief overview of the history and development of each task is provided, as well as typical results on each task for adults and children (including children with ADHD, as available). The tasks include the Simon,

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[1] The term "theories" is sometimes used to collectively refer to the models presented in this chapter, although the author concedes that Douglas' model does not meet the technical criteria for the title of theory (nor does Douglas present it as such). This convention was adopted solely for ease of reference.

flanker, stop-signal, blink, and continuous performance tasks. As briefly reviewed in Chapter 2 and detailed in Chapter 8, the blink task was based on past literature that used rapid serial visual processing to assess individuals' encoding capacity for rapidly presented visually patterned stimuli; it was given its name by the author. The final section of Chapter 5 includes a summary of the material presented in the chapter and an outline of hypotheses based on that material.

Chapter 6 focuses on the issue of environmental context and three ways in which it can be manipulated to influence a person's cognitive and behavioural functioning. Studies that address each of these types of environmental manipulation are reviewed. Effort was taken to highlight studies that involved tests of attention and children with ADHD. The three types of manipulation, in the order presented in the chapter, include the level and type of sensory input within an environment, the use of reward contingencies, and the nature and setting of a task. Hypotheses based on the findings of the reviewed studies are proposed in the final summary section of the chapter.

Chapter 7 is the last chapter in the literature review. It contains two sections. The first entails a summary of the hypotheses that have been proposed up to that point in the manuscript. The hypotheses are specific to the child experiment in the project and are based on the interaction of several domains of research, each of which was reviewed earlier in the manuscript: ADHD etiology (Chapter 3), ADHD theory (Chapter 4), past studies on the five tasks used in the project (Chapter 5), and past studies on the behavioural/cognitive effects of environmental context in children (Chapter 6). The latter section in Chapter 7 addresses the issue of task reliability, its assessment with adults in the first experiment of the project, and the possibility of an integrated Simon/flanker/stop task as a replacement for the individual Simon, flanker, and stop-signal tasks. Shorter administration time motivated the development of an integrated task alternative.

Chapter 8 provides the methods for Experiment 1. Task set-ups, stimuli measurements, and trial frequencies are detailed for each task. The reader will note that specific detail relating only to the tasks as they were used in the second, child experiment in this project is footnoted herein. Chapter 9 provides an overview and details of the results for Experiment 1. These results are specific to task reliability and the separate versus integrated manipulation of the Simon, flanker, and stop-signal tasks – all as assessed in the adult sample. Chapter 10 then provides a discussion of the results from Experiment 1.

Chapters 11, 12, and 13 parallel Chapters 8, 9, and 10 in form, but are specific to Experiment 2 in detail. Specifically, Chapter 11 provides the methods for Experiment 2 (with reference to Chapter 8 for details regarding the computerized attention battery). Chapter 12 provides an overview and details of the results for Experiment 2, and Chapter 13 provides a discussion of the results from Experiment 2. The discussion for Experiment 2 isolates the effects of ADHD, the effects of context, and the interaction of ADHD and context effects upon the individual components of attention that were assessed in the child sample.

Chapter 14 is the final chapter in the manuscript. It provides a general discussion of the project, including the conclusions that were made in relation to the main queries set forth at its outset. Chapter 14 also addresses the clinical implications of the project findings, highlights the main limitations of the current project, and identifies possible directions for future research. The purpose and findings of Experiment 1 are also addressed in Chapter 14 and, together with a discussion of Experiment 2, serve to highlight the value and importance of research that isolates the different components of attention as a cognitive construct, especially in the context of attention disorders such as ADHD.

Chapter 2. Attention

There is a great deal of existing literature on theories of attention. Although each theory differs in its approach to explaining attention, there is compelling and consistent evidence that attention, as a construct, can be divided into different, not quite independent, but definitely separable components. Although different theories, or frameworks, of attention divide the construct differently and may use different labels, components such as alertness, orienting, and executive control are found in all of them (e.g., Niemann, Ruff, & Kramer, 1996; van Zomeren & Brouwer, 1987). Understanding these components facilitates an understanding of human behaviour, both normal and disordered. For example, a child watching a movie would be described as maintaining *alertness*. Conversely, an adult with a traumatic brain injury to the frontal lobes may exhibit poor *executive control.*

In considering the situations detailed above, it quickly becomes apparent that the study of attention must account for the influence of surrounding context. Intuition might suggest, for example, that the child watching the movie will be more alert if the movie is playing on a theatre screen in an acoustic-friendly auditorium than if it is playing on a small television in a noisy, crowded room. Similarly, the adult with the traumatic brain injury may have more success pursuing a goal-directed activity in a familiar setting with memory prompts as opposed to a novel environment devoid of such cues. At least theoretically, it seems likely that different contexts would influence the many components of attention in unique and varying ways. Brighter lights, for example, may directly improve alertness but not response inhibition. Herein lies the basis of the current project. Multiple computerized tasks, each isolating specific components of attention, were administered to young children in an experimental ("video game") and a control ("traditional") context. The premise of the project was to investigate the influence that the contextual manipulation had on each of the studied attention components.

The tasks used in the two conditions of this project were exactly alike, with the contextual manipulations made independently from the task displays. The experimental context simulated a video game and included a storyline, colorful screens and prizes. The control context, by contrast, was intentionally "boring" and was not enhanced with attractive graphics or rewards. It provided a parallel to conventional lab tasks. The main queries for the project were thus: How does the change in context from traditional to video game (or vice versa) influence children's task performance? Are the various components of attention differentially influenced by the context of the environment?

A historian might argue that knowledge of history helps to inform the present and direct the future. A researcher could similarly argue that the study of abnormality helps to define normality and refine expectations. Although somewhat of a circular process, many developmental phenomena are better understood when considered in relation to known medical or mental health disorders. Such is the case with cognition and, in particular, the construct of attention. In investigating attention, then, the current study considers performance profiles from control children as compared and contrasted to children diagnosed with Attention-Deficit/Hyperactivity Disorder (A-D/HD, or simply ADHD). ADHD is a disorder that is characterized by developmentally inappropriate levels of inattention, impulsivity and hyperactivity, and is generally considered to affect approximately 3-5% of school-aged children, although estimates have ranged from 1-20% (Costello, Mustillo, Erkanli, Keeler, & Angold, 2003; Ford, Goodman, & Meltzer, 2003; Nolan, Gadow, & Sprafkin, 2001; Wolraich, Lambert, Bickman, Simmons, Doffing, & Worley, 2004).

ADHD is by far one of the most studied childhood disorders, yet is also one of the least understood (Barkley, 1997a; Lahey et al., 1988). Its history throughout the Diagnostic and Statistical Manual of Mental Health Disorders (DSM) is fraught with changing symptom lists, subgroups and labels (see Swanson et al., 1998 for a review of these changes). To date, the preponderance of literature on ADHD addresses sustained attention and response inhibition as attention components that are compromised in children with the disorder (e.g., Barkley, Grodzinsky, & DuPaul, 1992; Corkum & Siegel, 1993; Grodzinsky & Barkley, 1999; Lahey et al., 1988; Losier, McGrath, & Klein, 1996; Pennington & Ozonoff, 1996; Swanson et al., 1998). The current project broadens the scope of this research by investigating additional processes of attention that are essential to understanding the world (specifically, expectancy, encoding capacity, sustained attention, focusing, filtering, and interference control).

A video game context was chosen for study in this project on the basis that it may improve some components of attention in children with ADHD. For instance, one popularly held belief is that video games normalize the behaviour of children with ADHD. Many parents report, at least in clinical settings, that their child with ADHD cannot sit still for more than a few minutes in a school setting but can sit undisturbed for hours in front of video games (Tannock, 1997). Furthermore, past research has shown video game features to uniquely improve task performance in hyperactive children. Specifically, the addition of color and background music – two features typical of video games - to otherwise non-stimulating tasks have separately been shown to normalize the behaviour of these children (Klein, 1981; Zentall, 1986). It is interesting to investigate this phenomenon further and, as was done in this study, to do so while separately considering each of several different components of attention.

A review of cognitive literature shows that the construct of attention has been studied and typified using a number of perspectives, including developmental, empirical, and theoretical to name just a few. The first two of three frameworks discussed in this chapter are outlined to provide an example of the components that have been identified in this literature. The first framework was developed by Mirsky, Anthony, Duncan, Ahearn, and Kellam (1991) in a factor analytic study of 203 adults and 435 elementary school children. The second was developed by Coren, Ward, and Enns (1994) and includes components that they believe to be especially salient in understanding the world. The former was chosen for review here as an example of an empirical framework; the latter was chosen as a sample theoretical framework. The eight components that these two frameworks collectively identify are placed in the context of a broader neurological framework of attention later in this chapter; this integration of frameworks is followed by an overview of the components and tasks investigated in this project.

Empirical Framework of Attention

In their quest to develop a model of attention, Mirsky et al. (1991) administered a battery of cognitive tests to the adult participants in their study and child versions of a subset of these tests to the child participants. A factor analysis of all adult performance scores produced a four-component model of attention. Mirsky et al. were able to replicate the model using only the adult data for which they had corresponding child data and then again using only the child data. They identified their four components of attention as independent cognitive processes and highlighted the robustness of their factors to participant age and type of factor rotation. Before reviewing their framework, however, two notes of caution are warranted.

The first caveat for interpreting Mirsky et al.'s (1991) framework of attention is in regard to the heterogeneity of their adult sample. The adult sample included a mix of controls (n = 73) and psychiatric patients (n = 130) hospitalized on either an in- or out-patient basis for a variety of conditions, including eating disorders, epilepsy, schizophrenia, affective disorder, and head injuries. Although the tests used would have tapped the same cognitive abilities in all adults and the sample size is impressive, the inherent variability within and between these individuals may have compromised the integrity of the resulting attention model; Mirksy et al. did not address this factor in their published report. The second caution is that the factor conceptualization used to build the framework arguably lacks precision. For example, the variables that load onto the factor that they entitled *focus* primarily came from tests of working memory; the factor would perhaps be better labeled as such. The framework is outlined, however, to show how attention - as a whole and complex cognitive construct - can be understood as a constellation of smaller, interrelated cognitive processes. In this regard, Mirsky et al. do a noteworthy job of suggesting four distinct attentional processes.

Focus

Mirsky et al. (1991) defined focus as "the ability to select target information from an array for enhanced processing" (p. 111). The scores that loaded onto Mirsky et al.'s focus factor were from a letter cancellation test and the Digit Symbol Substitution subtest of the Wechsler Adult Scale of Intelligence – Revised (WAIS-R) in the adult data and from a digit cancellation and the Coding subtest of the Wechsler Scale of Intelligence for Children – Revised (WISC-R) in the child data. These are all timed tasks that require manual responses. Mirsky et al. thus concluded that focusing is an integral part of response execution and perceptual-motor speed.

Sustain

Mirsky et al. (1991) defined sustain as "the capacity to maintain focus and alertness over time" (p. 112). Scores from a continuous performance test loaded onto the sustain component within their factor analysis for each of the child and adult models. Sustained attention was first studied during World War II when it was noticed that, after a certain period of active duty, radar operators became fatigued and were less able to detect enemy planes relative to the start of their work shifts. Although not physically tiring, the mental work involved in constantly monitoring visual space taxes a person's limited cognitive resources.

Sustained attention and vigilance are often considered interchangeable terms. Douglas (1983) presents a caveat to this parallel, however, especially in reference to complex events and tasks. She notes that three related aspects of attention, all self-regulated, are sometimes implicated in references to sustained attention. These include the maintenance of attention (i.e., alertness) over time, the self-direction and organization of attention, and the investment of effort into the attention-demanding task or activity. Douglas (1983) advises authors to explicitly limit the phrase *sustained attention* to refer only to the maintenance of alertness over time (as is done in this project), thus validating a parallel with the term vigilance and isolating behavioural energetic processes (e.g., effort, self-direction) for separate analyses and consideration.

Shift

Mirsky et al. (1991) defined shift as the "ability to change attentive focus in a flexible and adaptive manner" (p. 112). Performance scores from the Wisconsin Card Sorting Task (WCST) loaded onto a principal component of shift in both their adult and child models of attention. The WCST requires a person to categorize a series of cards according to the color, form, and number of shapes on each card. The rules for categorization are not explicitly told to participants and must be determined on the basis of feedback from the examiner. The process of shift occurs as a participant shifts focus, or *mindset*, from one aspect of the cards to a second aspect. Perseveration in responses reflects a failure to shift attention.

Encode

It was through their principal components analysis of test performance data, and not a priori hypothesizing, that Mirsky et al. (1991) isolated the encode component of attention. Although they expected scores on the Arithmetic and Digit Span subtests of the WAIS-R (in the adult sample) and WISC-R (in the child sample) to load onto a focus factor in their analyses, study results actually showed them to load independently onto a separate and unique factor, which they labeled encode. Encode, at least within the context of this attention framework, thereby captures the diverse processes of sequential registration of stimuli, recall and mental manipulation of numeric information.

Theoretical Framework of Attention

In their book *Sensation and Perception,* Coren et al. (1994) identified four processes of attention: orient, filter, search and expect. As will be shown, these processes relate to, and often overlap with, those identified by Mirsky et al. (1991).

Orient

Orienting refers to the physical adjustment of sense organs towards objects and events of interest such that sensory receptors can receive relevant information for further processing. The physical adjustment of the sense organs (e.g., eyes) toward stimuli is an overt orienting response. By contrast, covert orienting involves mental shifts in a person's attentional gaze and no movements of the eyes or other sense organs. Attentional gaze has been referred to in past research as a zoom lens, an attentional spotlight, and the mind's eye. It is a metaphor for the narrowed region of visual space that a person attends to at any given moment in time; in other words, it is the area upon which attention is "gazing." The direction of one's attentional gaze is independent from that of visual gaze. However, just as vision cannot be pulled to more than one location in the visual field at any instant of time, the attentional spotlight usually cannot be pulled to more than one location in the visual field (Coren et al., 1994; D'Aloisio & Klein, 1990).

Filter

Filtering is the process whereby a person, having oriented to an object or event of interest, excludes ("filters out") extraneous stimuli from the surrounding environment in order to facilitate continued focus on the key object or event. Filtering can also involve choosing from an array one of several stimuli to attend or, similarly, choosing one of several features of a stimulus to attend. For example, one might search for objects based on their color, shape, texture or size (Coren et al., 1994). Along the same line of thought, Enns and Akhtar (1989) have defined filtering as "the mechanisms and strategies involved in inhibiting the processing of task-irrelevant information" (p. 1188). Focused attention is the product of successful filtering. Its antithesis is divided attention. Divided attention involves attending to multiple sources of stimulation, or "information channels" simultaneously. The information channels can be from the same modality, as in two ongoing events in different regions of the visual field, or from different modalities, such as listening to a nearby conversation while also trying to read a book (Coren et al., 1994).

Search

Search is an integral part of attention. It involves the visual scanning of one's environment for an expected stimulus. The pattern of eye movements used in searching a visual field is determined by the searcher's intentions and previous experience, as well as the biological design of the visual system. Research has shown that humans develop the ability to rapidly inspect spatial locations in systematic, efficient ways when looking for a target. This skill is not fully developed until age six or seven years old and is significantly compromised in the elderly. Research has also shown that humans tend to look at unusual objects in a visual scene for longer periods of time than they spend looking at ordinary, typical objects (Coren et al., 1994).

Expect

Expect, as a component of attention, refers to a person's anticipation of an event, or series of events, within his/her environment. Visual and auditory signals, also known as information cues, often affect expectations and thereby influence where attention is oriented, what is searched for, and what extraneous information is filtered out of conscious processing. Much research has been completed on the use of such cues, including the study of valid versus invalid (or misleading) cues and their respective advantages and disadvantages in the search process. For example, when a cue correctly orients one's (c)overt attention to a location where a stimulus then occurs, the stimulus is more quickly detected than if there had been no cue. Conversely, when an invalid cue directs a person's gaze to a location where no stimulus occurs, the person is slowed in detecting the stimulus elsewhere in his or her visual space. Furthermore, a person is generally slower to analyze cued stimuli relative to uncued stimuli when the latter occurs abruptly and thereby commands automatic and hence immediate, as opposed to voluntary and slow, attention (Coren et al., 1994).

Thus far, this chapter has reviewed just two of many published frameworks of attention. To summarize, Mirsky et al. (1991) identified focusing, sustaining, shifting, and encoding as independent components of attention, whereas Coren et al. (1994), in similarly parsing attention into its elements, identified orienting, filtering, searching, and expecting. Although the eight different labels suggest independent and mutually exclusive processes, such is not the case. As implied in the first paragraph of this chapter, the cognitive skills responsible for attention - although unique in quality - function interdependently. For example, focusing and filtering are closely related processes that naturally occur together – at least in the presence of distracting stimuli. Given the models outlined in this chapter, a person cannot – by definition - focus on a stimulus without simultaneously filtering distractions from his or her conscious awareness; the target stimulus can be visual, auditory, or otherwise. Collectively, the focusing and filtering components can be considered a component termed *interference control.* Similarly, attentional expectancy, encoding, and shifting work together to guide behaviour in an organized fashion. The overall component that they create can be labeled *planning.*

Neurological Framework of Attention

Posner and Raichle (1994) developed a comprehensive framework of attention on the basis of early research using functional brain imaging technology. The breadth of the framework makes it a useful tool for placing the eight identified components of attention in context with each other and in context with the construct of attention as a whole. Furthermore, its neurological perspective has shown promise for revealing exactly which components of attention are deficient in children with ADHD and, related to that, the biological mechanisms that are responsible for these deficiencies (Fossella et al., 2002; Swanson et al., 1998). Given these applications and their relevance to the current project, Posner and Raichle's attention framework is used in combination with those of Mirsky et al. (1991) and Coren et al. (1994) to provide guidance and structure to this project.

Posner and Raichle's (1994) framework of attention includes three distinct neural networks: an alerting network, an orienting network, and an executive control network. According to the framework, alerting involves the suppression of background neural noise in order to achieve and maintain a state of high sensitivity to incoming stimuli. It is associated with the frontal and parietal regions of the right hemisphere and is modulated by norepinephrine that originates in cell bodies within the locus coeruleus of the midbrain. Orienting involves neural activity as required to select information from sensory input for further processing. The orienting network is purportedly modulated by a cholinergic system that arises in the basal forebrain and involves the superior colliculus, the thalamus, and the posterior parietal lobe of each hemisphere. Posner and Raichle also propose that orienting involves the frontal eye fields. Their third network, that of executive control, involves neural mechanisms associated with the investment of effort as well as neural mechanisms associated with resolving conflict among motoric responses to surrounding stimuli. The midline frontal areas (in particular, the anterior cingulate), the lateral prefrontal cortex, and the basal ganglia are all implicated in the executive control network. Neurochemically, executive control is modulated by a dopaminergic system for which cell bodies arise in the ventral tegmental region of the midbrain.

Some researchers have considered the alerting, orienting, and executive control networks of attention to be technological equivalents of the more traditional concepts of sustained attention, selective attention, and divided attention, respectively (Swanson et al., 1998). In a similar regard, the traditional attention components identified by Mirsky et al. (1991) and Coren et al. (1994) can be mapped onto the alerting, orienting, and executive control networks of attention. It seems that the best fit between the three frameworks would be: (1) the alerting network encompasses the sustain, encode, and expect components of attention, (2) the orienting network encompasses the shift, orient, and search components of attention, and (3) the executive control network encompasses the focus and filter components of attention.[2]

Intuitively, focused attention seems more related to processes of selection and orienting than executive control. However, focusing is categorized as a process of executive control by Posner and Raichle (1994) (and also in this project) because, similar to the tests that loaded onto the focus factor in Mirsky et al.'s (1991) study, tests of focus

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[2] For ease of reference, components of attention associated with Mirsky et al.'s (1991) model of attention are single-underlined and components associated with Coren et al.'s (1994) model are double-underlined.

generally do not isolate the process of visual perception. Rather, due to their timed nature and the dependent variables they offer, measures of focus tap more into the executive functions of response execution and perceptual-motor speed than into the orienting function of stimulus selection.

Although useful, it was not feasible for this project to include consideration of all the networks and components of attention that have been identified in this chapter. Consideration is thus restricted to the two networks (alerting and executive) and six components (expectancy, encoding capacity, sustained attention, focusing, filtering, and interference control) that are most consistently implicated in ADHD (see review of related literature in Chapters 3 through 6). A convention of terminology will hereafter be adopted in this manuscript to reduce confusion around these similar and sometimes overlapping constructs.

The phrase *component(s) (of attention)* will be reserved in this manuscript for the cognitive processes identified by Mirsky et al. (1991) and Coren et al. (1994) in their respective frameworks of attention and investigated in this project using computer tasks. On the other hand, the phrase *neural network(s) of attention* will be reserved for the more comprehensive neurologically-oriented processes identified by Posner and Raichle (1994). The quantifiable constructs reflecting each of the attention components will be referred to as *subcomponents*. Finally, the term *performance measure* will be reserved for the dependent variables or combination of dependent variables that are recorded on each task. As shown by Table 1, the performance measures can map onto the subcomponents, the components themselves, or the larger neural networks to which the components belong.

Attention Tasks & Components Studied in Current Project

Five tasks were used in this project to study children's alertness and executive control; these were the Simon, flanker, stop-signal, blink,[3] and continuous performance tasks. Three components of alertness – (1) expect, (2) encode, and (3) sustain, and three components of executive control – (1) focus, (2) filter, and (3) interference control, were studied. The components isolated by each task, and the performance measures that reflect these components, are mapped out in Table 1 and described briefly in the following five subsections. To facilitate understanding of the tasks, a visual depiction of at least one sample trial from each is provided in the appendix. The appendix also includes, for each task, details on trial timing and the instructions given to participants.

Simon task

The Simon task is named after Simon who, together with his colleague Small, first demonstrated the stimulus-response compatibility effect that now bears his name (Simon & Small, 1969). Specifically, the Simon effect refers to the influence that irrelevant location information has on a person's reaction time to simple visual stimuli. Although originally discovered using auditory stimuli, recent literature on the Simon effect references the use of visual stimuli (Lu & Proctor, 1995). A Simon paradigm typically presents participants with rapidly occurring stimuli in a serial fashion on a computer screen. Each stimulus (i.e., target) occurs on either the left or right of the computer screen and demands a forced-choice identification response. The stimulus location is irrelevant to the task demands yet produces a significant retarding effect on processing when the stimulus location is opposite to the response key location (relative to the participant's vertical body midline). Significant response facilitation, by contrast, occurs when the target and response key locations are compatible with each other (Lu & Proctor, 1995). These effects, largely the result of automatic spatial encoding, are considered – at least within the context of this project – to reflect a type of imperfect attentional filtering.

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[3] The blink task was given its name by the author. It is a non-traditional variant of a rapid serial visual processing (RSVP) task paradigm. See methods (Chapter 8) for further details.

The dependent variables that reflect the filtering component of attention in this project, as taken from the Simon task, include: (1) the lag in participants' target reaction time on incompatible relative to compatible trials and (2) the reduction in participants' target accuracy on incompatible relative to compatible trials. Filtering was viewed herein as a product of Posner and Raichle's (1994) executive control network of attention. A second component of the executive control network that was tapped by the Simon task was that of focused attention. Specifically, participants' processing efficiency - as reflected by their target reaction times and accuracies on the Simon task - was categorized as a subcomponent of focused attention.

In addition to cognitive focusing and filtering, the Simon task in this project was used to tap into attentional expectancy. Auditory tones were presented at a variety of pre-target intervals on a subset of trials in order to facilitate target expectancy on those trials. Participants' target reaction times and accuracies relative to the different lengths of warning intervals were considered to be measures of attentional expectancy. The expectancy component of attention was viewed as a product of Posner and Raichle's (1994) alerting network of attention. Finally, the stability (or lack thereof) of participants' performance on all task measures over testing time was recorded as a reflection of sustained attention. As with attentional expectancy, sustained attention was thought to tap into the alerting network of attention.

Flanker task

The flanker task, developed by Eriksen and Eriksen (1974), is a classic in the study of selective attention. Because selection is integral to Posner and Raichle's (1994) orienting network of attention, the flanker task could thus be classified as a test of orienting. However, given the central roles that visual focusing and filtering simultaneously play in the target selection and response processes on the flanker task, it was classified as a test of executive control in this project. In particular, the flanker task was used to isolate the interference control component of attention (which itself was viewed as an interaction of the focusing and filtering components of attention, as will be explained in the next paragraph). The interference on a flanker task is provided by two or more irrelevant stimuli that are termed flankers. The flankers on any given trial of a flanker task are typically alike and are paired with either no response or a response that is the same as, or different than, the target response. Participants are asked to identify the target stimulus on each trial by means of a key press and are explicitly instructed to ignore the flankers. The classic flanker effects involve response facilitation or interference depending on the level of competition that does or does not exist between the stimuli and their respective responses (Eriksen & Eriksen, 1974; Miller, 1991).

Thus far, the reader may have noted that both the Simon and flanker tasks require the cognitive filtering of irrelevant from relevant information during task completion. A key difference lies in the nature of the irrelevant information that must be ignored on each task. Specifically, the information to be filtered on the Simon task – target location – is spatial in nature whereas the same on the flanker task – flanker identity – is visual in nature. Given the presence of visual distracters, the process of filtering on the flanker task simultaneously demands a type of visual focus that is not required on the Simon task. In this regard, the Simon task has been identified as isolating the attention component of filtering whereas the flanker task incorporates both focusing and filtering, and is thus considered a task of interference control. Notably, the focusing of the attention beam on the flanker task should facilitate the filtering of the task-irrelevant information.

To capture the efficiency with which participants narrow their visual focus to the centrally located targets on flanker trials – and simultaneously filter the irrelevant identities of the flankers - the target-to-flanker separation distance was manipulated on the task version used herein. Thus, the measures of interference control were the pattern of participants' target reaction times and the pattern of their target accuracies over the (two) trial types and (three) target-to-flanker separation distances employed. A participant with good interference control, then, would process targets more quickly and more accurately on trials with response-incompatible flankers, regardless of the flankers' proximity to the targets, relative to a participant with poor interference control who, in turn, would exhibit worse task performance (especially on trials with proximal flankers).

In addition to interference control, the flanker task tapped into processing efficiency that, as previously indicated, was categorized herein as a subcomponent of focused attention. As with the Simon task, participants' processing efficiency on the flanker task was measured by their overall target reaction time and accuracy. Finally, as with their performance on the Simon task, the stability of participants' performance on the flanker task over testing time was measured as a reflection of sustained attention. Whereas interference control and focused attention are within the domain of the executive control network of attention, sustained attention was viewed as a product of Posner and Raichle's (1994) alerting network of attention.

Stop-signal task

The stop-signal paradigm, upon which the stop-signal task is based, has been the topic of theoretical and empirical research for decades (Logan, Schachar, & Tannock, 1997; Schachar, Tannock, & Logan, 1993). Generally speaking, the stop-signal task involves the rapid presentation of simple visual stimuli (known as targets) in serial fashion on a computer screen. A person completing the stop-signal task is instructed to make a forced-choice identification response to each target as quickly and accurately as possible, with the proviso that he or she is to attempt withholding a response to any target that is accompanied by a "stop signal." Stop signals generally take the form of short auditory tones and are presented at varied intervals (known as *stop delays*) following random target onsets on a predetermined proportion of trials (e.g., 25%; e.g., Logan et al., 1997).

The stop-signal task is recognized as a measure of inhibitory control of motor responses and has been hailed in the ADHD literature as the "gold standard" among measures of impulsivity. For example, Stevens, Quittner, Zuckerman, and Moore (2002) identified three advantages of the stop-signal task over that of alternative measures of impulsivity to be: (1) relative to control children, children with ADHD have repeatedly demonstrated poorer performance on the stop-signal task, (2) relative to other measures, performance on the stop-signal task has shown independence from demographic data, and (3) relative to other cognitive and behavioural functions, inhibitory control is uniquely isolated on the stop-signal task.

The response inhibition required by the stop signal task used in this project was categorized as a subcomponent of focused attention. It was measured as participants' stop signal reaction time (SSRT), an index of inhibitory efficiency that is explained with greater detail in Chapter 5. In addition to their SSRTs, participants' processing efficiency on the trials for which a stop signal was not given (measured as their mean target reaction time and mean target accuracy) was recorded as a measure of focused attention. Finally, sustained attention was tapped by the analysis of participants' performance stability over time. Whereas focused attention was categorized as a process of executive control, sustained attention was categorized as a product of the alerting network of attention (as it is defined by Posner and Raichle, 1994).

Blink task

Attention researchers have long been interested in the eye saccades that humans typically use to scan their visual environments. Studies have shown that a person's visual processing system is automatically suppressed during these rapid saccades in order to avoid overwhelming the attention system with the countless stimuli that are fleetingly present on the retina. This very phenomenon – the rapid presentation of stimuli across space - is artificially recreated in a psychology lab using the temporal rather than the spatial domain in tasks that are described as employing a *rapid serial visual processing* (RSVP) paradigm. A person completing an RSVP task is asked to view a series (or *stream*) of visual items that are presented in rapid succession at the same spatial location over a period of several hundred milliseconds (Raymond, Shapiro, & Arnell, 1992).

The visual items in a RSVP stream include two targets interspersed among a series of distracters. The detection/identification of the first target item (T1) generally interferes with the observer's ability to detect or accurately identify the second target item (T2, sometimes called a probe) when the two targets are presented in close temporal proximity and both are immediately followed by at least one distracter. It is as if the observer's attentional system "blinks" following T1 and thereby misses T2. This phenomenon of a virtual gap in visual attention - coined attentional blink by Raymond et al. (1992) – is the basis for the blink task used in this project. The magnitude of a person's attentional blink is thought to produce a measure of his/her encoding limit for rapidly presented visually patterned information.

Participants' blink magnitude is just one of the two measures of an encoding limit used in this project. The second measure, also taken from the blink task, was participants' accuracy in identifying T2 on only the trials for which T1 was correctly identified; this subset of targets is hereafter referred to as T2 | T1 ("T2 given T1"). The way in which blink magnitude and T2 | T1 accuracy reflects a capacity limitation of a person's attentional resources requires a general understanding of the models used to explain the phenomenon. The models are briefly explained in the subsection on the blink task in Chapter 5. In essence, the accurate identification of T2 | T1 requires a memory store in which T1 and T2 are consecutively – or concurrently (depending on the model) – held (or, stored) and cognitively processed. As a matter of consequence, a participant's performance on T2 | T1 varies directly with his/her encoding capacity for small visually patterned icons that are rapidly and serially presented at the same location in space. Alternately, T2 | T1 performance varies inversely with blink magnitude. In this regard, a parallel is drawn between encoding capacity, as defined in this project, and working memory proficiency.

Participants' encoding limit, or encoding capacity, for rapidly presented visually patterned stimuli (as reflected by their blink magnitude and T2 | T1 accuracy) was thought to tap into Posner and Raichle's (1994) alerting network of attention. A third dependent variable of interest on the blink task was participants' accuracy in identifying T1; this measure was thought to be one of processing efficiency and was thus assumed to reflect focused attention. As previously indicated, focused attention was, like encoding capacity, categorized as a measure of Posner and Raichle's alerting network of attention.

CPT

The CPT was developed by Rosvold, Mirsky, Sarason, Bransome, and Beck (1956) and first used with hyperactive children in 1967 (Conners, Eisenberg, & Barcai, 1967). The most common computerized CPT paradigm is visual and involves the rapid serial presentation of letter stimuli in the centre of a computer screen. Participants are asked to monitor the stimulus stream for specific target stimuli and to make fast responses to targets when they occur. There are two common variants of the CPT, including one with single-item targets (often termed X paradigms) and one with a warning signal (e.g., "respond only to X if preceded by A," often termed A-X paradigms). Traditionally, the variables of interest on the CPT have been the reaction time to targets, the number of missed targets (i.e., errors of omission), and the number of responses to non-targets (i.e., errors of commission). Omission errors are considered to reflect inattention (i.e., lack of alertness) whereas commission errors are thought to reflect impulsivity (Corkum & Siegel, 1993; Levy & Hobbes, 1997). The inherent temporal uncertainty and irregularity in target presentation on the CPT has long been thought to capitalize upon the deficits in sustained attention and response inhibition (of prepotent responses) that are inherent to ADHD (Levy & Hobbes, 1997).

Response bias in the context of the CPT reflects a participant's decision criterion for initiating versus inhibiting motor responses on each trial. It appears to be isolated by an evoked potential (i.e., the N550 component) in the frontal lobe of children with ADHD and controls, as determined in a study of ERPs by Sartory, Heine, Müller, and Elvermann-Hallner (2002). Because it entails motor control and, by virtue of its value, reflects a participants' tendency towards response initiation versus inhibition (or vice versa), it can be considered a type of response inhibition and thus, a measure of attentional focusing. Similarly, a participants' false alarm rate can be considered an overall measure of response inhibition in that the occurrence of a false alarm reflects poor inhibitory control. Response inhibition as tapped by false alarms on the CPT notably differs from response inhibition as tapped on the stop-signal task in that the former requires the inhibition of a prepotent response on a non-target (i.e., distracter) trial whereas the latter requires the inhibition of an ongoing response on a target trial.

In conclusion, participants' response bias and false alarm rates as measured on the CPT in this project were considered performance measures of response inhibition and, thus, focused attention. Furthermore, the processing efficiency reflected by participants' hit reaction times and hit rates was categorized as a subcomponent of focused attention. In addition to response bias, false alarm rate, hit reaction time, and hit rate, target sensitivity on the CPT was taken as a measure of focused attention. The (in)stability in participants' performance on each of these measures over testing time was assumed to reflect sustained attention. As already indicated, focused attention was categorized herein as a product of Posner and Raichle's (1994) executive control network of attention whereas sustained attention was categorized as a product of their alerting network of attention.

Summary

Attention is indeed a broad cognitive construct. It can be viewed as a collection of smaller, somewhat independent cognitive processes that work together to facilitate a person's understanding of, and ability to interact with, the world. For example, Mirsky et al. (1991) identified focusing, sustaining, shifting, and encoding as four components of attention whereas Coren et al. (1994) addressed orienting, filtering, searching, and expecting as essential pieces of the cognitive mosaic. A component-based approach to attention was used in this project to better understand ADHD and the role that environmental context does (or does not) play in determining a person's ability to: (1) respond to alerting cues, (2) encode rapidly presented visual stimuli, (3) sustain focus upon a given object or event, (4) narrow that focus upon a visual target, (5) filter distractions from on-line cognition, and (6) control the interference from nearby distraction whilst focusing upon a visual target. The first three of these components – respectively labeled attentional expectancy, encoding capacity, and sustained attention – are considered, at least for the purposes of this project, to be products of a neural network responsible for alertness and proposed by Posner and Raichle (1994). The latter three components – respectively labeled focusing, filtering, and interference control – are considered to be products of a neural network that Posner and Raichle proposed as encompassing executive control.

Five tasks of attention were administered to the child participants in this project in each of two environmental contexts. The five tasks – the Simon, flanker, stop-signal, blink, and continuous performance tasks – were integrated within one computerized battery. The video game context in which it was administered included, in part, posters on the room walls, prizes for task completion, and brightly coloured computer graphics. By contrast, the traditional context paralleled (as its name suggests) a typical testing room in a psychology lab. The goals of the project were thus: to uncover a component-based attention profile of typically developing children as compared and contrasted with that of children with ADHD, and also to assess the influence that the contextual manipulation might have upon each attention component that was studied in each of these child populations. Discovering the potential for improving attention task performance among the children with ADHD via rewards and visual stimulation was a key motivation for the completion of this project.

Chapter 3. Etiology of ADHD

ADHD is very likely the product of interwoven genetic and environmental effects (Castellanos & Tannock, 2002). Given its high prevalence and the many challenges it presents to homes, schools and society in general, it is not surprising that many researchers have committed to untangling its etiological web. In this regard, researchers have identified five general areas of dysfunction in children with ADHD: (1) family and genetic factors, (2) prenatal and perinatal factors, (3) chemical "toxins," (4) psychosocial stressors, and (5) neurological (i.e., brain structure and function) abnormalities (Jensen, 2000).

Family and Genetic Factors

Genetic research has involved two approaches: twin/adoption studies and candidate gene analyses. Twin/adoption studies have typically shown the heritability of ADHD to be in the 0.70 to 0.80 range (e.g., Kuntsi & Stevenson, 2001; Levy, Hay, McStephen, Wood, & Waldman, 1997; also, see following reviews: Biederman & Spencer, 1999; Castellanos & Tannock, 2002; Faraone & Biederman, 1998; Jensen, 2000), although there is evidence to suggest that these estimates are inflated by reporter bias (Kuntsi & Stevenson, 2001). The two most popular candidate genes for ADHD are the dopamine transporter (DAT) and dopamine receptor (DR) genes. Specifically, the 10-repeat allele of the DAT1 gene and the 7-repeat allele of the DRD4 gene have been found more frequently in individuals with ADHD than in individuals without the disorder.[4] The implication of these genes in ADHD has been replicated in several studies, although their individual effects appear to be modest (Biederman & Spencer, 1999; Castellanos & Tannock, 2002; Faraone & Biederman, 1998; Jensen, 2000).

An exciting component of genetic research has been the linkage of several genes (including the candidate genes for ADHD) to dopaminergic functions and, on the basis of

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[4] The number in the respective gene labels (1 and 4) refers to the location within the DNA sequence where the ADHD-related tandem repeats are found.

that work, components of attention that are modulated by dopamine. This is relevant to ADHD research because abnormalities in the dopamine system and the attention functions they modulate - most notably, within the frontal-striatal neural pathways - are strongly implicated in the etiology of the disorder (see further detail and related references later in this chapter). For example, the DAT1, DRD4, monoamine oxidase A (MAOA), and catechol-o-methyltransferase (COMT) genes have all been associated with the metabolic degradation of dopamine at the dopamine synapse (Fossella et al., 2002). Various allele combinations of these four genes have been differentially linked to attention task performance in healthy adult populations (e.g., Fan, Fossella, Sommer, Wu, & Posner, 2003; Fossella et al., 2002; Malhotra et al., 2002; Tsai et al., 2003).

Diamond, Briand, Fossella, and Gehlbach (2004) have extended cognitive-biology work to healthy children on tests of attention and three allele combinations of the COMT gene. Diamond et al. demonstrated an impressive level of specificity between allele combination and task performance according to the need - or lack thereof - for dopamine in the construct of attention tested on each task. For example, Diamond et al. observed a much stronger relationship between an allele combination that causes slow dopamine turnover and level of performance on a task of interference control than between alleles related to faster dopamine turnover and performance on that task. The relationship between allele type and task performance was much greater on the task of interference control – a dopamine-dependent function of the prefrontal cortex - than on tasks tapping non-dopamine-dependent components of attention that are also mediated by the prefrontal cortex.

Prenatal and Perinatal Factors

Despite conflicting results about the exact factors and the degree of their association with ADHD, there is general consensus that several pregnancy and delivery complications predispose a child to the disorder. Related pregnancy complications have been shown to include toxemia, illness, bleeding, excessive nausea, undue weight loss or gain, and poor maternal health. Delivery problems associated with ADHD include lengthy labor and delivery, fetal postmaturity, fetal distress, low birth weight, and antepartum hemmorrhage (Faraone & Biederman, 1998; Jensen, 2000). Additionally, Toft (1999) suggests that striatal hypoxia in human neonates who have endured perinatal adversity may play a role in the pathogenesis of ADHD. These birth-related factors are not specific to ADHD and, because some demonstrate relevance only in children with family histories of ADHD, they also demonstrate limited sensitivity to the disorder (Jensen, 2000).

Psychosocial Adversity

The severity of ADHD symptoms in children with the disorder has been associated with family stressors and psychosocial adversity. There is no direct or clear evidence to suggest that these factors cause the disorder but there is evidence that they can exacerbate the disorder. A "snowball effect" can be created because children with complicated or comorbid presentations of ADHD are more likely to be burdened by environmental stressors. In turn, these factors may increase ADHD severity and comorbidity, thereby providing a positive feedback loop and even greater impairment for children with the disorder (Jensen, 2000).

In their literature review on the etiology of ADHD, Faraone and Biederman (1998) highlight past research that has linked ADHD with an index of psychosocial adversity. The index comprises six family-related factors that have been empirically connected to childhood mental illness: severe marital discord, low social class, large family size, paternal criminality, maternal psychopathology, and foster placement. Additional research has shown low maternal education and single parenthood to be associated with ADHD. In one study reviewed by Faraone and Beiderman, chronic conflict, decreased family cohesion, and exposure to parental psychopathology, particularly maternal psychopathology, were more common in families of children with ADHD than in control families. Faraone and Biederman concluded that factors of adversity such as family conflict and paternal criminality might be effects of the same genes that cause ADHD as opposed to independent causes of the disorder.

Chemical Toxins

Chemical agents such as nicotine (in utero), food additives, and even therapeutically administered medications have been implicated in ADHD. Similarly, attentional difficulties are part of the sequelae associated with alcohol intake during pregnancy and the effects of high levels of cumulative lead exposure on a child (Castellanos & Tannock, 2002; Jensen, 2000). It is unlikely that lead – or any other chemical factor – accounts for the bulk of ADHD cases (Faraone & Biederman, 1998). This has not stopped the pursuit of non-pharmacological interventions, however. Restricted and modified diets have been proposed as interventions. Notably, studies on dietary factors have shown mostly negative treatment results (Faraone & Beiderman, 1998).

Traumatic Brain Injury (TBI)

Insult to the human brain can produce significant personality and behavioural changes, a reality that has famously been associated with the story of Phineas Gage and a misguided iron tamping rod (Myers, 2004). In that regard, and because ADHD is diagnosed solely on the basis of observable behaviours, it is possible for a person to "acquire" the disorder following a TBI. This is not surprising when one considers the brain regions that may be selectively damaged by traumatic injury and, as will be discussed later in this chapter, their associations with attention and ADHD. For example, the frontal and prefrontal cortices are vulnerable to damage in a TBI due to their proximity to the skull. Similarly, long white matter tracts (such as those in the corpus collosum) can be subject to a shearing injury, and the striata can be forced to endure hypoperfusion of blood as a result of TBI-induced swelling (Jensen, 2000).

Neurological Abnormalities

In a recent review of 27 studies that used magnetic resonance imaging (MRI) to investigate neuroanatomical abnormalities in children with ADHD, Seidman, Valera, and Makris (2005) concluded the most replicated findings to be smaller than normal volumes of the dorsolateral prefrontal cortex, the caudate nuclei, the pallidum, the corpus callosum, and the cerebellum. Similar conclusions have been drawn in other reviews of the literature (e.g., Hale, Hariri, & McCracken, 2000; Hendren, DeBacker, & Pandina, 2000; Jensen, 2000). Seidman et al. also found, within their review of the literature, limited evidence for abnormalities of the lateral ventricles, and the temporal, parietal, and occipital lobes in children with ADHD. Some of the brain abnormalities associated with ADHD have been linked to performance deficiencies on attention tasks, thereby narrowing the divide that exists between the biology and psychology of the disorder (Hale et al., 2000). For example, in a study of young boys with and without ADHD, Casey et al. (1997) showed anatomical measures of the prefrontal cortex and basal ganglia (e.g., volume of right prefrontal cortex, caudate symmetry, volume of left globus pallidus) to correlate with accuracy and reaction time on tasks of inhibition of prepotent responses, inhibition of ongoing responses, and interference control; furthermore, the nature of these relationships differed across participant groups.

The neurophysiology of ADHD has been studied through the use of positron emission tomography (PET), single photon emission computed tomography (SPECT), quantitative electroencephalography (EEG), and functional MRI (fMRI). Studies using these technologies collectively indicate that the frontostriatal systems in the brains of persons with ADHD are hypoperfused, hypometabolic, and functionally disrupted relative to control brains (Hale et al., 2000; Jensen, 2000; Pliszka, McCracken, & Maas, 1996; Riccio, Hynd, Cohen, & Gonzalez, 1993). These methods have also identified areas of brain dysfunction during completion of cognitively demanding tasks. For example, diminished and late event-related potentials originating in the frontal cortex have been shown in children with ADHD relative to control children during completion of a CPT (Strandburg et al., 1996). Functional imaging techniques have also indicated the mechanisms by which stimulant drugs act to improve attention and reduce hyperactivity in children with ADHD. For example, increased frontostriatal activity as a result of methylphenidate has been detected by fMRI in children with ADHD during the completion of a go/no-go task (Vaidya et al., 1998). Using EEG, Loo, Teale, and Reite (1999) showed opposite patterns of electrical activity originating in the frontal cortex during the completion of a CPT by children with ADHD who positively responded to methylphenidate versus their nonresponder counterparts.

The main findings from all modalities of neurological research on ADHD converge to suggest a pathogenesis that involves dysfunction in the frontal lobes and various subcortical structures (most notably, within the basal ganglia) along with underlying dysregulation of one or more of the catecholaminergic systems (Biederman & Spencer, 1999; Faraone & Biederman, 1998; Hale et al., 2000; Mercugliano, 1995; Pliszka et al., 1996; Riccio et al., 1993; Seidman et al., 2005; Tannock, 1998). Additionally, there is suggestive evidence that the right hemisphere is more disrupted than the left hemisphere in individuals with the disorder (e.g., Baving, Laucht, & Schmidt, 1999; also, see review by Castellanos, 1999). In line with these findings, Hale et al. (2000) proposed that ADHD involves dysfunction in a "cortico-striato-thalamo-cortical" network in which dopaminergic and possibly noradrenergic brainstem nuclei (i.e., locus ceruleus, substantia nigra, and ventral tegmental area) act to regulate communication between the cortex, striatum, and thalami. This model is agreeable with earlier proposals of disruption to ascending and descending pathways that looped between the frontal lobes, basal ganglia, and thalamus (Riccio et al., 1993). The ascending pathways were proposed to maintain arousal to targeted brain regions at the level of the cortex, whereas the descending pathway controlled inhibition and, thus, selective attention.

Dysfunction in fronto-subcortical brain systems makes intuitive sense as an explanation for ADHD, largely because the implicated brain areas control exactly the functions – attention and motor behaviour - that are known to be deficient in the disorder (Biederman & Spencer, 1999; Levy & Swanson, 2001). For example, the frontal lobes and striatum function together to regulate executive control and behavioural responses such as arousal and inhibition (Hale et al., 2000). The dorsolateral prefrontal cortex within the frontal lobes has been further isolated as an area responsible for organization, planning, and working memory. Given the integral role these functions have in understanding ADHD, the dorsolateral prefrontal cortex has, not surprisingly, been shown to have a smaller volume in children with ADHD relative to control children in nine studies using MRI

(Seidman et al., 2005). In addition to localizing the functions of attention and motor behaviour to the fronto-subcortical brain systems, research has shown the catecholamine neurotransmitters to extensively innervate these regions (Biederman & Spencer, 1999; Faraone & Biederman, 1998; Jensen, 2000; Levy & Swanson, 2001). These neurotransmitters, including dopamine, norepinephrine/noradrenaline, and epinephrine/ adrenaline, play a large role in modulating the fronto-subcortical functions and are targeted by stimulant drugs and similar agents in individuals with ADHD, providing further support for the fronto-subcortical model of ADHD (Biederman & Spencer, 1999; Jensen, 2000). Dopamine has been implicated in inhibitory control and working memory whereas norepinephrine is largely responsible for arousal and orientation to new external stimuli, and epinephrine is involved in selective and sustained attention (Pliszka et al., 1996).

The prefrontal cortex and basal ganglia are especially rich in dopamine receptors (Jensen, 2000). The striatum (within the basal ganglia) has been associated with more dopaminergic activity than any other area of the brain (Volkow et al., 1995). By modulating the activity in the dopaminergic pathways of these structures, stimulants enhance the inhibitory influences of frontal cortical activity on subcortical structures (Biederman & Spencer, 1999; Faraone & Biederman, 1998; Levy & Swanson, 2001). Russell, Allie, and Wiggins (2000) have hypothesized that, relative to non-affected brains, the brains of individuals with ADHD have reduced dopamine and increased norepinephrine. In turn, they believe that the inhibitory activity associated with dopamine is decreased and the excitatory activity of norepinephrine is increased in individuals with ADHD relative to controls.

Pliszka et al. (1996) assert that a hypothesis suggesting too much or too little of a single neurotransmitter will not suffice as an explanation of ADHD. On the basis of their literature review, they concluded that there is a role for three of the catecholaminergic neurotransmitters – dopamine, norepinephrine, and epinephrine – in ADHD. By contrast, Biederman and Spencer (1999) focus only on the norepinephrine system and believe it to be primarily responsible for ADHD symptomatology. They report a modulatory role for the norepinephric system in the regulation of higher cortical functions such as alertness, vigilance, and executive function, and believe it to be especially involved in the maintenance of arousal. It seems most likely from the abundance of available literature on the topic that the catecholamines work together and influence each other in the regulation of attention.

Summary & Related Hypotheses

A multitude of research has linked ADHD with family and genetic factors, prenatal and perinatal factors, chemical toxins, psychosocial stressors, and neurological abnormalities (Jensen, 2000). Despite the vast coverage of the literature, a need persists for greater control of individual difference factors such as comorbidity, family history for ADHD, symptom differences, and perinatal complications. The exact role of these - and other - variables in the pathogenesis of ADHD has yet to be determined. For example – although not discussed in this chapter, most of the published MRI studies on children with ADHD have assessed boys between the ages of 4 and 18. Although the few studies on girls indicate similar findings (Seidman et al., 2005), the known sex effects on brain development in typically developing children suggests a great need for further research on this variable (e.g., Giedd, Castellanos, Rajapakse, Vaituzis, & Rapoport, 1997). ADHD subtype is another variable that implores further study. For example, no MRI studies have yet compared neurological differences between children with the predominantly inattentive subtype of ADHD and those with the combined subtype of the disorder (Seidman et al., 2005).

Given the implications of biological, psychological, and social factors in the etiology of ADHD, it is very likely that the disorder is a heterogenous condition with multiple causes. For some children with the disorder, ADHD may be the manifestation of multiple genes with modest effects. For others, it may primarily be the product of environmental adversity (Biederman & Spencer, 1999; Faraone & Biederman, 1998; Jensen, 2000). Indeed, there is no single pathophysiological profile of ADHD (Faraone

& Biederman, 1998). Rather, the disorder is probably best viewed as a final common pathway for a variety of complex brain developmental processes (Jensen, 2000).

It would indeed be a stretch to hypothesize results in this project on the basis of the nonspecific etiological factors associated with ADHD such as pregnancy complications or psychosocial stressors. The only real promise that etiological research can show for predicting cognitive task performance lies in genetic and neurological research. In that regard, genetic and functional neuroimaging studies have clearly indicated a role for dopamine in the modulation of attention and, in particular, for several components of attention that have been localized to frontal-striatal circuitry. Given the repeated implication of abnormalities in dopamine-specific genes, dopaminergic neurotransmission, and frontal-striatal neural circuitry in individuals with ADHD, it would be quite reasonable to hypothesize ADHD-specific deficiencies in the dopamine-dependent components of attention. Not surprisingly, these include components linked to the two neural networks that were studied in this project (alertness and executive control).

As the literature reviewed in this chapter suggests, alerting and executive control are most strongly associated with arousal, behavioural inhibition, and working memory. The related components of attention in this project are focused attention, sustained attention, and encoding capacity. Thus, the participants with ADHD are expected to demonstrate general impairment (relative to the control children) on the measures of these three components. Regarding the contextual manipulation, the video game attention battery is expected to facilitate neural responses linked to reward and motivation. Not surprisingly - given related literature on ADHD - these neural responses (similar to said attention components) pull for dopamine. Thus, increased dopaminergic neurotransmission in the video game context should facilitate a reduction of the deficits in focusing, sustaining focus, and encoding shown by the ADHD group in the traditional context. The control children, on the other hand, should demonstrate enhanced performance on these same components of attention in the video game context relative to the traditional context (at least to the extent that they can benefit from the increased dopamine). More detailed hypotheses regarding task performance in the traditional context are provided in the summary section of Chapter 5. Further detail on the hypothesized benefits of the video game context is provided in the summary section of Chapter 6.

Chapter 4. Theory of ADHD

A disorder representative of ADHD was first documented in published literature in the early 1900s. "Poor volitional inhibition and defective moral regulation of behaviour" (Barkley, 1997a, p. 65) were considered to be responsible for its symptoms. Problems with hyperactivity were not recognized as a core feature of the disorder until the late 1950s. Twenty more years passed before inattention and poor impulse control were added as core features of the disorder (Barkley, 1997a). Since that time, and partly in response to the newly recognized heterogeneity of the disorder, there has been a surge in published literature on ADHD. Related to the issue of heterogeneity have been questions about the disorder's validity (at least as it has been conceptualized by the DSM) and what appears to be a rapid increase in prevalence throughout the 1990s (Tannock, 1998). The decades-long hype about ADHD has witnessed the development of several models and theories that each attempt to explain the disorder's underlying pathology. For example, Douglas (1983, 1988) developed a model of impaired self-regulation throughout the late 1970s and early 1980s, as Zentall (1975) and Zentall and Zentall (1983) focused on issues of environmental stimulation and internal homeostasis. Throughout the 1980s, the mechanism for ADHD symptomatology was proposed to be a motivational deficit, a combination of poor stimulus control and poor rule-governed behaviour, and, alternately, a diminished level of sensitivity to reinforcement (Barkley, 1997a).

By the late 1980s and early 1990s, poor behavioural inhibition was suggested as the central impairment of the disorder (Barkley, 1997a). Since then, impairments in related but more general executive functioning have been implicated; these include a delay aversion and deficient working memory with disorder-specific problems in motor inhibition (e.g., Kuntsi, Oosterlaan, & Stevenson, 2001; Pennington and Ozonoff, 1996). Interestingly, Tannock (1998) has described the 1990s as the "era of executive dysfunction" (p. 69) because of the focus it was given in several developmental psychopathologies in addition to ADHD. Sergeant, Oosterlaan, and van der Meere (Sergeant, Oosterlaan, & van der Meere, 1999; Sergeant & van der Meere, 1990) provided part of the executive dysfunction focus on ADHD. They proposed a model of

ADHD based on Sternberg's additive factors logic for information processing. Specifically, they hypothesized that – while Sternberg's logic would apply to a typically developing child, it did not (by virtue of the disorder) apply to children with ADHD. Sergeant, Oosterlaan, and van der Meere's (1999) model of ADHD incorporates the behavioural energetics of arousal, activation, and effort. They view hyperactivity as a deficit localized to the output side of a child's information processing system.

Almost ten years ago, Barkley (1997a, 1997b) put forth a theory of ADHD implicating a core deficit in behavioural inhibition. It is quite possibly the most widely accepted view at present, although a more recent theory suggests that poorly regulated working memory is the primary causal process associated with ADHD symptoms (Douglas, 2005). The "wave of the future," however, appears to steer away from single-cause models and suggests a multi-faceted approach that simultaneously accounts for the genetic, neurological, and psychological abnormalities that have all been implicated in the disorder. Although some researchers and theorists have not entirely caught on to this new approach, Castellanos and Tannock (2002) have made impressive progress with their proposals of cognitive endophenotypes unique to ADHD.

This chapter reviews just three of the many models of ADHD that have been proposed within the past 30 years. The first, Zentall's (1975) underarousal theory of ADHD, was chosen on the basis of its relevance to the current project. It taps into the issue of environmental stimulation, the key variable of interest in the context manipulation used in the attention battery of this project. The second model, one of impaired self-regulation as proposed by Douglas (1983, 1988, 2005), reflects on the direct construct of attention perhaps more so than any other model and was pivotal in the recognition of inattention and impulsivity as core features of ADHD. The third model that is discussed, Barkley's (1997a, 1997b) hybrid model of executive functions and his related response inhibition theory of ADHD, was chosen because of its breadth and current popularity. In the final summary section of this chapter, the models will be considered in tandem and hypotheses suggested for the attention profiles to be investigated in this project.

Before reviewing the three indicated models of ADHD, it is important to note a recent divide that has been introduced between its subtypes. As a result of this divide, a trend has developed whereby models of the disorder exclusively account for the combined subtype and sometimes the predominantly hyperactive-impulsive subtype but not the predominantly inattentive subtype of the disorder (Tannock, 1998). Barkley's (1997a, 1997b) model is an example of this trend. The divide has been prompted by suggestive evidence that the cognitive and behavioural phenotype of children with the inattentive subtype of ADHD is qualitatively different from that shown by children with the hyperactive-impulsive and combined subtypes. Furthermore, the predominantly inattentive subtype has been linked with a later age of symptom onset, reduced male bias, and different pattern of comorbid disorders relative to the other two subtypes. Some researchers thus believe that the predominantly inattentive subtype represents an entirely distinct disorder from that which has traditionally been considered ADD/ADHD (e.g., Carlson, Shin, & Booth, 1999; also, see following reviews: Barkley, 1997a, 1997b; Nigg, 2001; Tannock, 1998).

Barkley (1997a, 1997b) believes that the hyperactive-impulsive subtype of ADHD is a developmental precursor for the combined subtype and, whereas its symptoms of hyperactivity and impulsivity begin to arise in preschool, its symptoms of inattention do not arise until a few years later. By contrast, he believes the inattention that is characteristic of the predominantly inattentive subtype arises even later in school years. The inattention associated with the combined subtype has been most strongly linked with poor sustained attention (in particular, limited persistence) and distractibility whereas the inattention of the inattentive subtype to be more reflective of daydreaming, "spacing out," lethargy, and a sluggish cognitive tempo. A deficit in speed of information processing and focused, or selective, attention has been more strongly associated with the inattentive subtype than the hyperactive-impulsive and combined subtypes of the disorder (Barkley, 1997a, 1997b; Nigg, 2001).

The notion that the current label of ADHD is an umbrella for two fundamentally distinct disorders is crucial to the field and, yet, it will probably take several more revisions of the

DSM before related research can adequately and accurately resolve the issue. Although the ideal would be for this project to restrict its sample to the combined subtype of ADHD on which recent models have focused, such an option was not feasible. The repeated measures design used in this project partially eliminates the problem with between-subjects variability. Furthermore, different components of attention appear to be compromised in the different subtypes (as discussed in the previous paragraph). This suggests that - even if subtype-specific effects occur herein - the effects will not cancel each other out but may simply lack the statistical power to be detected.

Zentall's (1975) Theory of Underarousal

According to Leuba's (1955) optimal stimulation theory, environmental stimulation plays a central role in human learning. The optimal stimulation theory proposes that:

> The organism tends to acquire those reactions [behaviours] which, when over-all stimulation is low, are accompanied by increasing stimulation; and when over-all stimulation is high, those which are accompanied by decreasing stimulation. (p. 29)

In other words, according to Leuba (1955), organisms behave so as to maintain optimal levels of stimulation – much as bodies work to maintain homeostasis by regulating levels of heat, food, and water (Lee, 1999). Zentall (1975) and Zentall and Zentall (1983) extended this theory to hyperactive children to explain their abnormally high levels of motor activity. According to the Zentalls, hyperactive children – relative to their typically developing peers - are consistently underaroused and therefore need more stimulation and novelty in their environments to achieve the same levels of functioning. Their self-generated motor activity purportedly operates to satisfy these needs. In contrast, typically developing children do not need such a compensatory system to maintain optimal levels of alertness and task engagement in their environments. Zentall (1975) and Zentall and Zentall (1983) have found support for an underarousal theory from studies of sensory deprivation, sensory overload, and stimulant therapy for hyperactive children. Regarding the latter, Zentall and Zentall (1983) propose that stimulants work by fulfilling the role that self-generated motor activity fulfils in unmedicated hyperactive children. Using the same reasoning, one might predict it possible to reduce and maybe even eliminate ADHD symptoms by creating high-stimulation environments above and beyond that which typically developing children would need to exhibit the same level of non-ADHD behaviour. The stimulation within these environments should provide a substitute, and thereby eliminate the need, for self-generated stimulation. This is exactly what Zentall (1975) proposed for intervention with hyperactive children who, by today's DSM-IV criteria, would be described as having the combined subtype of ADHD (Lee, 1999).

Douglas' (1983, 1988, 2005) Model of Impaired Self-Regulation

Douglas (1983, 1988) is a key player in the world of cognitive research on ADHD. Her work is often credited as fulfilling a pivotal role in the initial widespread recognition of inattention and impulsivity as core symptoms of the disorder (Barkley, 1997a; Carlson et al., 1999; Lahey et al., 1988; Swanson et al., 1998). This occurred largely in the 1970s and culminated in 1980 with the publication of the DSM-III and the introduction of a new diagnostic label; what was known as hyperkinetic reaction of childhood in the second edition of the DSM was redefined as attention deficit disorder (ADD) in the third edition and ultimately became known as ADHD in the fourth edition of the DSM (see Swanson et al., 1998 for a review of label and symptom changes of ADHD throughout versions II through IV of the DSM).

To this day, and largely because of Douglas' (1983, 1988) influence, inattention remains recognized as a primary aspect of the disorder. The review provided herein of her model of ADHD is based in part on a book chapter that she wrote over twenty years ago; the chapter outlines her model and an extensive array of supporting literature (mostly from studies using lab-based tests of attention) for each of its main tenets. Notably, Douglas received a lifetime contributions award from Canadian Psychological Association in 2004. She marked the occasion by presenting an update on her thinking of the disorder. Her original model was clearly pivotal to current conceptualizations of the disorder and, especially in its revised form (Douglas, 2005), shows overlap with components of Barkley's theory of response inhibition, Sonuga-Barke's model of delay aversion, and Sergeant, Oosterlaan, and van der Meere's model of behavioural energetic processes (see reviews referenced earlier in this chapter). The premise of this update is included here.

Douglas (1983, 1988, 2005; Barkley, 1997a, 1997b) believes that the attentional difficulties of children with ADHD are one piece in a larger puzzle of closely related deficits, all of which combine to have far-reaching implications for affected children's behaviour, academic pursuits, and cognitive functioning. She identifies the central impairment in ADHD to be that of poor self-regulation and believes that this impairment manifests as deficits in the ability to: (1) invest, organize, and maintain alertness and effort, (2) inhibit impulsive responding, (3) modulate levels of arousal in accordance with situation demands, and (4) delay attainment of reinforcement in situations of cognitive and behavioural demands. Douglas proposes that these *primary* deficits lead to, and can be led by, a collection of *secondary* deficits in functioning that include: (1) limited development of multi-component concepts, strategies, and academic operations, (2) impaired metacognition, and (3) diminished sense of efficacy and motivation.

Regarding their sensitivity to reinforcement, Douglas (1983, 1988, 2005) has hypothesized that children with ADHD have an abnormally strong inclination to seek immediate reward, are unusually vulnerable to possible arousing and distracting effects of reward, and become abnormally frustrated when anticipated rewards fail to appear. She is to clear to point out that, by suggesting children with ADHD are more sensitive to rewards than control children, she is not indicating that they are oversensitive in a way that more reward would mean better performance. She encourages other authors to be similarly careful with their use of the word sensitivity in reference to the underlying mechanisms of ADHD symptomatology (see summary by Douglas & Parry, 1994). For example, Douglas and Parry did not find support for hypotheses that children with ADD-H (in accordance with DSM-III criteria) require more reinforcement than typically developing children to achieve the same level of performance on tasks with partial reward schedules relative to tasks with continuous reward schedules (see Chapter 6 for further discussion of this study). Nonetheless, Douglas and Parry acknowledge the mediating role that task and setting factors have in the relationship between reinforcement and child performance.

In reviewing the literature that led to the development of her model, Douglas (1983) came to several conclusions regarding the status of selective attention in children with ADHD. She found little evidence to indicate that the performance of hyperactive children was more disrupted than that of control children by the specific presence of extraneous stimuli. She points out that responses to incorrect stimuli (i.e., distracters) on tasks requiring filtered attention do not necessarily result from a failure to ignore the stimuli. Instead, responses to distracters can result from a failure to inhibit strong response tendencies. On the basis of her literature review, Douglas (1983) believes it is indeed the latter case that occurs for children with ADHD. She thus discounts past hypotheses that ADHD entails faulty filtering mechanisms, discrimination problems, or difficulties with concurrent processing, and attributes errors of distractibility to underlying problems in concentration, response inhibition, arousal, or reinforcement (i.e., one of the four core deficits she has identified in ADHD). She noted some of the factors that elicited distractibility in the studies she reviewed to include the degrees of boredom, distaste, and difficulty associated with particular tasks. Within the filtering studies Douglas (1983) reviewed, distracters were placed in close proximity to the task stimuli or formed an integral part of the task to be performed (e.g., drawings among words to be read, non-target words spoken simultaneously with target words).

Similar to her conclusion about filtering abilities, Douglas (1983) does not believe that children with ADHD have a basic deficiency in their capacity to perceive visual or auditory stimuli. She believes that any deficits that are found on perceptual or memory tasks are attributable to a failure to invest sufficient effort in the processes of encoding, storing, and/or retrieving such information. In other words, apparent deficits in visual or auditory perception are – like that of selective attention – secondary to one or more of the four primary deficits she identifies in ADHD.

Douglas (1983) has a unique stance on intervention for children with ADHD. Although she acknowledges a role for stimulant medications and contingency management to counter the primary problems associated with ADHD, she believes it is also imperative to combat the secondary effects of the primary attention, inhibition, arousal and reinforcement problems. Douglas purports that cognitive training programs have proven to be more successful than stimulant medications or contingency programs for promoting the generalization and maintenance of treatment effects on cognitive, social, and academic functioning. She believes that combating primary deficiencies should reduce their impact on the development of secondary problems. By teaching self-regulation strategies, Douglas believes that children with ADHD can use their prior learning to direct new learning, the acquisition of higher-order schemata, development of sophisticated metacognitive processes, and motivation. More recent research has indicated that, while such approaches may hold promise for adolescents and adults with ADHD, their efficacy as an intervention option for children with the disorder is limited (Safren et al., 2005; Waxmonsky, 2005; Whalen & Henker, 1991).

Since originally proposing her model of impaired self-regulation, Douglas (2005) has continued to be "impressed by the self-regulatory nature of the cognitive and motor deficits shown by ADHD children" (p. 24). She has focused on how the self-regulatory problem could be defined more accurately and assessed empirically. In that regard, she currently conceptualizes the self-regulation problem to have at least three components, including an attentional, inhibitory, and strategic or organizational component. The attentional component references the effortful aspects of cognitive processing whereas the inhibitory component references the behavioural inhibition required for effective cognitive function. The third component of her self-regulation definition references "higher-order" processes that guide and direct cognitive processing such as preparation, planning, working memory, and set-shifting. Douglas (2005) believes the impairments associated with ADHD arise from problems in each of these domains of self-regulation. For example, deficiency in the inhibitory component leads to the impulsivity and inappropriate responding that partly characterizes the disorder.

Barkley's (1997a, 1997b) Theory of Behavioural Disinhibition

Barkley (1997a, 1997b) has proposed a now-popular theory to explain the hyperactivity and impulsivity that is characteristic of children with the predominantly hyperactive-impulsive and combined subtypes of ADHD. He pointedly excludes the predominantly inattentive subtype from his theory, citing evidence to suggest that it is a qualitatively distinct disorder from that demonstrated by the hyperactive-impulsive and combined subtypes. Barkley's theory is based on his hybrid model of executive functions and identifies a developmental delay in behavioural inhibition as the core deficit in children with ADHD. Barkley uses the term behavioural inhibition to refer to three cognitively controlled motor behaviours: (1) inhibiting an initial prepotent response to an event, (2) inhibiting an ongoing response, and (3) inhibiting the disruption of a response delay by competing responses and events (i.e., interference control). An example of inhibiting an initial prepotent response to an event would be not responding on a no-go trial in a go/no-go task. Commission errors on a CPT are failures to inhibit prepotent responses. An example of inhibiting an ongoing response is exactly that which is done on a stop trial in the stop-signal task, whereas an example of interference control is the filtering that occurs when responses are made on trials of Simon and flanker tasks.

According to Barkley's (1997a, 1997b) model, behavioural inhibition produces a pause in a person's physical activity, thus allowing time for four executive functions to come "on-line" and facilitate further behavioural regulation. Behavioural inhibition thus does not cause, but sets the stage for, four intermediate functions: (1) working memory, (2) self-regulation of affect, motivation, and arousal, (3) internalization of speech, and (4) reconstitution. Reconstitution refers to the ability to analyze past behaviour in short sequences and to then re-synthesize the sequences to generate novel, more complex behaviour. Barkley considers the four intermediate functions to be executive functions because they permit behaviour to be controlled by internally represented information and to be organized over time. By bringing behaviour under the control of internally represented information (e.g., rules, plans, intentions, goals, time), the executive functions directly influence motor control, fluency, and syntax. Because children with

ADHD have deficient behavioural inhibition, at least relative to same-aged peers and according to Barkley's theory, they exhibit suboptimal executive functions and, in turn, poor motor control in the form of impulsiveness and hyperactivity. Poor motor control can also directly result from the impaired behavioural inhibition. Given the hierarchical relationship between these functions, Barkley proposes that improvement of the inhibitory deficit in children with ADHD (by stimulant medications or reward contingencies, for example) should result in the normalization of the four functions that depend on it for efficient execution, and also in improved motor control.

Barkley (1997a, 1997b) proposes that the inattention shown by children with ADHD is not a primary symptom of their disorder but, instead, is a consequence of their impaired behavioural inhibition and interference control. In accordance with his theory and specific to children with ADHD, external and internal events disrupt the executive functions that provide for self-control and task persistence. Without self-control and task persistence, children with ADHD understandably appear distractible and cannot sustain attention. Barkley makes a critical distinction between two types of sustained attention: one that is contingency-shaped versus one that is self-regulated and goal- or task-directed. As suggested, it is the latter that he believes is disrupted in children with ADHD. The latter is driven by self-monitoring, a conscious decision to persist with a behaviour, and, in turn, goal-directed intrinsic motivation. Thus, when intrinsic motivation and reinforcement is required on a task, children with ADHD are likely to show performance deficits relative to control children. By contrast, as long as immediate and frequent external reinforcement is available for persistence in task performance, children with ADHD should not, according to Barkley's theory, demonstrate impairment in vigilance or motor control.

Clarification of Theoretical Deficit in Inhibitory Control

Nigg (2000, 2001) has developed a taxonomy of inhibitory processes that he uses to clarify the nature of the inhibition deficit that has been deemed deficient in several models of ADHD, including Barkley's (1997a, 1997b) theory of response disinhibition.

Nigg restricts his consideration of ADHD to the combined subtype, citing lack of research as reason to exclude the hyperactive-impulsive subtype and qualitative differences in clinical presentation as reason to exclude the inattentive subtype. His system outlines three types of inhibition: (1) executive, (2) motivational, and (3) automatic. Executive inhibition refers to the deliberate suppression of a response in order to achieve an internally represented goal. It can be characterized according to the type of response that is being inhibited – primarily motoric, cognitive, or related to response conflicts (i.e., interference control). Barkley's (1997a, 1997b) definition of response inhibition would thus fall into Nigg's category of executive inhibition, with the inhibition of prepotent and ongoing responses being processes of (executive) motor control and the inhibition of distracting events to prevent a response delay being (executive) interference control. Within Nigg's framework, motivational inhibition refers to inhibition that is controlled by fear of punishment or anticipation of reward and is typically motoric in nature. Automatic inhibition, on the other hand, refers to inhibition of motoric or cognitive responses that occur without effort and regardless of competing task demands.

In his review of related literature, Nigg (2001) distinguishes between disinhibitory models of ADHD that focus on the first two of the three types of inhibition outlined in his model: executive (or deliberate) behavioural inhibition versus motivational inhibition. Given the evidence he reviewed from past research such as studies conducted using antisaccade, go/no-go and stop-signal tasks, Nigg (2001) concluded that – at least for children with the combined subtype of ADHD – a deficit lies in executive inhibitory processes. He found the evidence for a motivational inhibition deficit to be far less convincing. Regarding the type of executive inhibition processes that he believes to be deficient in children with ADHD, Nigg (2001) found greatest support for deficient executive motor control but mixed evidence for deficient executive interference control. Thus, although they differ on the issue of interference control, Barkley (1997a, 1997b) and Nigg (2001) do agree that children with the combined subtype of ADHD have a core deficit in their executive control over motoric responses.

Both Nigg (2001) and Barkley (1997a, 1997b) agree on the nature of the underlying deficit in motor control that typifies children with ADHD. Specifically, they both agree that the behaviour of normal children is brought under the control of real time by the ability to internally represent and regulate decision-making in working memory. Similarly, both agree that this process is disrupted in children with ADHD. The behaviour of a child with ADHD is controlled less by internal processes and more by rewards and consequences within the immediate environmental context (i.e., the "here-and-now"). Hence, by virtue of their disorder, children with ADHD are not able to slow down enough cognitively to adequately process surrounding stimuli and, on the basis of such analyses, choose to respond or not. Instead, these children impulsively respond to their environment in physically active ways and are not able to stop their behaviours mid-stream as well as typically developing children can.

Summary & Related Hypotheses

The past three decades have seen a tremendous increase in published literature on ADHD. One of the major themes in this literature has been the development of an adequate model and related theory for the disorder. A multitude of psychological constructs have been implicated, including behavioural inhibition, working memory, and self-regulation. Three models were reviewed in detail in this chapter: Zentall's (1975) underarousal theory, Douglas' (1983, 1988, 2005) model of impaired self-regulation, and Barkley's (1997a, 1997b) hybrid model of executive functions (and related theory of impaired behavioural inhibition). These were chosen for review on the basis of their relevance to the current project and, as is especially the case for Barkley's theory, their current popularity in related literature.

It would be difficult to use Zentall's (1975) theory as a basis for generating hypotheses about the general attention profile that will be shown by either group of children in this project. This is largely because his theory, developed when hyperactivity was the major focus of ADHD, primarily accounts for gross motor overactivity and focuses on suitable intervention alternatives for hyperactive children. In that regard, one might hypothesize that the level of environmental stimulation in the traditional context will not be adequate for the children with ADHD to demonstrate optimal functioning. Thus, these children can be expected to demonstrate a general lack of motor control and, to the extent that this gross motor overactivity plays out in motor responses on attention tasks, these children should demonstrate poorer performance (relative to control children) on the speeded variables. It would be a misuse of his theory to extend it to hypotheses about specific cognitive functions. Nonetheless, his theory would directly suggest that the children with ADHD should respond more positively to the enhanced level of environmental stimulation used in the video game context and, in turn, should demonstrate general improvement in functioning in this context relative to the traditional context. Limitations to this prediction are indicated by related research, however (see Chapter 6 for further details).

On the basis of Douglas' (1983, 1988, 2005) model of ADHD, deficits in self-regulation can be expected in the attention profile of children with ADHD. These would be most evident on measures requiring high levels of arousal (e.g., tasks of focus and sustained attention) and effort, including measures of response inhibition. Barkley's (1997a, 1997b) theory would also predict impaired response inhibition for the children with ADHD, especially in the traditional context for which no rewards are used to bridge the temporal gap between the cognitively demanding aspects of the tasks and the intermittent breaks. More detailed hypotheses regarding task performance in the traditional context (for both groups of children) are provided in the summary section of Chapter 5.

Chapter 5. The Attention Tasks

The Simon Task

Inherent to any discussion of the Simon task is a reference to stimulus-stimulus (S-S) and stimulus-response (S-R) compatibility effects. S-S compatibility occurs when target and distracter stimuli share the same feature in a dimension such as color, form, or location. For example, S-S compatibility is evident on flanker trials when the target is a heart and the flankers are also hearts. Incompatibility occurs when there is a mismatch in the dimension attributes. S-R compatibility references the same concept, but with stimuli and responses that correspond in spatial mapping. S-R compatibility on a Simon task would thus be evident on a trial when the target appears on one side of a computer screen and the response key is on the same side of the response keypad. S-R incompatibility occurs in the event of a mismatch in the spatial mapping. S-S and S-R effects reflect measures of filtering wherein irrelevant information is filtered from conscious awareness and analysis (Kornblum, 1994). As discussed in Chapter 2, a notable difference between the Simon and flanker tasks lies in the different type of irrelevant information that is filtered on each. To reiterate, the irrelevant information is spatial on the Simon task but visual on the flanker task.

The author knows of only one study that has used the Simon task with children that have ADHD. It was in a PhD dissertation completed by McLaughlin (2003) under the supervision of Dr. Raymond Klein. McLaughlin administered an integrated Simon-flanker task to 16 children with ADHD (unmedicated for their symptoms) and 24 control children. Targets were single-digit numbers and were presented either in the centre or on the left or right side of the computer screen. Targets appeared alone or with two lateral flankers. The "pure" Simon effect was measured using the target-alone trials for which the targets were peripherally located. Discussion here is restricted to this subset of Simon trials.

The mean trial type difference score (incompatible – compatible) in reaction time was shown to be 21.31 ms (*SD* = 111.20) for the children with ADHD and 39.58 ms (*SD* = 83.04) for the control children in McLaughlin's (2003) study; this difference was not statistically significant. Similarly, the mean trial type difference score in error rate that McLaughlin obtained was 1.59% (*SD* = 5.62) for the children with ADHD and 3.28% (*SD* = 5.71) for the control children; this difference was also not statistically significant. Thus, McLaughlin did not find evidence for an exaggerated Simon effect in children with ADHD – although a researcher might expect it, given the difficulties that children with ADHD have with interference control and the role that filtering plays in that control.

The Flanker Task

The metaphor of a spotlight or zoom lens for attentional gaze (as introduced in Chapter 2) is central to any discussion of focused attention. This is because the beam of the spotlight, or the circumscribed view of the camera lens, represents the central area of focus for an observer scanning his or her visual field (D'Aloisio & Klein, 1990). The area of focus, at least for adults, can range from a point locus to dispersion across a whole perceptual field (Kinsbourne, 1980). Children are not as efficient as adults in their abilities for selectively focusing on visual information. For example, young children have repeatedly been shown to have more difficulty than older children and adults in restricting their attention to experimenter-defined aspects of a visual display. The attention component of focusing – and the component of filtering that naturally occurs with it - are thus understood as developmental phenomena (e.g., Enns, 1993; Enns & Akhtar, 1989). The flanker task is an optimal tool for studying these functions. Some flanker tasks, such as the one used in this project, employ several target-to-flanker distances. Generally, adults demonstrate reduced flanker interference effects with larger distances (Eriksen & Eriksen, 1974; also, see review by Miller, 1991). This variation of the task shows particular promise for revealing children's abilities for interference control.

Jonkman et al. (1999) used the flanker task to study perceptual versus response interference in children's attention to simple stimuli. Jonkman et al. administered the flanker task to 14 children with ADHD (unmedicated for their symptoms) and 14 control children, all in the age range of 7- through 13-years-old. They used four trial types: (1) target-alone, (2) target plus compatible flankers, (3) target plus incompatible flankers, and (4) target plus neutral flankers.[5] Jonkman et al. showed that, relative to other trial types, participants were slowest on incompatible trials and fastest on target-alone trials. Overall, the individuals in the ADHD group were not slower or faster than those in the control group in responding to the targets, nor was the interference in response speed due to S-S or S-R incompatibility (i.e., the flanker interference effects[6]) exaggerated for the ADHD group on either the neutral or incompatible trials.

All children on Jonkman et al.'s (1999) flanker task made more errors on incompatible trials relative to the three other trial types (target-alone, compatible, and neutral). Here, in the case of overall target accuracy, the children with ADHD showed worse performance than the controls. Furthermore, the error difference between incompatible and neutral trials was greater for the children with ADHD relative to the control children. The error difference between target-alone and neutral trials was, however, equivalent for the two participant groups. Thus, a group effect in interference control was evident only in the accuracy data and only for S-R incompatibility. Given the group difference, Jonkman et al. concluded that there was some evidence for children with ADHD to have a deficit in response preparation processes.

Further to the results of Jonkman et al. (1999), McLaughlin (2003) showed children (including, as stated in the discussion of her Simon task results in the previous

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[5] The terms congruent and incongruent are common alternatives to the terms compatible and incompatible (respectively) and were used by Jonkman et al. (1999) in their study.

[6] Just as flankers interfere with performance on incompatible trials, they facilitate performance on compatible trials. The converse of the flanker interference effect is thus termed the flanker compatibility effect (FCE; e.g., Eriksen & Eriksen, 1974; also, see review by Miller, 1991). The latter terminology (i.e., FCE) is used to discuss the results of the current project.

subsection, 16 unmedicated children with ADHD and 24 control counterparts) to experience both perceptual and response interference on a version of the flanker task. McLaughlin used four trial types: (1) target-alone, (2) target plus identical flankers, (3) target plus compatible flankers, and (4) target plus incompatible flankers. Flanker interference effects were found in both the reaction time and accuracy data, and did not differ in size across the ADHD and control groups for either of the incompatible S-S or S-R trial types. The reader will note here the discrepancy with Jonkman et al.'s work that demonstrated greater flanker interference in the clinical children's target accuracies than in the control children's accuracies. Regarding general speed and accuracy, McLaughlin showed that the children with ADHD – relative to the controls - were slower to respond but equally accurate in target identification on all trial types.

The Stop-Signal Task

The stop-signal task has benefited from increased popularity in studies of ADHD over the past decade. This is undoubtedly due to the increased attention that has been given to behavioural inhibition as a core deficit in ADHD. The variables of greatest interest on the stop-signal task can be divided into two types. The first type is associated with "go trials" (i.e., trials without a stop signal) and relate to the primary task process of response execution. These variables include the reaction time to targets on the go trials and the variability in the reaction time data over time. The second type of variable is associated with "stop trials" (i.e., trials with a stop signal) and relate to the secondary process of response inhibition. They include the percent of stop trials on which responses are successfully inhibited and – as will be discussed - alternate measures of the efficiency of the inhibitory process (Schachar et al., 1993).

Logan and his colleagues have developed a race model of inhibitory control to explain the behavioural processes that occur on stop trials in participants completing the stop-signal task. The model purports that, on any given stop trial, a response execution (or "go") process is in a race with a response inhibition (or "stop") process. The go process is initiated at target onset and involves stimulus recognition, response choice, response preparation, and response execution. Conversely, the stop process begins with the onset of a stop signal. The process that "wins the race" determines whether or not a response occurs or is successfully inhibited on that trial. The model assumes the task processes to be independent and, thus, affords the stop-signal task much praise for its ability to isolate the process of response inhibition (see review by Schachar et al., 1993).

The efficiency of the response inhibition process as tapped on the stop-signal task has been measured in several ways throughout past research (Carter et al., 2003). For example, some studies have plotted the rate of response inhibition as a function of stop delay (i.e., the inhibition function) and focused on the regression function that best fits the plotted data. Other studies have plotted participants' inhibition rate as a function of standardized scores that reflect the relative "finishing time" of the response execution and inhibition processes. The slope of this *z*RFT (*z* score of relative finishing time) function is then the variable of interest, with flatter lines generally reflecting poorer inhibition. Carter et al. identify limitations of the *z*RFT function and propose the area under the *z*RFT curve as a better measure of inhibitory control because it provides an estimate of the *amount* of a participant's inhibition as opposed to the *rate* at which it changes over a measure of time.

Perhaps the most popular measure of inhibition on stop-signal tasks is not that of inhibition functions but, rather, one that has been proposed by Logan et al. (1997). Logan et al. – and researchers since then - capitalize on the race model of the stop-signal task by using a computer algorithm that actively modifies the length of stop delay during task completion such that participants ultimately inhibit responses on approximately 50% of the stop trials. Using this approach, the stop signal task begins with an initial stop delay (e.g., 250 ms) that is lengthened by a predetermined interval (e.g., 50 ms) each time that a participant successfully inhibits a response and shortens it by the same interval each time response inhibition fails to occur; this iterative process is repeated until the inhibition rate stabilizes at around 50%. At this point, the stop and go processes are "tied" in their competition and participants' average target reaction time on go trials – or "go reaction time" – can be considered equal to the length of the stop delay associated with the 50% inhibition rate *plus* the length of the inhibition process. The length of the inhibition process is thus calculated by the formula [mean go reaction time – mean stop delay] and is said to equal the *stop signal reaction time* (SSRT).

Bedard et al. (2003) administered a modified stop-signal task to 59 clinic-referred children with ADHD and 59 control children from a community sample. Participants were required to discriminate between two auditory signals of different frequency in order to accurately complete the task. Whereas one frequency was to be ignored, the other prompted response inhibition. The task successfully tapped into children's abilities for selective response inhibition and, as is generally the case with the regular stop-signal task, elicited poorer performance from the children with ADHD (while unmedicated for their symptoms) relative to the control children on each of the traditional stop-signal task measures. Bedard et al. thereby demonstrated the robustness of the task to contextual manipulations, especially considering the co-occurring demands that were placed on children's working and short-term memories to remember and compare on a trial-by-trial basis the frequency of the tone that was played with the frequency that signaled the need to inhibit a response.

As did Bedard et al. (2003), Rubia, Oosterlaan, Sergeant, Brandeis, and Leeuwen (1998) modified the stop-signal task in their study of children's response inhibition. Rubia et al. used a simple graphic of an airplane as the target stimulus and an icon of a man holding a stop sign (i.e., the "stop man") as the stop stimulus. Targets appeared to either the left or right of fixation; the primary task was to simply identify the location of the target as either "left" or "right." On 30% of trials, the stop man replaced the graphic of the airplane at a predetermined stop delay. Children were instructed to respond as quickly and as accurately as possible to the primary stimulus but to inhibit responding (as much as possible) on the appearance of the stop signal.

As with Bedard et al. (2003) – and many studies that have used the traditional stop-signal paradigm – Rubia et al. (1998) showed hyperactive children (unmedicated for their symptoms) to be less efficient in their response inhibition and more variable in their go process (i.e., response execution) relative to control children. Rubia et al.'s study is highlighted here because of its successful use of a visual stop signal rather than an auditory tone. Tones are by far the most common stop signals used in related literature but, as done in Rubia et al.'s study, they were replaced with visual stop signals (specifically, white screen displays) in the current project. The robustness of the stop-signal task to contextual manipulations is also highlighted for reasons that will become evident in the hypothesis generation completed in the next chapter.

It is not surprising that much research has focused on the ability of the stop-signal task to discriminate clinical children from each other and from non-affected control children. Oosterlaan, Logan, and Sergeant (1998) completed a meta-analysis of eight studies that used the stop-signal task with clinical versus control children. In total, Oosterlaan et al. (1998) assessed the data from 456 children in the age range of 6- through 12-years-old. Four participant groups were generated: ADHD, Conduct Disorder (CD), ADHD + CD, "anxiety disorders," and controls. Taken together, the data from the eight studies demonstrated consistent and robust evidence for a response inhibition deficit in children with ADHD (unmedicated for their symptoms). For example, the authors calculated children with ADHD to take an average of 349.4 ms to inhibit their responses on stop trials. By comparison, control children demonstrated a mean SSRT of 246.4 ms. The difference of 103 ms represented a medium effect size (Cohen's $d = 0.64$).

Oosterlaan et al.'s (1998) meta-analysis was not able to distinguish children with ADHD from those with CD, nor from those with ADHD + CD. Surprisingly, the children with anxiety disorders were not shown to have deficits in response inhibition. The field of research on the stop-signal task is not without inconsistencies in findings, however. For example, Schachar, Mota, Logan, Tannock, and Klim (2000) later used the stop-signal task in children aged 7- through 12-years-old and were able to successfully demonstrate greater impairments in inhibitory control in children with ADHD relative to control children, children with CD, and children with ADHD + CD. The authors do not indicate the medication status of the clinical children.

The Blink Task

Many models have been proposed to explain the occurrence of the attentional blink; each can generally be classified as belonging to either an interference class or a "bottleneck" class (McLaughlin, Shore, & Klein, 2001). Models belonging to the former class suggest that the cognitive processing of a first target in an RSVP stimulus stream interrupts the processing of a second target in the stream. Conversely, models belonging to the latter class propose that initial targets in RSVP streams surpass a threshold that affords them attentional resources which, by virtue of a capacity limit, cannot be afforded to later targets (in other words, the later targets get "stuck" in a cognitive "bottleneck").

Despite differences in the mechanisms proposed for the attentional blink, all models involve the concept of limited resources. In essence, the assignment of attention resources to the first target in an RSVP stream means few, if any, resources remain for the second target in the stream. The blink therefore occurs, and its magnitude can be said to vary inversely with the quantity of attention resources (or, encoding capacity) that a participant has for rapidly presented visually patterned stimuli. Similarly, a participant's ability to identify T2 | T1 can be said to relate directly to his/her encoding capacity wherein an impressive ability to identify T2 | T1 reflects a large encoding capacity, or encoding limit. The blink, as traditionally elicited in RSVP research, generally begins within 200 ms after presentation of the first target and lasts for 500 to 700 milliseconds in healthy children and adults (e.g., Chun & Potter, 1995; Hollingsworth, McAuliffe, & Knowlton, 2001; Li, Lin, Chang, & Hung, 2004; Shapiro, 1994; Shapiro, Raymond, & Arnell, 1994).

The author knows of only two published studies that have compared performance on an RSVP task by participants with ADHD relative to participants without ADHD. The first was completed by Hollingsworth, McAuliffe, and Knowlton (2001) and involved the administration of an RSVP paradigm to 12 adults with ADHD (for which medication status was not reported) and 16 age- and education-matched controls. Their RSVP stream included black letters as distracters, one blue target letter (T1), and the (black) letter Z as a probe. Participants were asked to identify T1 and note the presence or absence of the probe in one of seven serial positions (T1+2 through T1+8) following the target. The single-task baseline (or control) condition required participants to ignore T1 and focus only on detecting the probe. Hollingsworth et al.'s (2001) data showed that the adults with ADHD were significantly worse than the controls on the baseline probe detection task, although the sensitivity difference between the groups was notably small. The ADHD group was also significantly worse than the control group on T1 identification in the dual-task condition, although their T1 performance was still much better than would be predicted by chance and a blink was demonstrated. No blink recovery was observed for the adults with ADHD throughout the entire 720 ms post-target interval. By contrast, the control participants showed the typical effect of probe position on probe detection wherein the latter was increasingly accurate in later probe positions.

In a second experiment, Hollingsworth et al. (2001) randomly assigned the probe to only the T1+1 through T1+4 positions. Results showed no difference in the groups' performance levels on the baseline probe detection task. On the target-then-probe detection task, both groups detected significantly more probes in the first post-target position relative to the other positions. Because their performance on the earliest post-target position was similar to that for controls, Hollingsworth et al. concluded that the adults with ADHD did not have a global deficit on the blink task but, instead, were only impaired in their ability to direct controlled attention to late probes. Hollingsworth et al. further concluded that attention to probes immediately following targets was automatic because - in this instance of a probe in the T1+1 position - the target and probe were analyzed as one unit. Thus, according to the authors, both the ADHD and control participant groups demonstrated intact automatic attention for the blue target whereas only the control group demonstrated intact controlled attention for the subsequent probes.

Li et al. (2004) followed up, using a child population, on the work completed by Hollingsworth et al. (2001). Li et al.'s key manipulation was the illumination of the target in their target-probe RSVP paradigm, with the underlying assumption that an illuminated target would attract automatic attention more strongly than a non-illuminated target. Li et al. administered their RSVP task to 43 children with ADHD (unmedicated for their symptoms) and 40 age- and education-matched healthy controls. On each trial of their task, the target (one of six Arabic numerals) was preceded by seven to 15 distracters, and followed by six distracters. The distracters were 34 Chinese phonological characters. The probe was a separate character similar to the English X.

Both groups of children exhibited an attentional blink in Li et al.'s (2004) study. The blink on both task versions (illuminated and non-illuminated) for both ADHD and control groups was equivalent in magnitude for the first two post-target positions and significantly greater in magnitude for the ADHD group relative to the control group at later lags (300 ms through 500 ms on the illuminated version, 300 ms through 600 ms on the non-illuminated version). Both groups appeared to recover from the blink by 600 ms post-target, although recovery was more evident for the control group. Given the equivalent group performance on probe detection for early post-target positions in both conditions, Li et al. concluded that Hollingsworth et al.'s (2001) account of the blink deficit in adults with ADHD did not apply to children with the disorder. Li et al. speculated that a slower closing of an "attention gate" mediated the impairment shown by children with ADHD on the RSVP task relative to controls.

The blink task in the current study did not use the RSVP format that has become standard in the field. Rather than the traditional visual stream of targets and distracters, the blink task in this study employed a "target, mask, target, mask" (TM-TM) paradigm. As its name suggests, the TM–TM paradigm involves the presentation of a target (T1), followed by a mask, and, then, subsequent to a lag of variable length, a second target (T2) and a second mask. The masks play the role of the distracters in the RSVP stream. As with the target-probe RSVP paradigm, an attentional blink is evidenced in the TM-TM paradigm by the reduced accuracy of T2 identification on the subset of trials for which T1 is correctly identified.

The TM-TM paradigm was adopted from McLaughlin, Shore, and Klein (McLaughlin, Shore, & Klein, 2001; Shore, McLaughlin, & Klein, 2001) and was shown by these authors to produce a blink in adults very similar in magnitude to that produced by a traditional RSVP task variant. McLaughlin et al. developed the new paradigm to investigate the relation between T1 difficulty and the ensuing blink without inheriting the confounding features of the prototypical RSVP task. Most notably, the TM-TM paradigm eliminates the task, set and location switching that is often used in RSVP paradigms. For example, the studies just outlined employed a task switch from stimulus identification to stimulus detection. Presumably, a portion of attention resources must be devoted to the task switch and is thereby taken from the processing of T2. By eliminating this confound, the TM-TM paradigm assures that all available attention resources are devoted to target identification. Secondly, the TM-TM paradigm eliminates the variation in resource allocation that can occur in RSVP paradigms when different levels of T1 difficulty are assigned to different test blocks or even participants. The TM-TM paradigm keeps resource allocation at its maximum for all participants (at least in McLaughlin et al.) by mixing T1s of varying levels of difficulty within each task block; the unpredictability presumably keeps resources at a maximal level for all T1 processing. Task difficulty is manipulated through changes in the target and mask durations, whilst the total duration of each TM pair is kept constant.

To conclude, the current author believes that the TM-TM paradigm is a "cleaner" task than the RSVP paradigm for studying the attentional blink. Although to date no known study has used the TM-TM paradigm in children, perhaps this project marks the beginning of a shift in the field. On the premise that blink magnitude data from adults on an RSVP paradigm was highly correlated with the same type of data from a TM-TM paradigm, it is assumed that – because RSVP paradigms have been successfully used with children in past research – the TM-TM paradigm should similarly elicit an attentional blink from children.

The CPT

A shift has occurred relatively recently in CPT research from the use of omission and commission error rates as the primary variables of interest to constructs within signal detection theory (SDT) such as hits, misses, false alarms, and correct rejections. The particular value of SDT application to CPT research has been the opportunity to generate independent measures of, first, a participant's ability for discriminating target events from non-target events and, second, a participant's general pattern of responding as liberal or conservative (Corkum & Siegel, 1993). These measures of target sensitivity and response bias, respectively, have nonetheless been subject to criticism. For example, SDT was originally developed for use in perception research as a means to quantify the physical amount of stimulus "signal" required for accurate detection by human observers. The suprathreshold nature of CPT events and the non-amenability of the task design to the use of receiver-operating curves is, according to Koelega (1995), reason for great caution in using SDT phenomena to understand CPT performance. Furthermore, SDT measures are parametric whereas the CPT measures are not (Koelega, 1995).[7]

Just as the measures used to analyze it have varied, so has the CPT itself. Variability has been particularly notable in researchers' choice of target stimuli, event rates, stimuli duration, and length of interstimuli intervals (Corkum & Siegel, 1993). Corkum and Siegel described the CPT as being developed during a time when unitary theories of sustained attention were considered sufficient to explain vigilance task performance. Since that time, much research has brought to light many factors that influence a person's level of vigilance, not the least of which are task parameters such as those just indicated. Nonetheless, many of these factors remain uncontrolled in current studies of attention.

Beyond task parameters, situational variables such as time of day, medication status, and level of ambient noise have all been shown to influence levels of perceptual sensitivity in adults. External variables such as performance feedback, rewards, task instructions, amount of practice, and the presence/absence of an examiner in the testing room have also been shown to influence a person's level of vigilance and, in particular, their

[7] Koelega (1995) does concede that nonparametric alternatives to the SDT measures of d' (sensitivity) and β (response bias) represent improvements in CPT analyses.

response criterion. Furthermore, age (but not sex) has been shown to mediate children's ability for target detection. A major improvement is observed in children's detection abilities at around eight to nine years of age (Corkum & Siegel, 1993). With these many (and more) issues at hand, it is not surprising that research using the CPT is typified by inconsistent findings and points of disagreement regarding its utility as a useful research tool in such clinical groups as children with ADHD (Corkum & Siegel, 1993; Losier, McGrath, & Klein, 1996; Sergeant & van der Meere, 1990). The reader's attention is brought here to the vulnerability of the CPT to contextual manipulations, a topic that will be revisited in hypothesis generation in the next chapter of this manuscript.

Despite its controversy and many limitations – and perhaps because of its intuitive appeal as a measure of sustained attention - the CPT has been described as the most widely used research tool to test for a deficit in sustained attention in children with ADHD (Corkum & Siegel, 1993). Nonetheless, in their review of 13 studies that examined performance differences on the CPT between children with ADHD and their control counterparts, Corkum and Siegel concluded that the CPT was ultimately not a useful research tool for studying ADHD. They came to this conclusion mostly on the basis of the tremendous variability that exists among the versions of the CPT used in research and – very likely related to that – the lack of compelling evidence of a deficit in sustained attention in children with ADHD.

In apparent contrast with Corkum and Siegel's (1993) conclusion is that by Losier and his colleagues (1996). Losier et al. completed a meta-analysis of 26 studies that used the CPT in samples of children with ADHD as compared to samples of control children.[8] Losier et al. acknowledge the existence of contradictory findings among individual reports on ADHD yet were able to generate solid conclusions from the collection of results that they reviewed. Ultimately, Losier et al. determined that the children with

[8] As a result of their exhaustive literature search for studies dated January 1970 through June 1995 that linked the CPT with ADHD, Losier et al. (1996) had a final tally of 259 studies. The vast majority of studies were not included in their meta-analysis on account of their strict exclusionary criteria. The abundance of literature in the field is clear, however.

ADHD in the 26 studies they reviewed made significantly more errors of omission and errors of commission than their corresponding control counterparts. Regarding SDT parameters, Losier et al. showed that the children with ADHD were significantly less sensitive to target occurrences (relative to non-target occurrences) than healthy control children. Conversely, the two populations demonstrated a comparable response bias on the CPT. Generally speaking, however, the sensitivity and specificity of the CPT to ADHD is limited (Corkum & Siegel, 1993; Koelega, 1995; Losier et al., 1996; Sergeant & van der Meere, 1990). Losier et al. separately analyzed the effects of psychostimulant medication on CPT performance; the results indicated here apply most consistently to unmedicated children with ADHD.

Summary & Related Hypotheses

There is a vast difference in the popularity of the Simon, flanker, stop-signal, blink, and continuous performance tasks as measures of attention in cognitive studies of typically developing children and children with ADHD. The stop-signal task and CPT are by far the most popular of these five tasks. This is perhaps not surprising as they are considered to isolate the processes of inhibitory control and sustained attention respectively – two components of attention that have long been considered deficient in persons with the disorder. On the contrary, the Simon, flanker, and blink tasks have barely made a mark in developmental research on attention and ADHD. The obvious bias in the literature thereby makes the generation of hypotheses for this project relatively easy when it comes to the stop-signal and continuous performance tasks but more difficult for the less popular tasks. Nonetheless, the following paragraphs address hypotheses for children's performance on all five tasks as administered in the traditional context of this project.

Relative to the control children, the children with ADHD are expected to demonstrate impaired performance on almost all measures from the stop-signal task and CPT in this project. In particular, the children with ADHD are expected to show poorer inhibition and response execution (in the form of longer and more variable reaction times) on the stop-signal task, and a lower number of hits, higher rate of false alarms, lower level of sensitivity, and longer target reaction times on the CPT. These group effects are also expected to be exaggerated over testing time as the need for sustaining focus is required.

On the basis of two past studies (only one of which was reviewed in this chapter), it appears that the Simon task produces the same S-R compatibility effects in children as it is known to produce in adults. Therefore, it will likely be an effective measure of attentional filtering in the child sample of the current project. The one past study that used the Simon task with an ADHD sample (reviewed herein) demonstrated the typical Simon effect in target reaction times and target accuracies, but did not find a group difference in the magnitude of these effects. The same results are thus expected in this project. Notably, given the lack of previous research, no hypotheses are made regarding children's response to the variable warning intervals preceding most Simon trials.

On the basis of results shown by Jonkman et al. (1999) and McLaughlin (2003), all children are expected to demonstrate flanker interference effects in both their target reaction time and accuracy data on the flanker task in this project. Furthermore, because neither of these studies found a group difference in the degree of flanker interference on the reaction time data, no such group difference is expected in this project. A discrepancy existed in these studies regarding a group by trial type interaction within the accuracy data, however, and, thus, no hypothesis is generated here for that particular effect. Regarding the manipulation of the target-to-flanker distance, the author is not aware of past literature that has directly addressed this issue in children. Given that children do not focus or filter as well as adults, they may not show the reduction in flanker interference effects on the middle- and far-flanker trials as clearly as would be expected for adults.

This chapter included a review of two published studies (one with adults and the other with children) that compared performance on a target-probe RSVP task by participants with ADHD with that from control participants. Both studies demonstrated an attentional blink within their respective participant groups, and showed it to be larger and longer for the participants with ADHD relative to the controls. These findings would thus suggest limits to all children's encoding capacities as they are measured on the blink task in this project and, further to that, a reduced encoding capacity for the children with ADHD. Nonetheless, a difference between these two studies and the current one lies in the nature of the paradigm that was used to elicit attentional blinks. The TM-TM paradigm of the current project is thought to remove the confound of task-switching found in RSVP paradigms. Thus, to the extent that group differences in the past studies are due to task switching, the effects will be reduced in the current project.

Chapter 6. Environmental Manipulation

The phrase *environmental context* can be used to refer to modifiable factors within an environment that can influence a person's thoughts, feelings, and actions, including his or her performance on cognitive and behavioural tasks. One such factor is the level and type of sensory input provided by an environment. A psychology lab, for example, can be enhanced with colourful posters, art displays, and ambient music. A second factor that can be modified is the motivational qualities of the task (or tasks) to be completed within an environment. In this regard, reward contingencies are frequently used in clinical and research settings to pull for optimal task performance from children. Reward contingency programs are especially popular as a means of intervention for children with ADHD. A third aspect of an environment that can be changed – and can thus produce change in a person's task performance - is the nature and/or setting of the tasks themselves. Some research, for example, has addressed children's attention on lab-based tasks versus video games. In this case, the nature of the tasks has generally changed from boring and non-interactive to fun and interactive, and the setting has (often) moved from a controlled lab environment to a naturalistic setting.

Relative to the traditional context, the video game context used in the second experiment of this project incorporated the three types of contextual manipulations outlined in the previous paragraph. Firstly, the video game context included increased sensory input in the form of colourful imagery and music clips. Secondly, it included rewards for task completion. Thirdly, although the tasks were identical in both conditions, their nature was modified by the storyline and goals that were assigned to them in the video game context. Whereas each participant's goal was to finish a specific number of tasks in the traditional condition, it was to complete a virtual journey throughout several lands of a fictional world in the video game condition. Goal progress could be monitored by point tallies displayed on the bottom of the computer screen. The remainder of this chapter will include an overview of select studies relevant to each of these three factors. The studies are organized according to whether or not they demonstrated performance enhancement in children as a result of their contextual manipulations.[9]

Level and Type of Sensory Input

Enhancement of task performance

The crux of Zentall's (1975) underarousal theory of ADHD regards the level and type of sensory input in everyday environments and its general inadequacy for hyperactive children. In line with his theory, Zentall and various colleagues (e.g., Zentall, 1986; Zentall & Zentall, 1976) have shown that making an environment more exciting and interesting is an effective method of intervention for hyperactivity. For example, by enhancing an ordinary square room with visual and auditory stimuli, Zentall and Zentall effectively reduced motor activity among 16 hyperactive children (aged 7 through 11 years) while each sat alone in the room for ten minutes and then completed a letter-circling task. Room enhancements included (in part) brightly coloured pictures, a cage with mice, flashing Christmas lights, and rock music. Although the children's motor activity during both portions of the experiment was lower in the high-stimulation condition relative to the low-stimulation condition, actual performance on the letter-copying task was equivalent in the two conditions.

On the basis of research published since his 1976 paper, Zentall (1986) reasoned that nonspecific intratask stimulation (such as colour) would be overwhelming to all children on new tasks, especially tasks that required multiple cue analysis and especially for children that are young, have learning problems, and/or no prior task practice. Thus, Zentall (1986) compared children's activity levels and performance on an easy task with

[9] An important caveat to this literature review – and the whole premise of this project - is the assumption that the environmental "enhancements" being discussed (e.g., colour, cartoon characters, small prizes) are indeed desirable stimuli for children. In turn, these stimuli are assumed to elicit an increase in children's physiological arousal and possibly their level of motivation for completing various tasks. This assumption is supported by research using a speeded reaction-time task (De Brabander, Declerck, & Boone, 2002) and a theory that links neuropsychology with neurophysiology (Ashton, 2002).

that on a complex task in each of three contexts: (1) using all black and white stimuli, (2) using black and white stimuli on early trials and colour stimuli on late trials (by which point the hard task should be learned), and (3) using colour stimuli on early trials versus black and white stimuli on late trials. Zentall (1986) labeled these contexts *low stimulation*, *delayed-high stimulation*, and *early-high stimulation* respectively. He used the CPT as an easy task and a concept identification task (similar to the WCST) as the harder task.

Participants in Zentall's (1986) study included 66 hyperactive and 80 control children; the medication status of the former group was not reported. The data confirmed most hypotheses. The hyperactive children were more active overall than the control children on both tasks but were less active in the delayed-high stimulation condition relative to the low and early-high conditions. Although expected, a similar condition effect was not found for the control group on either task. The hyperactive children made more errors on the CPT relative to the control children and especially so in the low stimulation condition relative to both high stimulation conditions. A condition effect was not found with the more difficult concept task, however, probably due to its complexity and corresponding floor effect. Given the findings with the CPT, Zentall (1986) concluded that hyperactive children derive greater gains than typically developing children from stimulation that is added to boring tasks; he argued this to be the case because, according to his view, hyperactive children are inherently less tolerant of low levels of stimulation. Zentall (1986) suggested that adding stimulation to rote tasks could be a mechanism for sustaining the attention of hyperactive children.

Zentall's (1986) colour study is noteworthy for its identification of a mediator (i.e., task complexity) in the relationship between environmental stimulation and children's performance on tasks of attention. Lee (1999) identified a similar caveat in his PhD dissertation, completed under the supervision of Dr. Sydney Zentall. In particular, Lee challenged the assumption that generally pleasant stimulation always reinforces children's performance on simple cognitive tasks. He completed two studies, with the respective goals of determining the reinforcement value of colour stimulation on a simple math task and establishing the limits of the reinforcement in the presence of competing stimulation. The same 17 children (16 boys) with the combined subtype of ADHD (as defined in the DSM-IV) completed the two studies; notably, 14 of these children were on psychostimulant medication during completion of each study.

Lee's (1999) first experiment included a low- and a high-stimulation condition. The background of the monitor screen (on which math problems were displayed) was all grey in the former condition and a variable array of colours in the latter condition. Additionally, transitions between screen displays were graphically enhanced in the high-stimulation condition. In his second study, Lee re-administered the high-stimulation math task but used two new conditions. In both new conditions, a second computer monitor was placed next to the task monitor. In the *low-competing-stimulation condition*, the second monitor screen was consistently grey. In the alternate *high-competing-stimulation condition*, the screen showed a continuous array of cartoons.

As hypothesized, Lee's (1999) results indicated that within-task stimulation in the form of colour and colour movement increased children's productivity on a simple math task. Not surprisingly, however, Lee found the reinforcement potential of colour to be limited by the attractiveness of the surrounding (i.e., "competing") cartoon stimulation. Although appealing, Lee's results must be interpreted with caution. Study limitations include the lack of a control group, the imbalance in medication status of the sample, and the failure to account for possible speed-accuracy trade-offs in task completion. Nonetheless, Lee's work was reviewed here because the impetus for the study is especially relevant to the current project and his general finding that competing stimulation limits the benefits of visually enhanced task materials carries intuitive appeal.

No Enhancement of Task Performance

As with Zentall (1975) and Lee (1999), Higginbotham and Bartling (1993) were interested in the effects of environmental stimulation on children's cognitive task performance. Notably, they extended this line of work into the classroom and used undesirable (rather than appealing) stimuli. Zentall's (1975) underarousal theory would implicate task interference in this scenario of distractions. Intuitively, it also makes sense that distractions would impede rather than facilitate cognitive performance. Eleven children with ADHD (according to DSM-III-R criteria and all medicated for their symptoms) and eight control children were administered a standard memory test that measured short-term recall of increasingly complex sentences. The participants, boys and girls in the third- and fourth- grades, were tested in each of four distracter conditions: (1) no distraction, (2) auditory distraction alone, (3) visual distraction alone, and (4) combined auditory and visual distractions.

Examples of distractions in Higginbothan and Bartling's (1993) study included an adult dropping a book outside of the testing room, an adult walking across the classroom and then leaving it, and an adult entering the room, sorting through papers within view and earshot of the child and then leaving the room. Not surprisingly – given fatigue and increasing complexity of the task over time - both groups of children showed a decrement in performance from the beginning to the middle to the end of the task. More interesting, however, was the finding that the decrement in performance directly attributable to the added stimulation (i.e., sensory distraction) was minimal. At least in some instances, then, additional stimuli in an environment do not significantly impact a person's level of cognitive task performance. Notable limitations of this study include the small sample size and mixed medication status within the ADHD group.

Although the video game literature on ADHD is most relevant to the discussion on task manipulations provided later in this chapter, a study by Tannock and her colleagues is more relevant to this discussion on variations in stimuli and their effect on children's behaviour. In the 1990s, Tannock (1997) completed a series of video game experiments with 8- through 12-year-old children.[10] Half of the children in each of their participant

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[10] Different pieces of this research (discussed here and later in this chapter) were initially presented at conferences in 1992, 1993, and 1995. Authors (in alphabetical order) include M. Barman, E. Benedetto, C. Kim, O. Pomerantz, R. Schachar, J. Shapiro, R. Tannock, and R. Urman. The source for this material was a summary provided by Tannock (1997).

pools were diagnosed with ADHD whereas half were typically developing children. The goal of their research was to examine the popular belief that playing video games can significantly reduce (or even eliminate) the symptoms of ADHD. One of their studies presented a variation in the level and type of stimulation across two video games. They asked all participants to play two video games that differed in level of intrinsic appeal and complexity. Within each game, participants played two levels that differed in cognitive demand.

Results from Tannock's (1997) two-game study indicated that the children with ADHD were more inattentive, restless, and talkative than their control counterparts on both games; medication-free status is not reported but strongly implied for the former group. The children with ADHD also completed fewer game levels and had to restart more games than the control children. This appeared to be due to poorer response inhibition while manipulating characters past obstacles and hazards. Although the ADHD group generally fared worse than the control group, the data did not show a differential effect of game complexity on the observable behaviour of the two participant groups. All children were more restless and talkative on the more appealing but more challenging of the two video games. All children were also more restless, inattentive, and talkative on the more difficult levels of both games. Thus, this research shows that the fast-moving, colourful stimuli, and quick responses associated with video games can sometimes overwhelm children's abilities to focus, maintain alertness, and inhibit impulsive behaviour.

Reward Contingencies

Enhancement of Task Performance

Barber, Milich, and Welsh (1996) studied the use of money as an incentive for children to perform well on a memory task. Participants included 45 boys with ADHD (using DSM-III-R criteria), unmedicated for their symptoms, and 45 control boys. All children were 7- through 10-years-old and received either no, partial (50% trials), or continuous (100% trials) rewards on a word-pair memory task. The words in each pair were related on one memory task and unrelated on the second task. Each boy was given feedback regarding the accuracy of his response on each and every trial of both tasks in all three conditions. Results indicated that all boys were adversely affected by the partial reinforcement schedule in the easier, related-word task and all showed optimal performance by continuous reinforcement in the harder, unrelated-word task. Although the authors' main conclusion regarded the effect of reinforcement schedules on children with ADHD, the value of this study for the purposes of this project lies in its evidence that continuous reinforcement (as was used in the videogame context of this project) enhanced children's performance on a cognitive test relative to less frequent reinforcement. Notably, the test was one of short-term memory and not attention per se. Nonetheless, stimulus registration on memory tests place demands on working memory - as do all tasks in the current project (especially the blink task).

Whereas Barber et al. (1996) investigated a construct not directly tested in this project, a study by Stevens et al. (2002) used reward contingencies in an attempt to influence children's response inhibition on the stop-signal task. They administered the stop-signal task to 152 children (half of whom had ADHD and were not medicated for their symptoms, and half of whom were controls) with ages ranging from 7- through 12-years-old. Each child was offered a monetary incentive for each correct response on both go and stop trials. Relative to the control children, the children with ADHD inhibited responses on fewer stop trials, demonstrated a longer response inhibition process, and were more variable in their target reaction times. Notably, however, all children demonstrated a shorter SSRT in the reinforced condition than in the non-reinforced condition. All children also demonstrated a higher rate of response inhibition and decreased variability in target reaction times when their performance was reinforced relative to when it was not. As with Barber et al. (1996), Stevens et al. (2002) did not find the reinforcement to differentially influence performance in the participant groups.

No Enhancement of Task Performance

Similar to Stevens et al. (2002), Oosterlaan and Sergeant (1998) used reward contingencies in an attempt to influence children's response inhibition on the stop-signal task. The participants ($n = 63$) were boys and girls aged 7 through 13 years; each was assigned to a group (ADHD, anxious, disruptive, or control) on the basis of questionnaire ratings. Reward and response-cost conditions were completed one day apart in a counterbalanced order across the four participant groups. Points (worth small prizes such as posters, toys, and baseball caps) were earned for correct responses in the reward condition and lost for incorrect responses in the response-cost condition. The data showed the children with ADHD to inhibit responses on a smaller percentage of stop trials and experience a longer SSRT relative to the control children in both conditions; the children with ADHD were not on medication for their symptoms. The reward conditions did not differentially influence either group's rate of response inhibition or SSRT. Thus, the authors did not find any evidence that positive relative to negative reinforcement was any more or less effective in improving children's response inhibition. It is difficult to directly compare these results with those from Stevens et al. (2002) because Oosterlaan and Sergeant (1998) did not use a condition with no reinforcement. Thus, it remains plausible that reward – *relative to non-reward* – can enhance performance on the stop-signal task for all children.

Mixed Effects on Task Performance

Douglas and Parry (1994) studied the influence that reinforcement had on children's reaction time and level of frustration during a chance-based task. Participants were elementary-school-aged (mostly boys) and included 30 children with ADD-H (by DSM-III criteria) as well as 30 control children. The medication status of the former group was not reported by the authors. The children were asked to toss pennies using a lever-operated apparatus. The time the children took to raise their hands from a platform to the lever at the onset of a light was taken as a measure of reaction time whereas the time taken to pull the lever through its full arc was taken as a measure of frustration (whereby faster lever pulls were thought to reflect greater frustration). The children earned marbles on a predetermined selection of trials (30%, 50%, or 100%), although were led to believe that the marbles were linked to the results of the actual coin tosses (i.e., heads or tails). The marbles were traded for money at the end of the task.

Somewhat surprisingly, the reinforcement schedules did not have a main effect on the clinical children's reaction times in Douglas and Parry's (1994) study. They showed an interaction with participant groups, however. The partial schedule facilitated faster performance for the control children and increased frustration among the clinical children (as evidenced by stronger lever pulls relative to control children on the early rewarded trials and late extinction trials in that condition). The children with ADD-H were also more frustrated than the control counterparts throughout extinction trials in the 100% reward condition. No group differences were found on the measure of frustration in the 50% condition. Given the increased frustration, Douglas and Parry concluded that children with ADD-H have an abnormally strong reaction to the loss of anticipated rewards.

As with the study by Barber et al. (1996), the key manipulation in Douglas and Parry's (1994) study regarded a reinforcement schedule. It is relevant (albeit indirectly) to the current project that the studies drew two different conclusions regarding partial reinforcement according to the cognitive/behaviour function studied. The conclusions demonstrate a detrimental effect of partial reinforcement on short-term memory in children with ADHD as well as control children. Conversely, partial reinforcement had a detrimental effect on motor control in children with ADHD but a facilitatory effect on motor speed in control children. It thus is reasonable, as suggested in the first chapter of this project, to propose differential effects of reinforcement on the different components of attention and across the two participant groups in this project. This conclusion must be interpreted with caution, however, as it was based on partial reinforcement (whereas continuous reinforcement is used in the current project) and the study did not include a no-reinforcement condition to allow for corresponding predictions.

Nature and Setting of Task

Enhancement of Task Performance

Video games offer a world of opportunities to researchers interested in childhood behaviour and cognition. Given their intuitive appeal and popularity, it is not surprising that they resurface in this discussion regarding environmental contexts and the potential for such contexts to enhance children's attentional capabilities. Accordingly, one of Tannock's (1997) video game experiments was presented earlier as a study on sensory input. In addition to being a mechanism for change in the level and type of sensory input experienced by a child, video games can be viewed as one of many possible media with which a child can interact (both physically and cognitively). Thus, just as video games introduce rapidly changing colourful stimuli and sound effects to a child's environment, they represent a change in the nature and setting of the task being completed in an environment. Tannock (1997) studied exactly the effects that alternate settings/tasks have on children's observable behaviours.

Tannock (1997) measured the behaviour and performance of children with and without ADHD in each of three settings: playing a video game, watching a cartoon, and completing a reaction-time lab task. The (unmedicated) children with ADHD were shown to be more restless, off-task, and talkative in all three settings relative to the control children. They were also slower and more variable in their responses on the reaction-time task and worse in their performance on the video game. Nonetheless, all children were much less restless and more visually attentive in the video game and cartoon settings than in the lab setting and, despite their higher level of off-task behaviour, the children with ADHD were still able to catch the theme of the cartoon. In a third study, Tannock (1997) showed stimulant medication (relative to placebo) to positively influence the observable behaviour of children with ADHD during video game play. The stimulant medication did not have a significant effect on game performance, however.

Video game research is not restricted to child populations. Koepp et al. (1998) completed PET scans of eight adult males in the age range of 36- through 46-years-old. Each male underwent two PET scans: one while playing a video game and one under a baseline condition of watching a blank screen. Binding of raclopride to dopamine receptors was assessed in the ventral and dorsal striata and compared to a control region of interest in the cerebellum. The data showed a significant reduction in raclopride binding in the striata during the video game play as compared to the baseline condition, suggesting increased neurotransmission of dopamine during video game play (because, presumably, more dopamine is occupying its receptors and therefore reducing opportunities for raclopride binding). The reduction in binding correlated positively with task performance and was most noticeable in the left ventral striatum. Koepp et al. interpreted their data as providing support for the proposed link between neurotransmission of extracellular dopamine and sensorimotor functions that are related to rewarding and aversive stimuli.

Although shown with adults rather than children, Koepp et al.'s (1998) indication of increased striatal dopamine as a function of video game playing is especially relevant to the current project when one considers the huge role that dopamine plays in the modulation of attention (see Chapter 3). Furthermore, as has only been hypothesized in childhood ADHD, past SPECT findings have successfully implicated reduced levels of striatal dopamine in unmedicated adults with ADHD relative to control adults (e.g., Dougherty et al., 1999; Krause, Dresel, Krause, Kung, & Tatsch, 2000). These dopamine levels have been shown to increase (to the extent that available dopamine transporters were reduced) as a direct result of stimulant medication (Krause et al., 2000).

Mixed Effects on Task Performance

Lawrence and her colleagues (2002) completed a study, the first of its kind in ADHD literature, that compared children's executive functioning on two video games with that shown in another natural setting event – walking through a zoo. Participants included 57 boys with ADHD according to DSM-IV criteria and unmedicated for their symptoms, including 20 with the predominantly inattentive subtype and 37 with the combined subtype,[11] as well as a control sample of 57 healthy boys. Participants ranged in age from 6- through 12-years-old. All participants played both video games and walked two routes

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[11] Notably, Lawrence et al. (2002) showed no performance differences between the two subtypes of children with ADHD on any of their video game or zoo measures.

in the zoo. The two zoo routes varied in complexity, with the more complex route covering more ground and requiring each child to look for more targets. The video games included a target shooting game and an adventure game, the latter of which required the navigation of a cartoon character past hazards and obstacles along a jungle path. Four game conditions were used, as defined by memory load (high/low) and distractibility (high/low). The high distractibility condition included a popular cartoon show playing on a monitor adjacent to the video game.

Given the mapping of their measures onto Barkley's (1997a, 1997b) hybrid model of executive functions, it is somewhat surprising that Lawrence et al. (2002) did not show deficiencies for the ADHD group on all measures. For example, both participant groups were equally accurate in their target shooting on the target video game. The groups were also equivalent on the measures of behavioural inhibition, nonverbal working memory, and reconstitution (in one of two cases) on the adventure video game. On the zoo tasks, the groups were equivalent on measures of working memory. Lawrence et al. (2002) reasoned that an inhibition deficit was not observed for the ADHD group on the video games because, unlike the lab tasks, the video games provided immediate and continuous visual feedback, auditory feedback, and reinforcement to players. Furthermore, although both the video games and the lab tasks required speeded responses, the video games allowed self-pacing but lab tasks did not.

Despite equivalencies on some measures, the children with ADHD did evidence deficits in several areas of functioning on both the video game and zoo tasks relative to the control children. For example, the children with ADHD demonstrated poorer verbal working memory and motor control/fluency on the adventure video game. Furthermore, they engaged in more task-related self-talk in the low (but not the high) distractibility condition of the same game. On the zoo component of the study, all children made more deviations from the zoo path, asked for more reminders of task directions both verbally and nonverbally, and took more time on the complex route relative to the simple route. The increase in path deviations and completion time on the complex route relative to the simple route was exaggerated for the ADHD group relative to the control group, indicating deficits in inhibition and motor control/fluency.

Lawrence and her colleagues (2004) extended their video game and zoo work by administering the Stroop task and the WCST to a subset of the participants from their 2002 study and then comparing measures of processing speed and executive function from the "real-world" tasks with those from the lab tasks. The findings indicated executive function deficits on the WCST and adventure video game in addition to processing speed deficits on the Stroop task, WCST, and zoo routes for the children with ADHD. Additionally, the study demonstrated several positive correlations between the performance variables on each of the real-life and lab tasks. The authors made two overall conclusions: first, boys with ADHD have deficits in executive function and processing speed on lab tasks *and* on real-world activities and, second, some aspects of performance on neuropsychological tasks are related to real-world performance. All together, Lawrence and her colleagues (2002, 2004) have detailed an impressive array of evidence from naturally occurring activities that children with ADHD, relative to themselves and relative to control children, *do not always* reap marked benefits in attentional and behavioural functioning in exciting contexts.

Summary & Related Hypotheses

The context of a person's environment can be modified in at least three ways. The level and/or type of stimulation can be changed, rewards can be introduced for specific behaviour, and tasks within the environment can be given "consumer appeal" and/or moved from the psychology lab to a more natural setting. Relative to the traditional attention battery used in this project, the video game battery incorporated changes in each of these areas. The findings from the many studies reviewed in this chapter can therefore be used to hypothesize contextual effects on the attention components of encoding, focusing, filtering, and interference control as they are investigated in this project.

Zentall's (1976) room study, Zentall and Zentall's (1986) colour study, and Lee's (1999) math study all indicate that the mere presence of desirable stimulation can elicit greater motor control and alertness from children with ADHD. The extent to which this can be done, however, is limited by the degree of task complexity and the amount of competing stimulation in the surrounding environment. The benefits of the desirable stimulation also appear to be restricted to gross body movements and simple cognitive functions such as single-digit mental arithmetic and the target detection demands on the CPT. Given this research, it is likely that the children with ADHD in this project will demonstrate greater motor control while completing the video game attention battery relative to the traditional battery – at least initially when the colourful computer screens, background music, and rewards display are most novel, at least during completion of the easiest tasks, and at least to the extent that the video game features do not detract children's attention from the task displays. The hypothesized improvement in motor control will likely be on too large of a scale to manifest as shorter reaction times or reduced variability in reaction times on the speeded tasks. Reduced error rates in the form of increased hit rates and fewer false alarms should be detectable, however, on the CPT as shown by Zentall and Zentall (1986) in their colour study.

Together, the findings from the reward-based studies that were reviewed in this chapter suggest that whether or not rewards appear to facilitate children's performance on lab tasks depends on the construct being tested, the frequency of the reinforcement, and the baseline condition (e.g., no reward or response cost) to which it is compared. Rewards seem most likely to facilitate task performance if provided on a continuous schedule and if performance is compared to the same situation with no rewards. They are also more likely to enhance short-term memory and response inhibition on skill-based tasks relative to motor speed/control on a chance-based task. As will be detailed in the methods of this project, virtual coins were awarded to the child participants on regular intervals in the video game version of the attention battery that was administered. The baseline condition (i.e., the traditional attention battery) offered neither rewards nor response costs. Thus, relatively speaking, the children studied herein can be expected to benefit in some ways from the virtual coins and their worth in prizes.

The reinforcement effects are likely to be strongest on the measures of response inhibition and may be evident on the measures that place demands on working memory (a function closely related to short-term memory). No group effects were shown for the reinforcement conditions on the memory or response inhibition studies. Group effects were shown, however, on the chance-based coin-tossing task. They were also shown for the stimulation associated with the target-shooting video game and some measures from the adventure video game and zoo route used by Lawrence et al. (2002). The group effects always favoured the ADHD group over the control group to the extent that the former performed as well as the latter despite an expected deficit or demonstrated an improvement (greater than that found for the control group) in the reinforced condition relative to the non-reinforced condition. Because no group differences were shown in the past studies for response inhibition specifically, and because the coin rewards are expected to benefit only that component of attention, differential reinforcement effects for the two groups are not expected in this project.

Beyond enhanced stimulation and the inclusion of rewards, a third manipulation in the video game context in this project reflected a shift in task nature from "plain" to video-game-like. Of the studies reviewed herein, only one demonstrated a direct benefit of a video game format on both children with ADHD *and* control children. Specifically, restlessness, inattention, and talking were reduced in all children on a video game relative to a traditional reaction-time lab task in a study by Tannock (1997). These gains were easily observable and thus the results map onto the research reviewed earlier (wherein more general environmental enhancement improved large-scale motor control). Furthermore, although children with ADHD can generally perform as well as controls on simple video games with low working memory demands (such as Lawrence et al.'s (2002) target shooting game), their executive control appears to be compromised when tasks (even fun ones) become increasingly complex and require certain goals, rules, and/or instructions to be kept in mind throughout task completion. This was clearly demonstrated in Tannock (1997) two-game study and by Lawrence et al.'s (2002) adventure video game and complex zoo route. These findings agree with Lee's (1999) conclusion that competing stimulation, when too high, leads to a compromise in cognitive functioning.

Herein lies a conflict in expectations for this project. On one hand, the enhanced environmental stimulation in the video game context in this project is expected to improve children's focusing and response inhibition on the CPT (in the form of increased hit rates and fewer false alarms, respectively). Similarly, the coin rewards are expected to increase response inhibition on the stop-signal task and possibly encoding capacity limits on the blink task. On the other hand, the demands for working memory in tracking the storyline and goal progress may overwhelm all children's capacities for improved cognitive functioning relative to the traditional context. The likely result will be a balance whereby improvement in the video game, relative to the traditional, context will be on the measures that are most robust to task manipulation and peripheral interference. Given the robustness of effects shown on the stop-signal task – but not the CPT – to contextual manipulations (see Chapter 5), the measures from the former but not the latter are most likely to demonstrate clear benefit from the collection of manipulations employed in the video game context of the current project.

Chapter 7. Hypotheses Overview and Task Reliability

Hypotheses Overview

The literature reviewed in this manuscript has addressed, in part, the etiological and theoretical underpinnings of ADHD. Within these two bodies of literature lies common ground for the hypotheses that have been indicated for this project. For example, the etiology of ADHD – at least to the extent that it has been linked to abnormal brain structure and function – implicates dysfunction in the frontal lobes and striata with underlying dysregulation of one or more of the catecholaminergic systems. The frontal lobes, striata, and catecholamines (most notably dopamine) are most strongly associated with arousal, behavioural inhibition, and working memory (see Chapter 4 for related references). Not surprisingly, these exact functions are among the most common processes that are identified as impaired in models and theories of ADHD. For example, impaired self-regulation of arousal and impaired behavioural inhibition are at the crux of Douglas' (1983, 1988, 2005) model of ADHD. Similarly, working memory and behavioural inhibition are disrupted in ADHD according to Barkley's (1997a, 1997b) theory of the disorder. Thus, within this project, the children with ADHD are expected to show impaired performance on the measures that tap into these processes – at least on the traditional version of the attention tasks.

The measures in this project that tap into arousal, behavioural inhibition, and working memory are, respectively, the measures that tap into: (1) focused and sustained attention, (2) response inhibition (a subcomponent of focused attention), and (3) encoding capacity. As detailed in Table 1, focused attention is reflected by participants' target reaction times and accuracies on the speeded tasks, participants' T1 accuracy on the blink task, and participants' target sensitivity on the CPT. Sustained attention is measured on all five attention tasks and is reflected by the stability, or lack thereof, of performance levels over testing time on all dependent variables. The next process of interest, response inhibition, is often used to refer to behavioural inhibition as it is tapped by reaction time tasks. It is – at least for the purposes of this project - considered a subcomponent of focused attention, and was measured by participants' SSRTs on the stop-signal task as well as their false alarm rates and response bias on the CPT. Whereas the cognitive processes involved in focusing - and maintaining that focus over time - are linked to arousal, and the process of behavioural inhibition is closely related to response inhibition, the construct of working memory is most directly connected to the capacity limit of a person's attentional resources. Such encoding capacity limits were measured in this project by participants' T2 | T1 accuracy and blink magnitude on the blink task.

Given the mapping of etiological and theoretical underpinnings onto the current project, the children with ADHD are hypothesized – as indicated - to show deficits in their focused and sustained attention, as well as the limits of their stimulus encoding, relative to their same-aged typically developing peers. These deficits shall take the form of reduced speed and decreased accuracy on the speeded attention tasks, reduced T1 accuracy on the blink task, and decreased target sensitivity on the CPT. Additionally, relative to the control participants, the participants with ADHD can be expected to demonstrate longer SSRTs on the stop-signal task, increased false alarm rates and a more liberal response bias on the CPT, as well as poorer T2 | T1 performance and larger attentional blinks on the blink task. Notably, the children with ADHD are expected to demonstrate the same profile of attentional expectancy, filtering, and interference control as the control children in this project.

There is an inherent assumption that participants will be attracted to the colourful computer screens, motivated by the rewards, and interested in the goal-oriented storyline that characterizes the video game context in this project - at least to a greater extent than they will be engaged by the traditional context (see related footnote in Chapter 6). In that regard, the video game attention battery is expected to facilitate dopaminergic neural responses linked to reward and motivation. Because arousal and inhibitory control are modulated by dopamine neurotransmission (see related references in Chapter 3), the children with ADHD should demonstrate relative improvements in the video game context on some of the very components on which they are expected to demonstrate deficits in the traditional context (specifically, focused and sustained attention).

Limitations are indeed evident for this prediction, however, as explained in the following two paragraphs.

To the extent that the stimulation in the traditional context will not be adequate for the children with ADHD to demonstrate optimal functioning on the attention tasks – and, similarly, to the extent that the video game context is appealing to these children - Zentall's (1975) application of Leuba's (1955) optimal stimulation theory to explain ADHD can be used to facilitate the development of context-specific hypotheses in the current project. Past research directly testing Zentall's (1975) theory has generally limited the remedial effect of environmental stimulation on children with ADHD to gross motor overactivity and performance on simple cognitive tasks such as target detection amongst serially presented distracters. Thus, it seems that the visually enticing stimuli used in the video game test battery should facilitate the ADHD group's abilities for target detection on the CPT - but it will unlikely extend its effects to measures involving high cognitive demands (e.g., incompatible trials on the flanker task). A caveat must be mentioned here, however. Notably, video game research has shown that extensive environmental stimulation can overwhelm a child's ability to optimally perform several different types of cognition. Hence, given the variability that children with ADHD typically demonstrate in their target detection abilities on the CPT as a result of contextual manipulations (Corkum & Siegel, 1993),[12] the participants with ADHD in this project are *not* expected to show higher hit rates in the video game versus traditional context.

Despite evidence to implicate equivalent (and, sometimes, worse) task performance in the video game relative to the traditional condition in the current project, there remains support for the conjecture that participants will show a cognitive benefit from the unique stimulation provided in the former condition. In particular, past research using the stop-signal task with children (including ADHD and control groups) in reinforced and non-reinforced conditions showed both groups to demonstrate greater inhibitory control as a

[12] Details are provided in Chapter 5.

result of reinforcement (Stevens et al., 2002; see Chapter 6 for details). The same result is thus hypothesized for children's performance on the stop-signal task in this project.

Considered together, the collection of hypotheses outlined herein indicate that – as set out in this project's rationale – the children with ADHD will demonstrate a profile of attention that reflects deficits in some, but not all, components of attention (relative to the profile of control children). Furthermore, the contextual manipulation used in this project will differentially influence the components of attention in both participant groups but, for any given component, may not influence the groups differently. Although the possibility of differential context influence on the two groups of children carries intuitive appeal (and is supported to some extent by the implicated neurology – see Chapter 3), it has not been supported in past studies (e.g., Stevens et al., 2002).

Task Reliability

One of the original themes that arose during the design stage of this project regarded two problems that are inherent to large multi-task attention studies. The first was the possibility of task order effects that could confound task results. The second was the high demand for participants' time. To deal with these issues, a goal to integrate the five separate attention tasks into one multi-component task was established. It was hoped that a broader, integrative task could simultaneously tap the attention components of greatest interest to the project in a shorter time than was required by the five separate attention tasks. After much brainstorming, however, it was decided that only the Simon, flanker and stop-signal tasks could be integrated into one task. These three tasks could be integrated on the basis of their similar demands for speeded forced-choice responses to single target stimuli that are serially presented on a computer screen. Thus, a "Simon/ flanker/stop" task (also referred to as the integrated task) was developed as an alternative to the separate Simon, flanker, and stop-signal tasks in this project. On any given trial of the integrated task, a target stimulus appeared on either the left or right side of the computer screen (a Simon trial) or flanked by two lateral flankers in the centre of the computer screen (a flanker trial). A visual stop signal (white screen) appeared on 25% of each of the Simon and Flanker trials (stop trials).

With the development of a Simon/flanker/stop task, two possible attention batteries could be used in the child experiment of this project. The first constituted the default battery of the separate Simon, flanker, stop-signal, blink, and continuous performance tasks. The second, shorter attention battery involved the use of the new integrated task together with the blink and continuous performance tasks. The first of two experiments in this project was designed to test the reliability of the shorter attention battery relative to the larger attention battery and known task effects as published in related literature. An adult population was chosen for the reliability experiment, largely for reasons of convenience and the adult-bias that exists in past research on the Simon, flanker, and blink tasks. Pending reliability of the integrated task, the shorter attention battery was to be used with children in Experiment 2 in place of the separate Simon, flanker, and stop-signal tasks.

There is an assumption here that the psychometric properties established using adults in Experiment 1 would also apply to children in Experiment 2. This assumption is based on the rationale that the separate attention tasks have successfully been used with adults and children in past research, sometimes in the same study and with equivalent parameters.[13] Furthermore, as far as has been tested, both populations demonstrate the same cognitive effects in each task. Thus, if the adults who complete the integrated test battery in Experiment 1 of this project show the same attention effects as their control counterparts who complete the five tasks in a separate manner, one could logically infer that the integrated and separate test batteries would obtain parallel effects in normal children. It therefore seems logical that the researcher can extend the reliability of data from university students to children (e.g., Corkum & Siegel, 1993; Enns & Akhtar, 1989; Jonkman et al., 1999; Mirsky et al., 1991; Tagliabue, Zorzi, Umilta & Bassignani, 2000; Williams, Ponesse, Schachar, Logan & Tannock, 1999).

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[13] The research referenced here includes published literature that used the same general task paradigms as are used in this project in addition to unpublished research conducted in the Department of Psychology at Dalhousie University that used exactly these tasks (Stewart, Klein, & Collins, work in progress).

Chapter 8. Experiment 1 Methods

Participants

Sixty students (43 female, 17 male), including undergraduate and graduate students, were recruited at Dalhousie University in Halifax, Canada to take part in Experiment 1. Recruitment methods included an advertisement on the Department of Psychology's webpage, posters posted throughout the university, and word-of-mouth. All participants reported that they met the inclusion criteria, as follows: (1) status as a university student currently enrolled in full or part-time studies, (2) normal or corrected-to-normal vision, (3) no known serious physical, intellectual, or mental health problems that would interfere with the ability to participate in the study, and (4) the ability to comprehend spoken English. Participants chose either one credit point (i.e., 1% toward overall grade) for a psychology undergraduate course currently underway or a monetary reward of $6 as reimbursement for the time taken to participate.

All sixty participants were included in the final sample, although outlying data were excluded on each task. The adults in the integrated condition had an average laterality quotient (LQ) of +66.25[14] (*SD* = 40.68) whereas their control counterparts in the separate condition had an average LQ of +54.64 (*SD* = 50.96); these means were statistically equivalent. Participants' mean LQ did not significantly vary across the six task orders used in the separate condition of Experiment 1.

Materials

Handedness was assessed for each participant using the Edinburgh Handedness Inventory (Oldfield, 1971). The computerized battery of attention tasks was programmed using CodeWarrior on a MacIntosh G3 computer running on an OS9 platform. The tasks were also presented to participants on a MacIntosh G3 computer. The monitor measured 15

[14] Exclusive right-handedness is reflected by a LQ of +100 whereas exclusive left-handedness is reflected by a LQ of –100.

inches diagonally and had 1024 x 768 pixel resolution. All participants completed the testing in the same room under the same lighting conditions. To facilitate understanding of the following task details, the reader's attention is again brought to the appendix wherein a visual depiction of at least one sample trial, information regarding trial timing, and an indication of participant instructions is provided for each task.

The stimuli used in the Simon, flanker and stop-signal tasks in this project were heart and diamond icons whereas the blink task incorporated heart, diamond, club, and spade icons. The CPT used icons of traditional playing cards as stimuli. No between-trial fixation points were used on either task. Speeded responses to a heart target in the Simon, flanker and stop-signal tasks were made by using the left index finger to press the "4" key on the number keypad of a standard computer keyboard. The "6" key was pressed by the right index finger for diamond targets. The number keys were centred relative to each participant's vertical body midline. Non-speeded responses to the club, heart, diamond and spade stimuli in the blink task were made by pressing the "2," "4," "6," and "8" number keys respectively. Responses to target card sequences in the CPT involved pressing the "4" key with the dominant index finger. The same stimulus-response key mapping was used for all participants. Each key was labeled with a picture of the shape (i.e., card suit) that it represented. Each task included one practice and three experimental (i.e., "test") blocks.

The display screen of the computer monitor was divided into two parts throughout all testing. The top portion of the screen, measuring 10 cm in height, displayed a green background upon which the stimuli were presented during all tasks. Instruction panels appeared in this part of the screen before each task in the practice block and then in abbreviated form in the experimental blocks. The abbreviated instructions cued each participant to which task was forthcoming and provided a brief reminder of how to complete that task. The bottom portion of the monitor screen was covered entirely by a piece of opaque black paper. The following several paragraphs describe each of the tasks used in this experiment. The Simon, flanker, stop-signal, blink and continuous performance tasks were used in the separate condition whereas the Simon/flanker/stop, blink and continuous performance tasks were used in the integrated condition.

Simon Task

The target stimulus on any given trial within the Simon task was either a heart or diamond; its inner edge was presented 9.07° (i.e., 9.07 visual degrees) to the right or left of the midpoint in the viewable portion of the computer screen. The stimuli were red in color with white borders (1 mm wide) and a thin red outline. At their vertical midlines, the diamond was 1.21° high and the heart was 0.99° high. At their horizontal midlines, both the diamond and the heart were 1.32° wide. A warning tone was used on five-sixths of the trials, with pre-stimulus onset times of 50 ms, 100 ms, 200 ms, 400 ms and 800 ms. The tone was 500 ms in duration and had a frequency of 440 hertz. It was designed to elicit different levels of alertness in participants and tapped into the attention component of expectancy. The order in which the different trial types appeared in the practice and experimental blocks was randomly determined for each participant.

Twenty-four trial types were possible within the Simon task: two target types (heart/ diamond) x two locations (left/right) x six warning intervals (no tone, 50 ms, 100 ms, 200 ms, 400 ms, 800 ms). The experimental blocks each included 72 trials, with each trial type being presented three times. The practice block included a random subset of 36 trials from the 72. The length of the warning intervals, or foreperiods, was chosen on the basis of past literature that has shown a u-shaped function between reaction time and warning interval on speeded reaction-time tests when the intervals range from zero through several hundred milliseconds. The range was intentionally broad to ensure detection of alertness effects; the distribution was weighted towards shorter intervals because research has shown optimal alertness to be elicited when the intervals range from 100-300 ms (Los, Knol, & Boers, 2001; Niemi & Näätänen, 1981; Teichner, 1954).

Flanker Task

The stimuli used in the flanker task in this experiment were exactly the same as those used in the Simon task. Notably, the use of hearts and diamonds contrasts with the traditional use of letters for stimuli in flanker tasks.[15] On all flanker trials in this experiment, a heart or diamond target appeared in the centre of the viewable top half of the computer screen. Each target was flanked by two stimuli equidistant from the target (one on either side of the target). All flankers were identical and were either compatible or incompatible with (same as, or different from, respectively) the target. Flankers were located at one of three possible distances from the target: near, middle or far. Corresponding minimum edge-to-edge separations between the target and either flanking stimulus were 0.77°, 2.09°, and 3.52° respectively. There were twelve possible flanker trials: two target types (heart/diamond) x two trial types (compatible/ incompatible) x three flanker distances (near/middle/far). The experimental blocks of the flanker task each included 36 trials, with each trial type being presented three times. The practice block included a random subset of 18 trials.

Stop-Signal Task

The stimuli used in the stop-signal task were identical to those used in the Simon and flanker tasks. The heart or diamond stimulus on any given trial was centrally located and not surrounded by flankers. A visual (white screen) stop signal was presented on a random subset (25%) of the trials. There were twenty-four possible trials: two trial types (heart/diamond) x two trial possibilities (stop signal/no stop signal) x six warning intervals.[16] This translated into twelve types of stop trials and twelve types of go trials. The experimental blocks on the stop-signal task included 48 trials, with each stop trial type presented once and each go trial type presented three times. The practice blocks included a random subset of 24 of the 48 possible trials. Following Logan et al. (1997), a

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[15] Using shape as the task-relevant dimension avoided the left-to-right bias that is associated with visual processing of alphanumeric stimuli (Harms & Bundesen, 1983).
[16] Warning intervals were used in the separate stop-signal task to parallel their use in the Simon/flanker/stop task. Analyses specific to the stop-signal task did not incorporate this variable, however.

computer algorithm was used to actively modify the stop delay during task completion such that each participant inhibited responses on approximately 50% of the stop trials in any given test block. Participants' SSRTs were thus estimated as their average go reaction time minus their average stop delay.

Simon/Flanker/Stop Task

The Simon/flanker/stop task, also referred to as the integrated task, incorporated 72 types of trials: (24 Simon trial types + 12 flanker trial types) x two (stop signal/no stop signal). This meant that there were 36 types of stop trials and 36 types of go trials. The experimental blocks in this task each included 144 trials, with each go trial type presented three times (3 x 36 = 108) and each stop trial type presented one time (1 x 36 = 36), to account for 25% of the trials. The practice block for the integrated task included a subset of 72 trials randomly chosen from the 144 trial types.

Blink Task

The blink task involved presentation of two masked stimuli in close temporal proximity. In particular, a trial sequence in Experiment 1 consisted of a 45 ms target (T1) followed immediately by a 15 ms blank screen, a 45 ms mask (M1), a short interstimulus interval, a second 45 ms target (T2), a second 15 ms blank screen and a final 45 ms mask (M2). The temporal masking paradigm used in this study, with no location switching and no task switching between T1 and T2, parallels that used by Shore et al. (2001).

The targets and masks that were used in the blink task filled a square outline that measured 0.77° by 0.77° visually. Five interstimulus intervals (ISIs) were used between the two TM pairs; their durations were 15, 135, 255, 375 and 490 ms. The exact target combinations that were used - and the order in which they were presented within the practice and each of the three experimental blocks - was randomly determined for the first participant and maintained for all remaining participants. Repeats were possible in the target combinations on any given trial; for example, a trial could have a spade for T1 and for T2. Four different masks (each made from several overlapping target segments) were used. The exact masks and their order of presentation were randomly determined for all participants in the practice and three experimental blocks. The practice block included 25 TM pairs whereas each experimental block included 50 TM pairs; the ISIs were equally represented in each block of trials.

As was the case for the blink task in this project, Shore et al. (2001) did not use a standard baseline condition in their TM-TM paradigm; it would have required participants to identify T2 while ignoring T1. This meant that the blink could not be quantified by summing the differences between T2 performance at baseline and T2 | T1 performance in the dual-task condition at each ISI, a method that has been used in past RSVP literature. Instead, Shore et al. assumed that participants' average performance on T1 would reflect their average performance on T2 in a baseline condition. Given that assumption, Shore et al. summed – on a participant-by-participant basis - the difference between overall T1 accuracy (the mean of T1 accuracy across all five ISI lengths) and T2 | T1 accuracy at each ISI. Because T1 performance varied as a function of ISI in this project (see results as given in Chapters 9 and 11), the author chose to replace average T1 performance with T2 | T1 accuracy at the longest ISI (495 ms) in Shore et al.'s formula; this "baseline" value was chosen on the assumption that the blink would have recovered by that length of delay following T1.[17] With this formula, larger absolute values reflect larger blinks. In turn, larger blinks reflect a diminished ability to recover attentional resources from an overload.

CPT

The CPT in this project employed a continuous stream of stimuli flashing in the middle of the viewable computer screen (i.e., its top half). The stimuli were pictures of the 52

[17] McLaughlin et al. (2001) used an approach similar to that used in this project. They quantified the blink according to the number of ISI lengths for which T2 | T1 performance was worse than asymptotic T1 performance (calculated as average T1 performance over all ISIs). Admittedly, this approach and the one used in this project are limited in that they underestimate blink magnitude for those participants who have not fully recovered from the blink at the longest ISI.

cards in a traditional deck of playing cards. The task employed five types of trials (one target plus four distracters), with each trial type consisting of a particular combination of six cards. The blocking of cards into groups of six was not made evident to the participant and involved no differences in stimulus onset or duration. One card flashed on the computer screen at a time. Each card measured 4.18° in height and 3.08° in width on the screen. The exact trials that were used, and the order in which they were presented within the practice and each of the three experimental blocks, was randomly determined for the first participant and maintained for all remaining participants.

The target trial block in the CPT consisted of the seven of hearts card followed immediately by the ace of spades card and then a series of four random cards; the target card sequence is hereafter denoted as [7H/AS]. The four types of distracter trials and their acronyms were: (1) the seven of hearts card followed by five random cards [7H Alone], (2) the ace of spades followed by five random cards [AS Alone], (3) the seven of hearts followed by a random card, the ace of spades, and three random cards [7H/R/AS] and (4) six random cards [All Random]. Each experimental block included 41 trials. The first trial was always random. After this, each of the five trial types was presented eight times, for a total of: 41 trials x 6 cards/trial = 246 cards. The practice block in each experiment included a series of 126 cards, consisting of an initial random trial (six cards) plus 20 remaining trials (each of the five trial types presented four times).

Nonparametric indices were used to measure target sensitivity and response bias on the CPT in this project. They were A' and B" respectively (Grier, 1971). Adaptations of each of Grier's formulas were used in cases where the mean hit or false alarm rate reflected below chance performance (Aaronson & Watts, 1987). A' is computed such that a participant's target sensitivity increases as his/her hit rate increasingly exceeds his/her false alarm rate. The range of possible values for A' is (0,1), with 0.50 reflecting chance performance, values greater than 0.50 reflecting high sensitivity, and values below 0.50 reflecting poor sensitivity (i.e., worse than chance performance, as indicated by a false alarm rate higher than a hit rate). B" compares a participant's correct rejection rate with his/her hit rate to determine if the participant tended towards conservative or liberal responding. If the correct rejection rate is higher than the hit rate, then B" is greater than zero and reflects a conservative response bias. If the hit rate is higher than the correct rejection rate then B" is less than zero and reflects a liberal response bias. A B" value of zero reflects no response bias. The total range for B" is (-1,1).

Procedure

Participants were randomly assigned to one of the two experimental conditions, separate or integrated, with thirty participants serving in each condition. Participants in the separate condition were further randomized into one of six possible task orders, with five participants completing each order. The task orders applied only to the Simon, flanker and stop-signal tasks, all three of which were completed before the blink task and CPT respectively. Participants in the integrated condition always completed the Simon/ flanker/stop integrated task first, followed by the blink task and then the CPT. The task order for any given participant remained consistent throughout both practice and experimental blocks.

Each participant served in a single session lasting approximately one hour. After providing informed consent, each participant completed the Edinburgh Handedness Inventory. Participants were then told that they would do several different types of computer tasks and would do each several times. Participants were seated 52 cm from the screen (as measured from eyes to screen) and encouraged to maintain this distance throughout all of the computer testing. To reduce discomfort, a chin rest was not used. A check was made on this distance (and required adjustments made, as applicable) just before the practice and first experimental test block, and again following a short break before the start of the second test block.

The experimenter explained the first task and stayed in the room while the participant then practiced that task. This was repeated for each of the four (separate condition) or two (integrated condition) remaining tasks, thereby constituting the practice block. The explanations for each task remained the same for all participants and were read by the experimenter. As needed or requested, further clarification of the task requirements was provided by the experimenter. The experimenter then left the room while the participant progressed through each of the tasks three more times (the experimental blocks). A short break was provided between the first and second experimental blocks.

Chapter 9. Experiment 1 Results

Part I: Overview

Study Design

Experiment 1 employed a mixed factorial study design. The between-subjects factors were task condition (separate versus integrated) and, for the participants in the separate condition, task order. The within-subjects factors on each task were as follows: test block (all tasks), trial type (Simon, flanker, stop-signal, and continuous performance tasks), warning interval (Simon task), and flanker distance (flanker task). The trial types were compatible versus incompatible on the Simon and flanker tasks, go versus stop on the stop-signal task, and hits versus false alarms on the CPT. The Simon/flanker/stop task used in the integrated condition incorporated warning interval, flanker distance, and trial type (go versus stop, and Simon versus flanker) factors.

Statistical Approach

Unless otherwise stated, repeated measures analyses of variance (ANOVAs) were used to make inferences about the data in this experiment. An alpha (p) value of .05 was chosen as the criterion for statistical significance. Follow-up tests to the ANOVAs generally included paired or unpaired t-tests, as applicable. To control for the Type I error rate among the post hoc tests, Bonferroni corrections were applied and a test result only reported as significant if its associated p value was equal to or less than the corrected p value. Planned contrasts were used subsequent to ANOVAs to follow up on expected within-subjects effects such as those of test block (performance generally expected to worsen over time) and warning interval (u-shaped function expected in target reaction time and accuracy data). All practice data were excluded from analyses, just as analyses of the RT data were restricted to only those trials on which participants correctly identified the target shape. All analyses were conducted using the statistical package *Statview 5.0.*

The distributions of the reaction time and accuracy data collected in this experiment were analyzed graphically (using histograms) and quantitatively (using values of skewness and kurtosis). As expected, the majority of reaction time data were positively skewed whereas the majority of accuracy data were negatively skewed and leptokurtic. All reaction time data were therefore log-transformed (using the natural log (*ln*) of each data point) and all accuracy data were arcsine-transformed. Accuracy data were also transformed using the formula $ln(x/(1-x))$, where x was a participant's mean proportion of correctly identified targets in a test block. These transformations successfully normalized the reaction time and accuracy data respectively. ANOVAs were computed and compared on all untransformed (i.e., raw) and transformed data. The results of these ANOVAs were extremely similar in all cases for every task and, unless otherwise noted, all results herein were taken from the untransformed data sets.

Outliers and Missing Data

Box plots and scattergrams were used to visually assess the distribution of the dependent variables measured in this experiment. For each dependent variable, decisions regarding outliers were made on the basis of how each participant's overall mean and range compared to that of his or her participant group. A participant was considered an outlier on any given variable if his or her overall mean was 1.5 (or more) *SD*s greater than the grand sample mean and/or his/her range encompassed 3.0 (or more) *SD*s. If a participant was deemed to be an outlier on a given variable, all of his or her data from the corresponding task were excluded from analyses. The number of outlying participants for Experiment 1 was as follows: Simon task ($n = 2$), flanker task ($n = 6$), stop-signal task ($n = 5$), blink task ($n = 4$), and CPT ($n = 6$).

Each of the participants in the final sample had, at most, one test block of missing data on any given task. These missing data were replaced with interpolated values. Suppose, for example, that a participant was missing a value for the second test block of a task. The grand sample mean (minus the incident person's data) would have been calculated for the first and third blocks combined and compared with the grand sample mean for the second test block; the difference between these values constituted the test block effect for Block 2. The subject effect was then calculated as the difference between his/her mean from Blocks 1 and 3 combined, and the grand sample mean for Block 2. To obtain the missing data point, the test block and subject effects were added to the grand sample mean (minus the incident person's data) from, again, the first and third test blocks combined. Ultimately, interpolation was only used to estimate missing data for one participant on the stop-signal task.

Report Organization

The results for each of the tasks are discussed separately and in the order they were administered to participants in the separate condition: (1) Simon, (2) flanker, (3) stop-signal, (4) blink, and (5) continuous performance. Because the condition manipulation (incorporating Simon, flanker, and stop-signal tasks into one) was being tested as a shorter alternative for the test battery, the data from the integrated condition were not included in the main analyses of task effects. Rather, the results that specifically address task reliability are from only the participants in the separate condition; they regard the effects of task-specific manipulations and are highlighted as effects of trial type, warning interval, flanker distance, and task order (as applicable). Both datasets (separate and integrated) were combined and analyzed for condition effects; these results are denoted by subheadings to that effect. The data from the integrated Simon/flanker/stop task were broken down by trial type and analyzed with the respective data from the separate Simon, flanker, and stop-signal tasks.

Part II: Findings of Task Reliability in Adults

Simon Task

Two types of effect were sought from the Simon task in this project. The first reflected an increase in participants' target RTs and a decrease in their target accuracies on incompatible relative to compatible trials. The second regarded a variation in participants' target RTs and accuracies as a function of the warning intervals for the alerting tones. To determine if these effects were indeed produced, repeated measures ANOVAs were computed on the mean target RTs and accuracies that were calculated for each participant on a block-by-block basis. Only the data from the traditional condition were included in these ANOVAs. Task order was entered as a between-subjects factor whereas trial type (compatible versus incompatible), warning interval[18] (no tone, 50 ms, 100 ms, 200 ms, 400 ms, and 800 ms), and test block (three in total) were entered as within-subjects factors.

To determine if the expected trial type and warning interval effects were elicited on Simon trials in the context of alternate flanker trials and random "white screen" stop signals, a second set of ANOVAs were computed on participants' mean target RTs and accuracies. Task condition (separate versus integrated) was entered into these ANOVAs as the only between-subjects factor whereas trial type, warning interval, and test block were entered as within-subjects factors. Related results are discussed in the forthcoming subsection entitled *Effects of task condition.*

Effects of trial type. Participants' target reaction times (RTs) on the Simon task showed the expected effect of trial type, $F(1,24) = 11.65, p < .01$. Participants were slower to respond to incompatible relative to compatible trials by a matter of 13.94 ms ($SE = 2.91$). A similar effect was observed for target accuracies in that participants correctly identified 2.1% ($SE < 0.01$) fewer targets on incompatible trials relative to compatible trials, $F(1,24) = 10.97, p < .01$.

Effects of warning intervals. The warning intervals that occurred between the alerting tones and target onsets on the Simon task significantly influenced participants' reaction time to the targets, $F(5,120) = 3.96, p < .01$. As expected, and as shown in the top left panel of Figure 1, participants were faster on trials with short (i.e., 50, 100, and

[18] The phrase *warning interval* is used to refer to the length of the interval between the onset of the alerting tone and the onset of a target on each of several Simon trials. For ease of reference, results regarding warning interval effects encompass the subset of trials that did not use a tone. "No tone" trials were treated in the same way as "tone" trials in planned contrasts.

200 ms) warning intervals relative to trials with no tone and those with longer (i.e., 400 and 800 ms) intervals, $F(1,120) = 47.74, p < .01$. A main effect of warning interval was also observed on target accuracies, $F(5,120) = 13.63, p < .01$. Not surprisingly, participants were least accurate on the trials that they responded to most quickly. Specifically, participants were less accurate on trials with 50 ms and 100 ms warning intervals relative to trials with no tone, 200 ms, 400 ms, and 800 ms intervals, $F(1,120) = 16.59, p < .01$ (see bottom left panel of Figure 1).

Effects of test block. Participants' target RTs on the Simon task changed over time, $F(2,48) = 9.44, p < .01$. Notably, participants were faster in the second test block relative to the first, $F(1,48) = 5.01, p = .03$, and in the third block relative to the second, $F(1,48) = 4.44, p = .04$, indicating a practice rather than fatigue effect. No second-order effects were shown for test block on the RT data. The ANOVA computed on the target accuracies revealed a change over time in the percentage of targets that participants correctly identified, $F(2,48) = 4.31, p = .02$. Specifically, participants were less accurate in Block 2 relative to Blocks 1 and 3 combined, $F(1,48) = 8.63, p < .01$. As Tables 2 and 3 reveal, the overall proportion of correctly identified targets was on the order of 94.9% ($SE < 0.01$) and the decrease from the first to second test block 1.4% ($SE < 0.01$). No second-order effects were shown for test block on the accuracy data.

Effects of task order. Task order did not directly – or indirectly via an interaction with warning interval - influence participants' RTs on the Simon task. An interaction between task order and trial type effects approached significance, however, in the *ln*-transformed RT data, $F(5,24) = 2.35, p = .07$. The interference in target RTs due to trial type incompatibility appeared to be largest for those participants who completed the Simon task prior to the stop-signal and flanker tasks. Parallel findings were revealed for participants' target accuracies. Specifically, the order of task completion did not have a main effect on participants' performance accuracy nor did task order interact with warning interval to influence the same. A trend occurred for the trial type effect within participants' target accuracies to vary across task order, $F(5,24) = 2.39, p = .07$. As with the RTs, the Simon effect in target accuracies tended to be largest for the participants whose first task in the attention battery was the Simon task.

Effects of task condition. The participants who completed the integrated task in Experiment 1 were slower in their responses to Simon targets than were the participants who completed the separate Simon, flanker, and stop-signal tasks, $F(1,56) = 25.62, p < .01$. Nonetheless, the effect of slowed responding on incompatible relative to compatible trials was equivalent in magnitude for the two groups. Warning interval also had the same main effect on participants' RTs in both conditions (see top panels of Figure 1). In addition to being slower to make their target responses, the participants in the integrated condition were – not surprisingly – more accurate in their overall target identification $F(1,56) = 17.51, p < .01$. Trial type had the same main effect on both groups' target accuracies. Notably, the warning interval variable differentially influenced the groups' accuracies, $F(5,280) = 2.43, p < .04$. Participants' accuracies were not influenced by warning interval in the integrated condition, $F(5,135) = 0.72, p = .61$, but, as indicated in an earlier subsection, were reduced on the trials with the shortest warning intervals in the separate condition (see bottom panels of Figure 1).

The main effect of test block on participants' Simon task RTs in the separate condition did not persist when the data was combined with that from the integrated condition, $F(2,112) = 0.27, p = .76$, although an interaction between test block and condition did not reach statistical significance, $F(2,112) = 2.16, p = .12$. Nonetheless, the data from the two conditions appear to have different patterns. In contrast with a practice effect (faster RTs over time) in the separate condition, a fatigue effect is suggested by the slower RTs over time in the integrated condition. A repeated measures ANOVA completed only on the integrated data, however, failed to demonstrate statistical significance for this effect of test block on participants' RTs. The main effect of test block on target accuracies persisted in the combined dataset, $F(2,112) = 3.10, p = .04$. An interaction between test block and task condition effects was not evident in the accuracy data.

Flanker Task

Trial type effects similar to those observed on the Simon task (i.e., slower and less accurate responses on incompatible trials relative to compatible trials) were expected on the flanker task in this project. Furthermore, a reduction in the magnitude of these effects was expected on trials with longer target-to-flanker distances. To determine if the current flanker task produced these effects – as reliably shown in past literature – repeated measures ANOVAs were computed on the mean target RTs and mean target accuracies from only those participants in the separate condition (and as calculated on a block-by-block basis). Whereas task order was entered into the ANOVAs as a between-subjects factor, trial type (compatible versus incompatible), flanker distance (near, middle, and far), and test block were entered into the ANOVAs as within-subjects factors.

To determine if the main effects of trial type and flanker distance, and the interaction of these effects, were elicited on flanker trials in the context of alternate Simon trials and random "white screen" stop signals, a second set of ANOVAs were computed on participants' mean target RTs and accuracies. The ANOVAs were computed on the data from both separate and integrated conditions, and included task condition as the only between-subjects factor. Trial type, flanker distance, and test block were entered into the ANOVAs as within-subjects factors. Related results are discussed in the forthcoming subsection entitled *Effects of task condition.*

Effects of trial type & flanker distance. As expected, a repeated measures ANOVA on participants' RTs from the flanker task revealed main effects of trial type, $F(1,22) = 8.36, p < .01$, and flanker distance, $F(2,44) = 4.99, p = .01$, as well as an interaction between the two, $F(2,44) = 8.09, p < .01$. As the graph of the interaction in the top left panel of Figure 2 shows, the FCE was larger on near-flanker trials relative to middle-, $F(1,44) = 6.07, p = .02$, and far-, $F(1,44) = 15.89, p < .01$, flanker trials. It was not larger on middle-flanker trials relative to far-flanker trials, $F(1,44) = 2.32, p = .14$. Furthermore, the FCEs on the middle- and far-flanker trials were both statistically equivalent to zero, $t(83) = 1.48, p = .14$ and $t(83) = -0.12, p = .91$ respectively. Notably, participants' accuracies were not influenced by trial type, flanker distance, or their interaction at a statistically significant level. Nonetheless, the accuracy data reflect the expected pattern of interaction (see bottom left panel of Figure 2).

Effects of test block. Test block had a main effect on participants' RTs, $F(2,44) = 8.65, p < .01$, on the flanker task. As with the Simon task, the RT data from the flanker task suggest a practice (rather than a fatigue) effect. Participants were faster to respond to targets on the second test block relative to the first, $F(1,44) = 12.96, p < .01$, but not faster on the third relative to the second, $F(1,44) = 0.00, p = 1.00$. No second-order effects were shown for test block in the RT data. Participants' target accuracies were not influenced by first- or second-order effects of test block.

Effects of task order. No first-, second-, or third-order effects of task order were evident in the RT data collected from the separate flanker task. Task order interacted with the trial type and flanker distance effects on participants' accuracies, however, $F(10,44) = 2.33, p = .03$. The FCE was only present in the accuracy data from participants who completed the flanker → Simon → stop-signal task order, $F(2,8) = 12.23, p < .01$. For these participants, the trial type effect was greater on near-flanker trials relative to middle-flanker trials, $F(1,8) = 13.54, p < .01$, but not on middle-flanker trials relative to far-flanker trials, $F(1,8) = 1.04, p = .34$.

Effects of task condition. The integrated task slowed participants' responses to flanker targets, $F(1,52) = 40.11, p < .01$. Although the trial type and distance main effects were statistically equivalent for the RTs in the two task conditions, the nature of their interaction differed (see top panels of Figure 2; $F(2,104) = 3.67, p = .03$). Whereas trial type and distance interacted to produce an attenuated FCE over larger flanker distance in the RT data from the separate condition (as expected – see earlier subsection), these factors did not interact in the RT data from the integrated condition, $F(2,50) = 1.19, p = .31$. Unexpectedly, an FCE persisted in participants' RTs on the far-flanker trials in the integrated Simon/flanker/stop task, $t(77) = 2.33, p = .03$. Regarding the accuracy of target identification, the participants in the integrated condition were more accurate than those in the separate condition, $F(1,52) = 17.36, p < .01$. The main effects of trial type and flanker distance on participants' target accuracies, as well as the interaction between these effects, were statistically equivalent for the two conditions (see bottom panels of Figure 2). Notably, separate analyses of the accuracy data from the integrated condition confirmed no main effect of flanker distance and no interaction between the trial type and distance variables but showed an effect of trial type (i.e., an FCE), $F(1,25) = 4.81, p = .04$.

The main effect of test block on RTs in the separate flanker task did not persist when that data was combined with the flanker trial data from the integrated task, $F(2,104) = 0.13, p = .88$, making an interaction between test block and condition evident in the entire RT dataset, $F(2,104) = 4.96, p < .01$. As was the pattern for the Simon task, the RT data from the flanker task reflected a practice effect in the separate condition and a fatigue effect in the integrated condition. Separate analyses of the data from flanker trials in the integrated task did not show the fatigue effect to be statistically significant, however, $F(2,50) = 1.54, p = .22$.[19] As was the case with the data from the separate flanker task, no main effect of test block was shown on participants' accuracies in the combined dataset. An interaction between condition and test block was thus not evident for accuracies in the entire dataset. (An ANOVA on only the integrated data also showed no main effect of test block on participants' accuracies.)

Stop-Signal Task

Exploratory analyses of the data from the stop-signal task in this experiment demonstrated much variability in the length (and respective frequencies) of the stop delays that were generated by the task paradigm and in the probabilities of response inhibition that were elicited from participants. The variability was especially evident across the task conditions (separate versus integrated). Decisions regarding analyses were thus made on the dataset as a whole (see forthcoming subsection on effects of stop

[19] Thus, the practice effects in the RT data on both the separate Simon and flanker tasks were significant whereas the fatigue effects in the RT data from both tasks in the integrated condition were not.

trials for details). Repeated measures ANOVAs were ultimately computed on participants' P(I | S) (i.e., their probability of response inhibition, "I," given the occurrence of a stop signal, "S"). The ANOVA for the separate condition included test block as a within-subjects factor. Given that the data were collapsed across condition for initial analyses, task order could not be entered into this analysis of P(I | S). ANOVAs on the mean SSRTs, target RTs, and target accuracies (as calculated for each test block on a participant-by-participant basis) were also computed for only those participants in the separate condition. Task order was entered into these ANOVAs as a between-subjects factor whereas test block was entered as a within-subjects factor.

Following analyses of the stop-signal data from only the separate condition, the data from the two conditions were combined and repeated measures ANOVAs on the P(I | S) and SSRT indices were computed. Similarly, repeated measures ANOVAs were computed on all participants' mean target RTs and accuracies (including the data from both Simon and flanker trials in the integrated condition). These ANOVAs incorporated condition as a between-subjects factor and test block as a within-subjects factor. The overarching goal of these ANOVAs was to determine the reproducibility of the results from the separate stop-signal task in an integrated context with Simon, flanker, and stop-signal trials co-occurring. To compare the efficiency of participants' go processes on Simon versus flanker (go) trials, ANOVAs were separately computed on only the mean target RTs and accuracies from the integrated condition. These latter two ANOVAs included test block and trial type as within-subjects factors.

Go trials. Participants' mean target RT on the go trials of the separate stop-signal task was 558.61 ms ($SE = 16.64$). On average, participants correctly identified 98.4% ($SE < 0.01$) of the targets.

Stop trials. To calculate participants' overall probability of response inhibition on the stop trials of the stop-signal task (i.e., their P(I | S)) - and to simultaneously account for trial distribution across the user-determined stop delays (see top panels of Figure 3), the mean probabilities of inhibition for each stop delay were calculated for the entire participant sample. The data were then split by condition and test block. On the basis of the trial distribution across the stop delays and the associated variability in inhibition probability (especially on the trials with infrequently-occurring stop delays), a decision was made to only include data from trials for which the associated stop delay had at least thirty observations. This accounted for 80% of the experimental (non-practice) data. Using these data, participants in the separate condition of Experiment 1 were shown to inhibit responses on an average of 52.1% ($SE = 0.02$) of the stop trials on the stop-signal task; a one-group t-test indicated that this rate was equal to the desired 50%, $t(11) = 0.88$, $p = .40$. Thus, it was appropriate to use the methodology outlined in Chapter 8 to calculate the mean SSRT. It was calculated to be 278.33 ms ($SE = 8.61$). The bottom left panel of Figure 3 shows a plot of participants' mean probability of response inhibition as a function of stop delay.

Effects of test block. Test block did not have a main effect on participants' P(I | S); this result was expected given the stop delay algorithm that was used to stabilize the probability of response inhibition at approximately 50%. Similarly, participants' SSRTs remained stable over testing time. Participants' target RTs on the go trials of the task, however, increased over time, suggesting a fatigue effect, $F(2,46) = 4.85, p = .01$. Although participants were not faster in Block 1 relative to Block 2, $F(1,46) = 2.25, p = .14$, nor were they faster in Block 2 relative to Block 3, $F(1,46) = 2.60, p = .11$, the mean RT in the third test block was significantly longer than that observed in the first test block, $F(1,46) = 9.69, p < .01$. Conversely, test block did not have a main effect on participants' target accuracies.

Effects of task order. Task order did not have a main effect on participants' P(I | S) or their SSRTs. An interaction between task order and test block effects nearly reached statistical significance within the *ln*-transformed RTs from the separate stop-signal task, $F(10.46) = 2.00, p = .06$. The data suggest that a fatigue effect only occurred among participants who completed the tasks in the Simon → flanker → stop-signal order and those who completed them in the stop-signal → flanker → Simon order. Trends were demonstrated for these effects when repeated measures ANOVAs were separately computed on the data from each task order, $F(2,8) = 3.24$, $p = .09$ and $F(2,8) = 3.78$, $p = .07$ respectively.

Effects of task condition. The participants in the integrated condition inhibited responses on an average of 53.7% ($SE = 0.02$) of the stop trials on the Simon/flanker/stop task. This probability was statistically greater than 50%, $t(28) = 2.18$, $p = .04$, yet equal to the mean probability of response inhibition for the participants in the separate condition, $F(1,35) = 0.25$, $p = .62$, which itself was statistically equivalent to 50% as reported in an earlier subsection (see bottom panels of Figure 3 for a plot of P(I | S) as a function of stop delay and condition). The mean SSRT for participants in the integrated condition ($M = 255.19$ ms ($SE = 8.66$)) was also equivalent to the corresponding value for participants in the separate condition. The main effects (or lack thereof) of test block on participants' P(I | S), SSRTs, RTs, and accuracies were statistically equivalent for the two participant groups.

Simon versus flanker go trials. Given the way in which the data from stop trials were organized for analyses (see earlier discussion regarding calculation of P(I | S)), neither P(I | S) nor SSRT could be calculated as a function of Simon versus flanker trial type for the participants in the integrated condition. Analyses of these participants' go trial data, however, revealed that they were faster on Simon trials relative to flanker trials within the Simon/flanker/stop task, $F(1,25) = 26.31$, $p < .01$. Their mean target RT was 669.36 ms ($SE = 22.74$) on Simon trials versus 698.58 ms ($SE = 23.77$) on flanker trials. Not surprisingly – given the nature of speed-accuracy trade-offs, these participants correctly identified fewer targets on Simon trials relative to flanker trials, $F(1,25) = 5.05$, $p = .03$. On average, 98.4% ($SE < 0.01$) of the targets on Simon trials and 99.0% ($SE < 0.01$) of the targets on flanker trials were correctly identified.

Blink Task

Two core effects were sought from the blink task administered in this project. The first was consistently high performance on T1 regardless of the length of ISI that followed it.

The second was a level of performance on T2 | T1 that varied inversely with the length of ISI that preceded it. These effects – traditionally observed in RSVP paradigms – were presumed, if found, to imply reliability for the blink task used herein. Beyond the opportunity to establish task reliability, an additional advantage of administering the blink task to adults prior to its use in Experiment 2 was the opportunity to test the formula chosen to quantify the attentional blink it produced in participants. The appropriateness of the formula was deemed to be dependent on the calculation of reasonable blink magnitudes that could correspond with those calculated in past research.

After ensuring consistently high performance on T1 across all five ISIs in each of the separate and integrated task conditions, the data were subjected to repeated measures ANOVAs. Specifically, repeated measures were computed on T1 accuracy, T2 | T1 accuracy, and, after concluding that the formula for calculating blink magnitude was appropriate, blink magnitude. These ANOVAs were computed only on the data from participants in the separate condition and included task order as a between-subjects factor versus test block as a within-subjects factor.

To determine the effect, if any, of task condition on participants' performance on the blink task, the repeated measures ANOVAs originally computed on T1 accuracy, T2 | T1 accuracy, and blink magnitude for the data from the separate condition were recalculated using the data from both task conditions. These ANOVAs included condition as a between-subjects factor and test block as a within-subjects factor. (No condition effects were expected as the only manipulation between conditions involved the format of the Simon, flanker, and stop-signal tasks that were completed.)

Effects of ISI. Unexpectedly, ISI was shown to have a main effect on participants' T1 performance on the blink task in Experiment 1, $F(4,88) = 15.74, p < .01$. Simple linear regression modeling showed a trend for a linear relationship between the two variables, $F(1,13) = 4.12, p = .06$. Within this model, ISI accounted for 18.2% of the variation in T1 accuracy.[20] Participants' ability to detect and correctly identify T2 | T1 also varied significantly across the ISI, $F(4,88) = 13.79, p < .01$. As expected, the relationship between T2 | T1 accuracy and ISI was linear in form; this was confirmed with simple linear regression modeling, $F(1,13) = 19.02, p < .01$. ISI was shown to account for 56.3% of the variation in T2 | T1 accuracy. These data are plotted (for each test block) in the left panels of Figure 4. Regarding participants' attentional blink (as defined in Chapter 8), the data from the separate condition demonstrated a mean blink magnitude of 0.44 ($SE = 0.06$).

Effects of test block. In addition to ISI (see previous subsection), test block had a main effect on participants' T1 accuracy, $F(2,44) = 4.37, p = .02$. Participants correctly identified a smaller proportion of initial targets in the first test block relative to the second and third test blocks combined, $F(1,44) = 8.73, p < .01$), thus indicating a practice effect. The ISI and test block effects interacted in their influence on participants' T1 performance, $F(8,176) = 4.18, p < .01$. It appears that participants' T1 performance only improved as a linear function of ISI length in the second and third test blocks. Separate regression analyses run on the data from these blocks barely suggested trends for such, however, $F(1,3) = 0.00, p = 0.97$, $F(1,3) = 4.29, p = .13$, and $F(1,3) = 4.31, p = .13$ for Blocks 1, 2, and 3 respectively (see top left panel of Figure 4).

As with their T1 data, a practice effect was observed in participants' T2 | T1 data, $F(2,44) = 7.91, p < .01$. Participants correctly identified fewer second targets (following successful identification of initial targets) in the first test block relative to the second and third test blocks combined, $F(1,44) = 13.88, p < .01$. The main effect of ISI varied across the test blocks, $F(8,176) = 5.12, p < .01$. Separate regression analyses of the T2 | T1 data from each of the test blocks revealed the linear relationship between ISI and T2 | T1 accuracy to only be statistically significant in the second test block, $F(1,3) = 48.43, p < .01$ (see bottom left panel of Figure 4).

[20] Regression analyses were completed separately for the data from the two task conditions.

Not surprisingly – given the practice effects evidenced by improvements in T1 and T2 | T1 accuracies - the mean magnitude of participants' attentional blink decreased significantly over time, $F(2,44) = 3.43, p = .04$. It was not significantly different between the first and second blocks, $F(1,44) = 1.11, p = .30$, or second and third blocks, $F(1,44) = 2.40, p = .13$, but was significantly smaller in the third test block relative to the first, $F(1,44) = 6.77, p = .01$. The means for each of the test blocks are provided in Table 3.

Effects of task order. As expected, task order had no main or interaction effects on T1 accuracies, T2 | T1 accuracies, or blink magnitude.

Effects of task condition. The participants in each of the two task conditions identified an equivalent proportion of T1s and T2 | T1s on the blink task. ISI did not differentially influence their performance on either set of targets, as shown in the four panels of Figure 4. Participants in each condition also experienced equivalent blink magnitudes. As indicated in Table 2, the mean magnitude for participants in the integrated condition (0.56 (*SE* = 0.07)) is statistically equivalent to that for participants in the separate condition (again, 0.44 (*SE* = 0.06)).

The main effects of test block on T1 accuracy and T2 | T1 accuracy, as found in the separate-only dataset, persisted in the combined (separate + integrated) dataset, $F(2,108) = 12.73, p < .01$), $F(2,108) = 22.58, p < .01$ respectively) and did not interact with the condition variable. The ISI by test block interactions that were found in the separate-only dataset also persisted in the combined dataset for T1 accuracy, $F(8,432) = 10.71, p < .01$) and T2 | T1 accuracy, $F(8,432) = 9.20, p < .01$. These ISI by test block interactions did not vary across the two task conditions. Similarly, the combined data from the separate and integrated conditions demonstrated a continued main effect of test block on blink magnitude, with no interaction between the test block and condition variables.

CPT

Initial analyses of the data from the CPT in this experiment were exploratory. The goal of these analyses was to determine if the current version of the task elicited, for each of its indices, reasonable values as compared to those that are reliably obtained and reported in the literature. The indices of interest included participants' overall hit rate ([0,1] range), false alarm rate ([0,1] range), target sensitivity – A' ([0,1] range), and response bias - B" ([-1,1] range). After determining reasonable values in all test blocks and in both task conditions, a repeated measures ANOVA was computed on the test block means for each index (and for target RT) from only the participants in the separate condition. The findings of interest were the patterns that each index demonstrated over time, with performance maintenance presumed to reflect sustained attention, an improvement in performance presumed to reflect a practice effect, and a decrement in performance presumed to reflect a fatigue effect. Task order was entered as a between-subjects factor, and test block as a within-subjects factor, into each of these ANOVAs.

To determine the effect, if any, of task condition upon participants' CPT performance, the ANOVAs were repeated on the entire dataset (i.e., data from both the separate and integrated conditions). Task condition was entered into these analyses as a between-subjects factor whereas test block remained as a within-subjects factor. (No condition effects were expected as the only manipulation between conditions involved the format of the Simon, flanker, and stop-signal tasks that were completed.)

Target card sequences. As expected, test block had a main effect on participants' hit RTs, $F(2,44) = 8.50, p < .01$) on the CPT. As indicated in Table 2, participants were not faster in the first block relative to the second, $F(1,44) = 0.55, p = .46$, but were faster in the second block relative to the third, $F(1,44) = 9.88, p < .01$. A change was also observed in participants' hit rates, $F(2,44) = 3.76, p = .03$. Just as Table 2 shows, participants detected a greater proportion of target card sequences in the first block relative to the second, $F(1,44) = 7.42, p < .01$, but not in the second relative to the third, $F(1,44) = 1.19, p = .28$. The mean hit rate in the first test block was higher than that in the last two blocks combined, $F(1,44) = 6.33, p = .02$. Together, the RT and accuracy data suggest a fatigue effect (as was also found on the stop-signal task but contrasts with the practice effects shown on the Simon and flanker tasks).

Distracter card sequences. As expected, participants' overall false alarm rate on the CPT increased over testing time, $F(2,44) = 16.12$, $p < .01$. Despite an unexpected trend for it to be lower in the second test block relative to the first, $F(1,44) = 3.64$, $p = .06$, it was significantly higher in the third test block relative to the second, $F(1,44) = 31.21$, $p < .01$. The different types of distracter trials influenced the overall false alarm rate, $F(3,66) = 41.42$, $p < .01$. Participants responded to significantly more [7H Alone] trials relative to the three other types of distracter trials ([7H/R/AS], [AS Alone] and [All Random]; $F(1,66) = 123.91$, $p < .01$). Furthermore, test block and distracter type interacted in their influence on participants' rate of false alarms, $F(6,132) = 12.09$, $p < .01$. In particular, the data revealed a significantly higher response rate on the [7H Alone] trials relative to the three other distracter types in the first, $F(1,66) = 15.87$, $p < .01$, and last, $F(1,66) = 123.13$, $p < .01$, test blocks but no effect of distracter type on participants' false alarm patterns in the middle test block, $F(3,72) = 1.00$, $p = .40$; this interaction is graphed in the left panel of Figure 5.

All card sequences. Participants' sensitivity to target versus distracter card sequences on the CPT was very high across all test blocks (see Table 3), with an overall mean of 0.99 ($SE < .01$). Nonetheless, the decrease over time was statistically significant, $F(2,44) = 4.47$, $p = .02$. Planned contrasts showed that participants were significantly more sensitive in the first test block relative to the second, $F(1,44) = 4.29$, $p = .04$, but not in the second relative to the third, $F(1,44) = 0.69$, $p = .41$. Also revealed in Table 3 is the finding that participants' mean response bias on the CPT varied over the three test blocks, $F(2,44) = 11.41$, $p < .01$. The overall bias was slightly conservative, with a mean of –0.18 ($SE = 0.07$). The pattern over time was not expected. Whereas a fatigue effect would implicate an increasingly liberal bias over time, a planned contrast showed the unexpected twist that participants responded more conservatively in the middle test block relative to the first and third blocks combined, $F(1,44) = 18.90$, $p < .01$. In other words, participants were more conservative in their responding on the second test block relative to the first (perhaps as a function of increased task familiarity; $F(1,44) = 7.71$, $p < .01$) but more liberal in the third test block relative to the second (as expected, and presumably due to increased fatigue; $F(1,44) = 22.60$, $p < .01$).

Effects of task order. As expected, task order had no first-, second-, or third-order effects on any of the dependent variables in the CPT of this project.

Effects of task condition. As expected and as indicated in Table 1, the participant groups did not differ in their overall target RTs on the CPT, nor did test block and condition interact to influence their RTs. The two groups also detected a statistically equivalent proportion of the [7H/AS] targets, although test block and condition unexpectedly interacted to influence this proportion, $F(2,104) = 3.30$, $p = .04$. Post hoc t-tests revealed an almost-significant finding that participants in the integrated condition made more hits in the second test block than did participants in the separate condition, $t(52) = 1.96$, $p = .06$. The two participant groups had statistically equivalent hit rates in the first, $t(52) = -1.50$, $p = .14$, and third, $t(52) = -0.48$, $p = .63$, blocks. This, then, suggests a delayed fatigue effect for the integrated condition. The groups did not differ in their overall false alarm rate or their false alarm rates across the four types of distracters (as graphed in Figure 5). Test block did not differentially influence the groups' overall false alarm rate or their false alarm rates for each of the different distracters.

As with their target RTs, hit rates, and false alarm rates, the two groups of participants did not differ in their target sensitivities. An almost-significant interaction suggested that they differed in their patterns of sensitivity over the testing time, however, $F(2,104) = 2.99$, $p = .05$. As was the case for their hit rates, post hoc t-tests showed the two groups to be equally sensitive in the first, $t(52) = -0.60$, $p = .55$, and third, $t(52) = -0.75$, $p = .46$, test blocks but a trend for the participants in the integrated condition to have been more target-sensitive than their control counterparts in the second block, $t(52) = 1.95$, $p = .06$. The difference was not significant in the context of a Bonferroni adjustment for the family-wise error rate but suggests, as was the case for hit rate, a delayed decline in performance in the integrated condition. Task condition did not have a main effect on participants' response bias on the CPT nor did it interact with test block to influence bias.

Chapter 10. Experiment 1 Discussion

Five tasks of attention (Simon, flanker, stop-signal, blink, and continuous performance) were administered to a sample of 60 university students in Experiment 1 of this project. These tasks were chosen on the basis of past literature to provide isolable measures of filtering, interference control, response inhibition, encoding capacity limits, and sustained attention, respectively. The tasks themselves were designed for specific use in the main child experiment of this project (Experiment 2) and employed parameters that are common in the literature. An appreciation for the particular time demands that study participation can have on children (especially those with ADHD) and their caregivers motivated the development of an integrated Simon/flanker/stop task. The integrated task required less administration time than the total of the three tasks administered separately but was designed to produce the same effects. Prior to adopting its use in place of the three separate tasks, however, its reliability needed to be determined. Therein lay the purpose of Experiment 1.

Because two of the three shortened tasks (Simon and flanker) were originally developed using adult populations and have since been primarily used with the same, an adult (rather than child) population was chosen for study in this experiment. A "bonus" was the opportunity to test the reliability of the two additional tasks (blink and continuous performance) that were also designed for specific use in the second experiment of the project. The five separate Simon, flanker, stop-signal, blink and continuous performance tasks were administered to 30 adults in the separate condition of Experiment 1 whereas the integrated, blink and continuous performance tasks were administered to 30 adults in the integrated condition of the experiment. It was hypothesized that the five separate tasks would demonstrate their expected effects (as detailed in adult literature) and that the integrated task would demonstrate the expected effects on the Simon, flanker, and stop-signal trials. If this proved to be the case, the shorter attention battery (including the integrated task) was to be used in Experiment 2. If the integrated task failed in its ability to isolate the intended components of attention, the longer battery with the five separate tasks was to be used in Experiment 2.

The adults in the separate condition of Experiment 1 performed as expected on each of the five separate attention tasks that were administered. For example, on the Simon task, the adults demonstrated a response-interference effect due to the S-R conflict that was present between the target location and the location of the appropriate response key. This effect was observed in both their processing speed and their accuracy and showed that the adults could not perfectly filter the irrelevant location of the target. (Notably, given the lack of visual distracters, the focusing component of attention was not considered to be isolated on the Simon task.) The warning tones that preceded most Simon trials by varying intervals effectively warned participants that the target, and hence the need for a response, was imminent. Participants received the greatest alerting benefit (evidenced by shorter RTs) on the trials with the shortest cueing intervals. The increased alertness produced a speed-accuracy trade-off on these trials.

Whereas the Simon task was considered to isolate only the filtering component of attention (at least as conceptualized in this project), the flanker task tapped into an integration of the focusing and filtering components of attention. Participants were required to cognitively filter the irrelevant identities of the flankers. The manipulation of the distance between the targets and the flankers allowed an assessment of the participants' proficiency in spatially focusing their attention so as to accomplish that filtering. For the purposes of this project, such an integration of the focusing and filtering components was termed interference control.

As expected, the adults demonstrated slower mean reaction time on incompatible relative to compatible trials, presumably because of the S-S and S-R conflict that existed between the targets and flankers on these trials. A significant reduction of this FCE was observed on middle-flanker trials relative to near-flanker trials. A further reduction was not observed on the far-flanker trials, however. This suggests a possible plateau in the adults' ability to narrow their visual attention beam, at least within the unique stimulus displays that typified the flanker task in this experiment. Whereas the adults were not able to fully narrow their attention beam to the 2.86° that spanned the minimum edge-to-edge flanker separation on near-flanker trials, they could effectively narrow it to the 5.50°

that spanned the equivalent distance on middle-flanker trials (at least to the same extent that they narrowed it on far-flanker trials wherein 8.36° separated the internal edges of the flankers).

Notably, the main effect of trial type and an interaction of the trial type and flanker distance effects were observed in participants' accuracies but did not reach statistical significance, most likely due to ceiling effects. Participants' accuracies were generally very high, indicating that the target identification task was easy for them. All in all, the participants showed improved interference control as a function of an increase in the spatial expanse separating task-relevant from task-irrelevant stimuli – at least, this is one interpretation of the data. Alternately, the adults had a reduced need for interference control on the far-flanker trials and, thus, demonstrated equivalent task performance on the middle- and far-flanker trials. Further detail regarding the adult's visual attention beam and its width (as measured on the flanker task and relative to that of children) is provided in the discussion of Experiment 2 (see Chapter 13).

As with the Simon and flanker tasks, the adults in Experiment 1 demonstrated the expected effects on the stop-signal task. Participants ultimately withheld their responses to targets on approximately half of the stop trials. Thus, the stop delay paradigm (modeled after Logan et al., 1997) operated in the manner in which it was intended. Furthermore, the visual stop signal (i.e., white computer screen) was shown to be as effective as an auditory tone that is traditionally used in stop signal paradigms. Given these successes in administration, the stop-signal task designed for this project was considered to be an effective measure of response inhibition. The blink task, on the other hand, was shown to be an effective measure of the capacity limit of the attentional system for rapidly presented visual stimuli. As expected, the adults had no difficulty identifying the initial masked target on each trial but difficulty – increasing as the ISI increased – in identifying the second masked target. Furthermore, the magnitude of the attentional blink that participants experienced was successfully measured without the use of a baseline condition. The blink was quantified on the assumption that participants' average performance on the second target on trials with the longest ISI reflected how well the second target might be processed in the absence of a demand to process the first target (or in the actual absence of the first target). One curious finding on this task was the positive correlation between ISI length and T1 accuracy. The same finding occurred in Experiment 2 and will be addressed in more detail in the discussion of that experiment.

As expected, the adults demonstrated a reduced ability to sustain alertness over time on the fifth and final task administered in this experiment, the CPT. The decrease was evidenced by longer RTs, fewer hits, more false alarms, and decreased target sensitivity over testing time. Despite its statistically significant decrease over time, participants' target sensitivity was very high overall and almost established a ceiling effect – thus indicating that the task was easy for adults. Participants' response bias was expected to become more liberal over testing time. Surprisingly, participants were more conservative in their response style in the second test block relative to the first. Nonetheless, they responded more liberally in the third test block relative to the second. The type of distracter trial was varied and differentially influenced participants' false alarm rates. Not surprisingly, false alarms were most frequently made to [7H Alone] card sequences; this pattern reflects anticipatory responses as the target sequence was [7H/AS]. The anticipatory responses were only significantly more frequent than the other types of false alarms in the first of three test blocks, indicating improved performance as a result of practice on, and exposure to, the task.

The adults in the integrated condition appeared to have experienced greater demands on their working memory than those in the separate condition. This is not surprising, as they were required to remember multiple "rules" about how to perform on each trial of the integrated task (versus one rule on the separate tasks). Furthermore, there was a level of uncertainty on each trial regarding what type of stimulus display to expect - and thus what type and level of cognitive demand would need to be invested. Given the trial uncertainty, it is likely that the participants needed to maintain a broad expanse of visual focus on all trials of the task to account for possible peripheral targets (as occurred on Simon trials) and respond accordingly. The maintenance of a broader attentional beam over what was a comparatively longer testing time in any given test block was arguably more cognitively taxing than the maintenance of broad/narrow attention beams for shorter blocks of time as occurred on the separate (Simon, flanker, and stop-signal) tasks.[21] Past research with a blink paradigm similar to that used in this experiment indicates that trial uncertainty within a test block produces a maximal allotment and maintenance of attentional resources relative to trial predictability within a test block (Shore et al., 2001).

Given the likely increase in their cognitive load, it is not surprising that the participants in the integrated condition demonstrated generally slower performance on the Simon, flanker, and stop-signal trials relative to their control counterparts in the separate condition. In response to the likely increase in cognitive load, however, these participants appeared to have made a greater cognitive investment. This is indicated by their relatively higher accuracy rates on the Simon and flanker trials.

The increased accuracy on the Simon and flanker trials in the integrated task was equivalent to the mean rate of accuracy on the go trials of the separate stop-signal task. Other equivalent effects between the separate and integrated tasks included the effect of the pre-tone warning intervals on participants' target RTs on Simon trials. The trial type and flanker distance factors did not interact in the expected manner on either group's target accuracies. As for effects on stop trials, both participant groups demonstrated equivalent SSRTs and P(I | S).

Some task manipulations in the integrated Simon/flanker/stop task did not have the expected effects on participants' performance. For example, the different warning intervals did not influence participants' target accuracies on Simon trials (whereas they did in the separate Simon task). Furthermore – and most relevant to the decision about the attention battery for Experiment 2 – participants in the integrated condition demonstrated an FCE in their target RTs that did not decrease in magnitude as the

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[21] The reader is reminded here that test blocks in the integrated task were respectively longer than any given test block from the corresponding separate tasks (Simon, flanker, and stop-signal; see Methods for details).

flankers were located further from the targets. The presence of an FCE that did not interact with distance suggests that the participants in the integrated condition did not focus their attention beam effectively. The most convincing difference in the flanker task performance by the separate versus integrated group is apparent on far-flanker trials. On these trials, the separate group shows no FCE in their target RTs whereas the integrated group shows a large one. The most likely reason for the lack of filtering of far flankers by the integrated group relates to the locations that must be attended on each trial. As previously indicated in this discussion, participants completing the integrated task must continually monitor the full computer screen for optimal task performance (given the possibility for peripheral targets as occurred on Simon trials). Conversely, the participants completing the separate flanker task can safely narrow their attention beam to the largest flanker-to-flanker expanse (as occurs on the far-flanker trials) and still maintain optimal performance. Of note is the difference in width of these two expanses: the distance from the external edge of a "left" Simon trial (i.e., target on the left side of the computer screen) to the external edge of a right Simon trial was 20.78° whereas the edge-to-edge distance of the stimulus display on a far-flanker trial was only 11.00°.

Beyond those already identified, other effects were observed in the performance comparisons of the two participant groups. One was that the main effect of trial type on participants' target accuracies reached statistical significance on flanker trials in the integrated task (whereas it did not on the separate flanker task). Additionally, unexpected effects of condition were shown for the decline of participants' hit rates and target sensitivity over time on the CPT. Although follow-up tests did not reach statistical significance, trends were indicated for delayed declines in these indices for the participants in the integrated condition. These delayed fatigue effects are suggestive of a greater level – or persistence – of alertness which, in itself, may be a function of the suspected increase in allocation of cognitive resources relative to the separate condition (see related discussion earlier in this chapter). It is especially interesting that the benefits of the increased cognitive resources, elicited by manipulations of the Simon, flanker, and stop-signal tasks, extended to the CPT (which, to remind the reader, was exactly equivalent in the two conditions). Other than the trends indicated, the two groups demonstrated equivalent performance on the CPT. As expected, both groups demonstrated equivalent performance on all measures from the blink task.

Several decisions were made about the attention battery in Experiment 2 as a result of the findings in this experiment. The first was that all of the separate attention tasks were reliable measures of the intended components of attention. The second decision was that the integrated task did not effectively isolate the interference control component of attention. Thus, the longer attention battery incorporating five distinct tasks was chosen for use in the second experiment in this project. The third decision made as a result of Experiment 1 findings was to fix the task order for all children in Experiment 2. As detailed in the results, the order in which the Simon, flanker, and stop-signal tasks were administered to participants influenced some performance effects. By fixing the order of the tasks in the second experiment, any task order effects that would be produced in the children would be consistent for both groups and in both contexts – and thus would not confound any effects of the same.

Chapter 11. Experiment 2 Methods

Participants

A total of 73 children took part in this study at Dalhousie University in Halifax, Canada. This included 29 children with ADHD according to DSM-IV criteria (8 girls, 21 boys) and 44 control children (23 girls, 21 boys). As part of the study, each child had at least one parent or guardian complete a series of questionnaires and interview questions regarding the child's behavioural and emotional functioning. These caregivers (hereafter referred to as parents) included: biological mothers ($n = 55$), fathers ($n = 10$), and aunts ($n = 3$), as well as adoptive mothers ($n = 3$) and fathers ($n = 3$), and one foster mother. The children were recruited through word of mouth ($n = 22$), an advertisement on a local radio station ($n = 17$), advertisements in local newspapers ($n = 11$), posters distributed throughout local workplaces ($n = 9$), an e-mail distributed by a university newsgroup ($n = 4$), advertisements by the local support agency for families of children with ADHD ($n = 2$), and an announcement on a local television morning show ($n = 2$). The recruitment source was not recorded for six children.

The inclusion criteria for children in this study were: (1) between 7 and 11 years old, (2) no known serious physical, intellectual or mental health problems (except ADHD, as applicable), (3) normal or corrected-to-normal vision, (4) the ability to comprehend spoken English, and (5) an IQ (as measured by a brief screen) of 80 or higher.[22] The children with ADHD were required to have the diagnosis assigned by a physician or

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[22] An IQ > 80 was chosen as an inclusion criterion to eliminate below-average intelligence (APA, 2000) as a possible reason for any results. This cut-off has been used in a variety of research on children with ADHD (e.g., lab-task studies: Grodzinsky & Barkley, 1999; Jonkman et al., 1999; reward studies: Barber et al., 1996; Lawrence et al., 2004; ERP studies: Sartory et al., 2002; MRI studies: Casey et al., 1997).

Notably, in using the stop-signal task in four subgroups of children (control, ADHD, disruptive, and anxious), Oosterlaan and Sergeant (1998) showed a statistically significant (albeit weak) association between IQ and mean reaction time, and between IQ and mean standard deviation of reaction time. Thus, using a restricted intelligence range as an inclusion criterion in a study on children's attention appears to hold some value.

mental health professional. Additionally, as applicable, children were required to be removed from stimulant medication for at least twelve hours prior to testing. Control children were required to have no immediate family members diagnosed with ADHD. To be involved in the study, parents required the ability to comprehend spoken English and the ability to answer questions (both orally and in writing) about his/her child's behavioural and emotional functioning. Each parent/child pair received a total of $30 as reimbursement for the time taken to participate. Each child also received several small prizes (e.g., bubble gum, "whoopee cushions," "slinkies") during the study.

The final sample used for data analyses in this project included 45 of the 73 children that were tested: 19 children with ADHD (six girls, 13 boys) and 26 control children (14 girls, 12 boys). The excluded participants included ten children with ADHD (two girls, eight boys) and 18 control children (nine girls, nine boys). Children were excluded from the ADHD group for the following reasons:[23]

1. Did not meet criteria for ADHD on either of the following: KSADS-P/L, CPRS-R:L, DBD Rating Scale ($n = 4$)
2. Data loss due to power failure ($n = 1$)
3. Estimated IQ < 80 plus:
    a. Global developmental delay ($n = 1$)
    b. Significant learning difficulties[24] ($n = 1$)
4. Met criteria for ADHD-PI but < 3 hyperactive symptoms on KSADS-P/L ($n = 1$)
5. Met criteria for Conduct Disorder on KSADS-P/L ($n = 1$)
6. Suspected Fetal Alcohol Effect + global developmental delay ($n = 1$)

Children were excluded from the control group for the following reasons:

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[23] See *Materials* section in this chapter for full names of checklists/questionnaires.

[24] As suggested by parent's report of child's longstanding academic difficulties, extensive use of in-school resource services, and need for individualized tutoring.

1. Four ADHD symptoms (threshold level) endorsed on at least one of the following: KSADS-P/L, CPRS-R:L, DBD Rating Scale ($n = 5$)
2. Estimated IQ < 80 ($n = 3$)
3. Did not return for second session ($n = 2$)
4. Six ADHD symptoms (subthreshold level) endorsed on at least one of the following: KSADS-P/L, CPRS-R:L, DBD Rating Scale ($n = 1$)
5. Functional impairment due to symptoms of Separation Anxiety Disorder ($n = 1$)
6. Data loss due to technical error ($n = 1$)
7. One session not completed due to time restraints ($n = 1$)
8. Symbol processing deficits + history of medical concerns ($n = 1$)
9. Reason #1 + less than normal-level vision ($n = 1$)
10. Reason #2 + history of medical concerns ($n = 1$)
11. Reason #1 + Reason #8 ($n = 1$)

Some inconsistencies were present in assigning subtypes on the basis of the clinical interview and the KSADS-P/L versus the behavioural checklists (i.e., CPRS-R:L and DBD Rating Scale), a non-surprising result considering the variation inherent in different interview modalities, symptom wording, and Likert scale options. Clinical judgement was applied to these collective results and the following subtype distribution determined for the final ADHD sample: combined ($n = 14$), predominantly hyperactive-impulsive ($n = 1$), and predominantly inattentive ($n = 4$). A combined-measures approach was also used for determining comorbidity with Oppositional Defiant Disorder (ODD). A conclusion was drawn that nine of the children with ADHD (and none of the control children) met DSM-IV criteria for ODD. Of the children with ADHD, 11 were reported to have a history for the disorder within their immediate biological families whereas five were negative for immediate-family history. This information was not known for two of the children and was not recorded for one child. None of the children in the control group had a positive history for ADHD within their immediate families.

Reports by parents regarding additional resource services received at school, individualized tutoring received outside of school, and academic difficulties throughout school history suggested that two of the children in the ADHD group experienced mild learning problems, an additional child in the ADHD group experienced significant learning problems, and no child in the control group experienced any level of learning problems. Eight of the children in the ADHD group were reported by their parents to be currently on psychostimulant medication for ADHD symptoms (excluding the 12 hours prior to each testing session). Similarly, eight were reported to have been on one or more psychostimulant medications in the past for ADHD symptoms and three were reported to be psychostimulant-naïve. No child in the final sample was determined on the basis of the KSADS-P/L interview to meet full DSM-IV criteria for any of the following disorders: Conduct Disorder, Separation Anxiety Disorder, Social Phobia, Mania or Major Depressive Disorder.

The racial make-up of the final sample of 45 children was as follows: 40 were Caucasian, two were African Canadian, one was Chinese Canadian, one was biracial (Native Canadian / Caucasian) and one was born in Canada to parents who had emigrated from Somalia. Data regarding family structure was also gathered in this project. Of the final sample of 45 children, 42 lived with their biological mothers and three lived with adoptive mothers. Similar data regarding fathers was not reported for 11 children (this likely included single-mother households). Reported data revealed that 25 children lived with their biological fathers, six lived with stepfathers and three with adoptive fathers. Demographic data regarding parental education and income is revealed in Table 4.

The mean age for the final sample of children in this experiment was 9.75 years (SD = 1.34) for the participants with ADHD and 9.72 years (SD = 1.44) for their control counterparts; an unpaired t-test showed that these mean ages were statistically equivalent. Similarly, no differences were found in the average laterality quotient for the ADHD group (M = +58.81, SD = 34.09) and that for the control group (M = +35.58, SD = 53.89), $t(43) = 1.65, p = .11$. The mean estimated IQ for the ADHD group was 99.95 (SD = 11.90) and for the control group was 114.58 (SD = 13.57); the difference was statistically significant, $t(43) = -3.76, p < .01$. When broken down by ability type, the children with ADHD were shown to have a significantly lower verbal IQ, $t(43) = -4.45, p < .01$, and a trend towards a significantly lower performance IQ, $t(43) = -1.93$, $p = .06$, than the control children.

As will be outlined in the procedure for this experiment, participants were shown playing cards one at a time for 30 seconds and asked to label as many as possible. On average, the children with ADHD correctly identified 13 cards and incorrectly identified one card. Control children identified an average of 15 cards correctly and no cards incorrectly. These levels of correct versus incorrect performance were statistically equivalent for the two groups. The order in which the children in Experiment 2 completed the two test batteries ("context order") was counterbalanced in each of the participant groups. A chi-square test completed on the order distribution within the two participant groups showed it to be equivalent.

Materials

The Edinburgh Handedness Inventory (Oldfield, 1971) was used, as in Experiment 1, to assess each participant's handedness. Cue cards were used to teach the children how to complete the Simon, flanker, stop-signal, and blink tasks. A traditional deck of playing cards was used to teach the children how to complete the CPT and also to assess their level of familiarity with the four card symbols. The Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) was used to gain an estimate of each child's intelligence. Additionally, parents completed the following measures regarding their children: (1) a clinical interview that included questions about mental health, educational history, and medication use,[25] (2) the Kiddie Schedule for Affective Disorders – Present/Lifetime Version (KSADS-P/L; Kaufman, Birmaher, Brent, Rao, & Ryan, 1996), (3) the Conners' Parent Rating Scale Revised – Long Version (CPRS-R:L; Conners, 1997), (4) the Parent/Teacher Disruptive Behavior Disorder Rating Scale (DBD Rating Scale; Pelham, Gnagy, Greenslade, & Milich, 1992), and (5) a short demographic questionnaire on socioeconomic status (developed for this study).

[25] The interview was developed for this study and based on Barkley's (1990) ADHD Clinic Parent Interview.

All participants completed both paper-and-pencil and computerized testing in the same room under the same lighting conditions, with the exception that one child's video game condition was completed in an alternative room due to a room scheduling oversight. The same experimenter administered all tests to (approximately) the first 55 children in the experiment; a second experimenter completed all testing for the remainder of the sample. The computerized attention battery used with the adults in Experiment 1 was reprogrammed (and the video game display newly programmed) for Experiment 2, using OSX rather than OS9. The use of CodeWarrior and a MacIntosh G3 computer remained the same. Except for a small number of task modifications (detailed in the following paragraph), the attention battery used in both conditions of Experiment 2 was identical to the one used in the separate condition of Experiment 1 (see Chapter 8 for details).

The trial sequence and time parameters used for the blink task in Experiment 2 was the same as in Experiment 1, with the exception that target durations were 90 ms for T1 and 60 ms for T2 (rather than 45 ms and 45 ms, respectively). Whereas target combinations and trial order were randomly determined for the first participant and maintained for all remaining participants on the blink task in the adult experiment, they were randomly determined for each and every participant in the child experiment. Similarly, trial type and trial order were randomly determined for all participants on the Simon task in Experiment 2 (versus only the first participant as was the case in Experiment 1).

The display screen of the computer monitor was divided into two parts throughout all testing in Experiment 2 (in the same fashion as in Experiment 1), with task-relevant stimuli restricted to the top portion of the screen. The task-specific instruction panels that appeared in the top half of the computer screen throughout the attention battery were identical in each of the two conditions in Experiment 2. In the traditional condition, the program's software was designed to have the bottom of the monitor screen appear black. In the video game condition, the bottom half of the screen showed a changing background whereby the participant faced an illusion of traveling along a gravel path toward a bridge as he/she completed each task. Advancement toward the bridge was made with each response in each task, regardless of response accuracy. The completion of each task corresponded with the illusion that the participant had reached the bridge and the water stream that appeared to flow underneath it. At the start of the next task, the screen was refreshed and the participant faced a continuance of the same gravel path, again with the illusion of progressing toward a distant bridge as he/she completed the task.

Computer-generated graphics of cartoon characters, animals and scenery (e.g., a dog, a barn, flowers) accompanied the image of the path and stream that appeared in the video game condition of Experiment 2. As the participant progressed toward the bridge in each task, he/she appeared to approach and recede away from each of these objects. Ten coins (graphically speaking) were evenly dispersed along the path from its origin to the bridge in each task administration, including the practice tasks. As each participant reached a coin, it was added to the tally of "Total Coins" shown in the bottom left of the screen and to the "Coins in this Land" counter shown in the bottom right of the screen. In contrast with the latter counter, the former counter was not reset between tasks and therefore showed a running total of the number of coins the participant had earned up to a given point in the attention battery.

At the completion of each task in the video game condition of Experiment 2, animated fireworks were shown on the entire computer screen, accompanied by explosion sounds. The fireworks were followed by the image and sounds of a piggy bank filling with the ten coins from the task just completed. The video game condition was also unique in that it provided colorful depictions of coins, crowns, creatures, prizes and the like on screens (hereafter referred to as story screens) in the top half of the computer screen at the beginning of the attention battery and between tasks. These story screens were in addition to task instruction screens and were used to explain the story that accompanied the visual cartoon display.

The story that accompanied the video game graphics was explained to participants at the start of the computerized task battery by a pre-recorded human voice. Upbeat background music accompanied the story telling. The participants stepped through the story sequence at their own pace by pressing a button on the keyboard when ready for the next piece. The story line, path images, fireworks and coins were not a part of the traditional attention battery. The traditional attention battery included only the standard task instruction screens and blank coloured screens that corresponded to the story screens in the video game battery. The task parameters (e.g., stimuli, timing) were exactly equivalent in each of these two conditions.

Procedure

Each child and his/her parent came to the lab on two occasions approximately one week apart, with each visit lasting approximately two hours and involving one of the two task conditions (traditional or video game). The children were randomly assigned to one of the two testing orders (traditional then video game or vice versa). On the first visit to the lab, informed consent was obtained from both parent and child for participation in the study. Following this, a research assistant brought the child into the testing room and began testing. In the meantime, the researcher (SS) interviewed the parent using the clinical interview (discussed in the Methods) as well as the KSADS-P/L. The parent then completed the CPRS-R:L, the DBD Rating Scale, and the demographic questionnaire. Although the interviews were almost always administered prior to the form completion, this order was reversed for some parents for scheduling reasons.

After making the child feel comfortable and allowing him/her to explore the testing room, the research assistant administered the Edinburgh Handedness Inventory (Oldfield, 1971) to the child by reading each item aloud and asking for the appropriate response. Next, the assistant gave an overview of the computerized attention battery, explaining that there were five tasks and each child would be asked to complete the series of five tasks four times. This overview was aided by graphic representations of the task set-ups that were posted on the wall. The assistant explained that the first time through the tasks would be practice and the remaining times would be "the real thing" (referring to experimental blocks).

After the child seemed to understand the set-up of the attention battery, the experimenter explained the tasks and practiced them using cue cards and a deck of playing cards. The assistant then showed the child one playing card after another and asked the child to name each card as quickly as he/she could. The child was given 30 seconds for this activity. Next, the child's attention was directed towards a poster on the wall that listed two rules: (1) stay in your seat and (2) stay on task. The child was told that, if he/she followed these rules for all of one round (series of five tasks), with an allowance of one warning per rule per round, the child would earn a "prize grab." A prize grab was the opportunity for the child to reach his/her hand into a box covered in wrapping paper and pull out a small prize.

The child began the attention battery by watching and listening to a series of voice-accompanied screens that introduced the test battery. In the video game condition, this involved watching and listening to the introduction of the storyline in which the tasks would be embedded. The child (for simplicity, suppose it was a girl) was welcomed to "Fast Card World" and was told that the creatures within the world were glad she was there. The story indicated that the creatures needed a ruler and were hoping she could be it. She could become the ruler by reaching the ruler's crown at the end of a very long gravel path. Along this gravel path, she would go through a series of five lands (i.e., the tasks). Within each land, she would earn ten coins. Going through five lands constituted one adventure and there were four adventures in total. The sky above the path would change across the lands from dawn to noonday to dusk to night, thereby giving an indication of progress toward the end of an adventure. If she reached the crown, she would have a total of 200 coins that could be traded in for a collection of prizes (prizes were awarded different values of 50, 100, 150 or 200 coins). She was allowed to browse through the prizes beforehand and choose, if desired, which one(s) she would work for. If she ended early, she would still get to trade the coins she earned for prizes of that value. Notably, the attention tasks were referred to as "tasks" in the traditional condition and as "lands" in the video game condition. The completion of all five tasks was referred to as a "round" in the control condition versus an "adventure" in the video game condition.

Participants were seated 52 cm from the screen (as measured from eyes to screen) and encouraged to maintain this distance throughout all of the computer testing. To reduce discomfort, a chin rest was not used. A check was made on this distance (and required adjustments made, as applicable) at the start of testing and each time the child returned to his/her seat after retrieving a prize grab or taking a short break.[26] The computer testing began with the Simon task ("task 1" / "Speedy Finger Land"). The research assistant read instructions for this task to the child and then watched as the child completed the practice block for this task. This was repeated for each of the remaining tasks: the blink task ("task 2" / "Shape Alert Land"), the flanker task ("task 3" / "Centre Shape Land"), the CPT ("task 4" / "Look-Out Land") and the stop-signal task ("task 5" / "Watch for White Land"). The research assistant provided feedback, including corrections as needed, on each child's mastery of the task requirements. The task instructions used were a simplified version of those used in Experiment 1 and were identical in each condition. Assuming that the child followed the rules for all of the first round/adventure, the child was awarded a prize grab. This whole procedure was then repeated three times for each of the remaining rounds/adventures. Children were given a ten-minute break between the second and third rounds/adventures, in addition to other shorter breaks, as needed, throughout the remainder of the testing.

During the second testing session, parents completed any interviews and questionnaires that had not been completed in the first session. In the meantime, the research assistant administered the WASI to the child in the testing room. Next, the child was provided with an overview of the traditional or video game condition of the attention battery, whichever was not completed in the first testing session. Given that the child generally remembered the instructions for each task (with or without a brief overview), no practice with cue cards or playing cards was provided. Additionally, the 30-second card-naming game was not completed nor were the task instructions formally read to the child in the practice block as they had been in the first testing session. The second attention battery

[26] This was the minimum number of distance checks that were made. More frequent checks were conducted if deemed necessary for any given child.

(i.e., the one not administered in the first session) was then administered. Reminders of instructions were provided at the beginning of each task (in both attention batteries) via graphic computer screens. Assistance in understanding each task was provided by the experimenter as needed.

Chapter 12. Experiment 2 Results

Part I: Overview

Study Design

Like Experiment 1, Experiment 2 was a mixed factorial study. Two between-subjects factors were present: participant group (ADHD versus control) and context order (i.e., the order in which participants completed the two attention batteries). The within-subjects factors on each task were as indicated for Experiment 1: test block (all tasks), trial type (Simon, flanker, stop-signal, and continuous performance tasks), warning interval (Simon task), and flanker distance (flanker task).

Statistical Approach

- See corresponding section for Experiment 1 (Chapter 10).

Outliers and Missing Data

The number of outlying (and thus, excluded) participants on each task in Experiment 2 was as follows: Simon task ($n = 1$), flanker task ($n = 2$), stop-signal task ($n = 6$), blink task ($n = 5$), and CPT ($n = 5$). Each of the participants in the final sample had, at most, one test block of missing data on either - or both - of the traditional and video game versions of any given task. Missing data values were interpolated in the same manner as in Experiment 1. Grand sample means (calculated for the purposes of data interpolation) were calculated using only the data from the corresponding participant group and task context. Ultimately, interpolation was used to estimate missing data for two children on the Simon task, one child on the flanker task, two children on the stop-signal task, and two children on the CPT. (For further detail, see corresponding section for Experiment 1 in Chapter 10).

Report Organization

The results for Experiment 2 are presented in two sections. The first section encompasses only the data from the control children and reflects task reliability.[27] The second section encompasses the data from both the control children and those with ADHD; this second section addresses the project's queries regarding group and context effects on the components of attention. The data in both sections are organized by task and presented in the same task order as the results from Experiment 1. Table 5 provides the group (ADHD versus control) means on each of the dependent variables collected in the experiment. Table 6 provides these means for the contexts and Table 7 provides them for the test blocks. To avoid repetition, these tables will not be re-referenced in this chapter. Table 8 maps out which effects – group, context, group*context, and/or context order - were found to be significant for each of the performance measures of attention, with the exception that this information is provided in Table 9 for the measure of performance stability. All tables are organized according to the components/performance measures of attention as listed in Table 1.

Part II: Findings of Task Reliability in Children

Simon Task

To determine if the Simon task elicited the same trial type and warning interval effects in children as it did in the adults from Experiment 1, repeated measures ANOVAs were computed on the control children's test block means for target RT and target accuracy. Trial type (compatible versus incompatible), warning interval (no tone, 50 ms, 100 ms, 200 ms, 400 ms, and 800 ms), and test block were entered as within-subjects factors.[28] *Effects of trial type.* Trial type showed the expected main effect on the control children's

[27] Data from the clinical group was excluded on the assumption that children with ADHD may show atypical results. The control data included both contexts (i.e., traditional and video game).

[28] Context was automatically entered in all ANOVAs for Experiment 2 as a within-subjects factor. Its effects were only investigated in Part III of the results, however.

RTs, $F(1,22) = 28.45, p < .01$) on the Simon task in Experiment 2. In particular, the children were slower to respond to targets on incompatible trials relative to compatible trials by a matter of 32.69 ms ($SE = 4.71$).[29] A parallel main effect was found for their target accuracies, $F(1,22) = 25.00, p < .01$), wherein the children correctly identified a smaller mean proportion of targets on incompatible trials (92.5% ($SE < 0.01$)) relative to compatible trials (96.3% ($SE < 0.01$)).

Effects of warning interval. The warning intervals for the tone used on the Simon task influenced participants' processing speed, $F(5,110) = 2.38, p = .04$. As shown in the top left panel of Figure 6, participants were faster on trials with the 50 ms warning interval relative to all other trials, $F(1,110) = 4.85; p = .03$, and faster on the combination of trials with 50 ms, 100 ms, and 200 ms warning intervals relative to all remaining trials, $F(1,110) = 7.41, p < .01$. Figure 6 also reveals a pattern for participants' target accuracies that is very similar to the pattern in the RT data (see bottom left panel). However, the effect of warning interval on target accuracy did not reach statistical significance.

Flanker Task

To determine if the flanker task elicited the trial type, flanker distance, and – of greatest interest, the interaction of trial type and flanker distance - effects in children as it did in the adults from Experiment 1, repeated measures ANOVAs were computed on the control children's test block means for target RT and accuracy. Trial type (compatible versus incompatible), flanker distance (near, middle, and far), and test block were entered as within-subjects factors.

Effects of trial type & flanker distance. Neither trial type nor flanker distance had a main effect on participants' target RTs on the flanker task, although a trend for the expected trial type effect (i.e., an FCE) was evident in the *ln*-transformed RT data,

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[29] Although not referenced until Part III, all graphs for Part II of Experiment 2 Results include the data from the ADHD group to facilitate group comparisons.

$F(1,22) = 3.81$, $p = .06$. Despite no clear main effects, trial type and flanker distance interacted in the expected way to influence the participants' processing speed, $F(2,44) = 3.85$, $p = .03$. As shown in the top left panel of Figure 7, the FCE was larger on near-flanker trials relative to middle-flanker trials, $F(1,44) = 6.63$, $p = .01$, and larger on near-flanker trials relative to far-flanker trials, $F(1,44) = 4.78$, $p = .03$.[30] The FCEs on the middle- and far-flanker trials were statistically equivalent in magnitude to each other, $F(1,44) = 0.15$, $p = .70$, and each was equivalent to zero, $t(153) = 0.04$, $p = .97$ and $t(153) = 0.48$, $p = .63$ respectively.

In contrast with the RT data, an FCE was evident in the accuracy data, $F(1,22) = 4.43$, $p = .05$. Flanker distance did not show a main effect on participants' accuracies, although the normalized accuracy data did show a trend for accuracies to increase with flanker distance ($ln(x/(1-x))$-transformed data: $F(2,44) = 2.70$, $p = .08$). Just as the flanker task is designed to show, this finding is suggestive of improved interference control as peripheral distraction is distanced from a central area of focus. In contrast with the RT data, the FCE in participants' target accuracies did not vary in magnitude over the flanker distances. This lack of interaction is evident in the bottom left panel of Figure 7.

Stop-Signal Task

The stop-signal data from the children in Experiment 2 were analyzed in much the same way as the corresponding data from the adults in Experiment 1 (see Chapter 9 for details). Ultimately, an ANOVA that assessed task reliability for the P(I | S) measure among control children included test block as a within-subjects factor. Similar ANOVAs were run on the control children's test block means for target RT, *SD* of target RT, and target accuracy. These ANOVAs included test block as a within-subjects factor.

Go trials. The control children responded to targets on the go trials of the stop-signal task with an overall mean RT of 753.92 ms (*SE* = 11.66). The mean *SD* of the RTs

[30] It is evident in Figure 7 that the interaction between trial type and distance effects cancelled out individual main effects.

was 38.09 (*SE* = 1.21) and the mean proportion of targets that were correctly identified was 96.6% (*SE* < 0.01).

Stop trials. The relationship between the stop delays and participants' P(I | S) on the stop-signal task was analyzed using the same approach as in Experiment 1 for each of the ADHD and control participant groups (see top panels of Figure 8 and related details in Chapter 10). To remove outlying data points, a decision was made to include only data from the stop trials for which the associated delay had at least fifteen observations. As was the case in Experiment 1, this meant 80% of the available data (for each group) were included in statistical analyses regarding participants' response inhibition. Participants' mean P(I | S) is plotted as a function of stop delay and participant group in the bottom panels of Figure 8.

On average, the control children in this experiment successfully inhibited target responses on 67.8% (*SE* = 0.02) of the stop trials. This rate was unexpectedly high and significantly differed from the desired 50% rate ($t(31) = 9.37, p < .01$. It was therefore not valid to calculate the mean SSRT using the race model outlined in Chapter 7. Simple linear regression was used as an alternate approach to study the stop delays and their relation to participants' inhibitory control.[31] The regression showed a linear relationship between the stop delay and P(I | S) variables, $F(1,30) = 7.67, p < .01$. A total of 17.7% of the variation in participants' P(I | S) was explained by the length of the stop delays.

Blink Task

To determine if the blink task elicited the same desired effects from children that it elicited from the adults in Experiment 1, the control children's test block means for T1 accuracy, T2 | T1 accuracy, and blink magnitude were subjected to repeated measures ANOVAs; these ANOVAs included test block as a within-subjects factor.

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[31] Regression analyses were completed separately for the data from each participant group.

Effects of ISI. The repeated measures ANOVA conducted on the data from the blink task indicated that T1 accuracy varied across the ISIs, $F(4,80) = 18.66, p < .01$. A simple linear regression model fit these data well (see top left panel of Figure 9; $F(1,28) = 14.26, p < .01$)[32] and showed that ISI accounted for 31.4% of the variance in the T1 data. Participants' performance on T2 | T1 also varied across the ISIs, $F(4,80) = 23.75, p < .01$. As with T1 accuracy, regression showed T2 | T1 accuracy to increase linearly as a function of ISI (see bottom left panel of Figure 9; $F(1,28) = 67.11, p < .01$. ISI accounted for 69.5% of the variation in T2 | T1 performance. The method used to assign a magnitude to adults' attentional blinks in Experiment 1 (see Chapter 8) was also successful in quantifying children's encoding capacity. On average, the control participants in this study demonstrated a blink magnitude of 0.29 (*SE* = 0.06).

CPT

As was the case for Experiment 1, initial analyses of the CPT data collected in this experiment were exploratory. The goal was to determine that, as for the adults in Experiment 1, the current version of the CPT reliably produced *in children* reasonable values for each of its key indices relative to published literature on the same. The key indices were hit rate, false alarm rate, A', and B". Exploratory analyses separately addressed the means from each test block for each of the participant groups. Further task reliability was assessed via repeated measures ANOVAs of the control children's test block means for target RT, hit rate, false alarm rate, A', and B". The only factors in these ANOVAs were test block and, for the false alarm data, distracter type (wherein four non-target trial types were used in addition to the target card sequence of [7H/AS]). Test block and trial type were within-subjects factors.

Target card sequences. A repeated measures ANOVA on the data from the CPT shows that the children's overall hit RT varied significantly across the test blocks; the means confirm that the RTs got longer as time progressed, $F(2,42) = 4.77, p = .01$. Planned contrasts showed that the increase from the first to second block was almost significant,

[32] See previous footnote.

$F(1,42) = 3.83, p = .06$, but the increase from the second to third blocks was not, $F(1,42) = 1.19, p = .28$. Although the mean target accuracies also suggest that – at least in absolute magnitude - participants detected more target sequences in the first block relative to the last two, the main effect of test block lacked the power to demonstrate statistical significance. The planned contrast of the hit rate in the first test block relative to that in the last two blocks demonstrated a slight trend for decreased target detection over time, $F(1,42) = 3.30, p = .08$. Collectively, the findings support the conclusion of a fatigue effect developing over testing time.

False alarm card sequences. Somewhat surprisingly, participants did not commit a greater proportion of false alarms as testing progressed on the CPT, nor did their false alarm rate vary as a function of the distracter type (see left panel of Figure 10). Additionally, an interaction between the effects of the test blocks and the distracter type was not observed on participants' overall false alarm rate. These results may be due to a ceiling effect, as participants only made an average of 2.70% ($SE < 0.01$) false alarms throughout the three test blocks.

All card sequences. Although participants' target sensitivity appeared to decrease and their response bias appeared to become increasingly liberal over testing time (see Table 7), these test block effects were not statistically significant.

Part III: Effects of ADHD and Context on Attention Task Performance[33]

Simon Task

[33] The reader is reminded here that the analyses in this section included the data from both participant groups.

To assess the effects that ADHD and experimental context had on the attention components of filtering, focusing, sustained attention, and expectancy – all as measured on the Simon task, repeated measures ANOVAs were computed on all participants' mean target RTs and accuracies. Group (ADHD versus control) and context order (traditional → video game or vice versa) were entered as between-subject factors. Trial type, warning interval, test block, and context were entered as within-subjects factors.

Overall speed & accuracy. The children with ADHD were, relative to the control children, significantly slower to respond to targets on the Simon task by 98.84 ms (SE = 4.46), $F(1,38) = 6.24, p = .02$. Similarly, as indicated in Table 6, all participants were significantly slower to respond to target stimuli in the video game context relative to the traditional context by 54.34 ms ($SE = 4.58$), $F(1,38) = 15.15, p < .01$. The participant groups were not differentially influenced by the contexts in their target RTs. Regarding target accuracies, the children with ADHD correctly identified an average of 6.0% ($SE <$ 0.01) fewer targets than the control group throughout the Simon task; this difference was statistically significant, $F(1,39) = 12.37, p < .01$. Context did not have a similar main effect on the children's performance accuracy, nor did it differentially influence the groups in terms of their target accuracies.

Participants' target RTs on the Simon task changed over time, $F(2,76) = 18.67, p < .01$. Planned contrasts showed that participants were faster in the first test block relative to the last two test blocks, $F(1,76) = 38.47, p < .01$. This main effect was not qualified by interactions with the group or context variables, nor was a three-way interaction between test block, group, and context observed for the target RTs. As with the RTs, test block had a main effect on the children's performance accuracy, $F(2,78) = 4.93, p < .01$. Participants were more accurate in the first test block relative to the final two blocks, $F(1,78) = 7.35, p < .01$. The main effect of test block on participants' accuracies was not qualified by interactions with the group or context variables, nor was a three-way interaction between test block, group, and context observed for the target accuracies.

Effects of trial type. The trial type compatibility effects on participants' target RTs on the Simon task were equivalent for the two participant groups, in the two contexts, and across the three test blocks. For example, whereas the control children were slowed by 32.69 ms ($SE = 4.71$) in responding to incompatible relative to compatible trials (see earlier subsection in this chapter on task reliability), the children with ADHD were slowed by a statistically equivalent extent of 40.17 ms ($SE = 7.83$). Similarly, all participants were 36.62 ms ($SE = 6.12$) slower on incompatible relative to compatible trials in the traditional context versus 35.24 ms ($SE = 6.08$) in the video game context. An interaction was not observed between the effects of participant group, experimental context, and trial type on participants' target RTs.

As was the case for their target RTs, participants' target accuracies demonstrated trial type effects with statistically equivalent magnitudes for the two participant groups, in the two contexts, and across the three test blocks. The control children correctly identified an average of 3.8% ($SE < 0.01$) fewer - and the children with ADHD, an average of 6.4% ($SE < 0.01$) fewer - targets on incompatible trials relative to compatible trials on the Simon task. The difference in accuracies across the trial types, in favor of the compatible trials, was 4.6% ($SE < 0.01$) in the traditional context and 5.3% ($SE < 0.01$) in the video game context. Additionally – and as with the target RTs – an interaction was not observed between the effects of participant group, experimental context, and trial type on participants' target accuracies.

Effects of warning interval. The pre-target warning intervals had the same influence on participants' RTs for each of the two participant groups (see top panels of Figure 6) and in each of the two contexts. Additionally, their influence on the target RTs did not vary across the test blocks nor did an interaction occur between group, context, and warning interval effects upon the target RTs. The same effects were observed for the children's target accuracies. Specifically, as shown in the bottom panels of Figure 6, each participant group demonstrated the same pattern of mean target accuracies across the trials with different lengths of warning intervals. The warning intervals also similarly influenced target accuracies in the traditional and video game contexts, as well as the three test blocks. Finally, an interaction did not occur between group, context, and warning interval effects upon participants' target accuracies on the Simon task.

Effects of context order. The order in which participants completed the traditional and video game attention batteries did not directly influence their target RTs on the Simon task, nor did context order influence the effects that trial type and warning interval had on participants' target RTs. Notably, context order did influence the effect that test block had on participants' RTs, $F(2,76) = 5.76, p < .01$. As with the RT data, context order did not have a main effect on participants' target accuracies nor did it influence the effects that trial type and warning interval had on these accuracies. A significant interaction was found, however, between the effects of trial type, context, and context order on participants' mean target accuracy, $F(1,39) = 5.08, p = .03$. Participants' accuracies also demonstrated an unexpected interaction between the effects of warning interval, context, and context order, $F(5,195) = 2.55, p = .03$. These interactions are beyond the scope of this project and are therefore not discussed any further.

Flanker Task

To assess the effects that ADHD and experimental context had on the attention components of interference control, focusing, and sustained attention - all as measured on the flanker task in this project, repeated measures ANOVAs were computed on all participants' mean target RTs and accuracies. Group and context order were entered into the ANOVAs as between-subject factors. Trial type, flanker distance, test block, and context were entered as within-subjects factors.

Overall speed & accuracy. The children with ADHD were significantly slower than their control counterparts in responding to targets on the flanker task by 138.96 ms ($SE = 6.53$), $F(1,36) = 17.51, p < .01$. Furthermore, all participants were significantly slower to respond to target stimuli in the video game context relative to the traditional context by 52.86 ms ($SE = 6.91$), $F(1,36) = 9.81, p < .01$. In addition to being slower, the children with ADHD correctly identified significantly fewer targets – specifically, an average of 4.6% (SE < 0.01) fewer targets - than their control counterparts, $F(1,37) = 8.74, p < .01$. Experimental context did not have a main effect on target accuracy, however.

The two participant groups were differentially influenced by the traditional and video game versions of the flanker task in terms of their target RTs, $F(1,36) = 6.53, p = .02$. The children with ADHD responded to targets with equal speed in each of the two contexts, $t(304) = 0.73, p = .47$, whereas the control children were slower by a matter of 75.82 ms ($SE = 7.53$) in the video game context relative to the traditional context, $t(455) = 9.82, p < .01$. The children with ADHD were still significantly slower than the control children by 175.76 ms ($SE = 9.17$) in the traditional context, $t(759) = 13.28, p < .01$, and by 103.22 ms ($SE = 9.02$) in the video game context, $t(772) = 7.91, p < .01$. A differential influence of context on each group's target accuracies was not shown.

Children's target RTs changed over time on the flanker task, $F(2,72) = 6.10, p < .01$. Planned contrasts showed that, on average, all participants were faster in the first test block relative to the last two test blocks, $F(1,72) = 9.55, p < .01$. A trend was shown for this pattern to be different for the control and ADHD participant groups, $F(2,72) = 2.98, p = .06$. Test block means for each group suggest that the children with ADHD were faster in the first test block relative to the final two test blocks whereas the control children were (surprisingly) faster in the first *and* third blocks relative to the middle block. A corresponding main effect of test block upon target accuracies was not found, nor was an interaction observed between test block and participant group effects upon target accuracies.

The effects of task context and test block interacted in their influence on children's target RTs on the flanker task, $F(2,72) = 3.50, p = .04$. The context effect appeared to decrease from the first two testing blocks to the third and final testing block. In other words, the slowing effect of the video game context seemed to be less pronounced over testing time. Indeed, post hoc paired *t*-tests on the least squares means of the context effects demonstrated the effect to be significantly larger in the first test block relative to the third test block, $t(238) = 2.44, p = .02$. A three-way interaction between context, test block, and participant group did not take place within the RT data. Converse to the findings with participants' target RTs, the effects of context and test blocks did not interact to influence participants' target accuracies. Additionally, a three-way interaction between test block, context, and participant group did not take place within the accuracy data.

Effects of trial type & flanker distance. The main effects of trial type and flanker distance - and the interaction of these effects - upon participants' target RTs did not differ across the control and ADHD participant groups (see top panels of Figure 7). The main effect of trial type and the interaction between trial type and flanker distance on participants' RTs were also equivalent in the traditional and video game contexts. Notably, the effect of flanker distance on participants' RTs varied according to the context, $F(2,72) = 3.60, p = .03$. Near-flanker trials produced a context effect that was significantly larger than that produced on middle-flanker trials, $t(238) = -2.57, p = .01$. The effect was equivalent in magnitude on the middle- and far-flanker trials, $t(238) = 0.81, p = .42$. As with context effects shown on other tasks in this experiment, it took the form of slower processing in the video game context relative to the traditional context. The main effects of trial type and flanker distance - and the interaction of these effects - upon participants' target accuracies, as with their RTs, did not differ across the control and ADHD participant groups (see bottom panels of Figure 7). Trial type, flanker distance, and the interaction of these two variables, had the same effects on participants' target accuracies in each of the two contexts.

The effects of trial type, group, and task context interacted in their influence on children's target RTs on the flanker task, $F(1,36) = 8.79, p < .01$. The mean trial type difference scores, as plotted in the top panels of Figure 7, suggest that the children with ADHD experienced a larger FCE in the video game context than in the traditional context. Conversely, the control children appeared to experience the same level of interference in both contexts. Post hoc paired t-tests confirmed that the control children's FCEs were equivalent in the two contexts, $t(227) = 0.89, p = .38$, but failed to demonstrate statistical significance for the difference in FCE magnitude across contexts for the ADHD group (although a very slight trend was indicated for this ADHD-specific finding, $t(151) = -1.60$, $p = .11$). The nature of the interaction between the group and context effects on the RT data did not vary across the flanker distances. A four-way interaction among the trial type, distance, group, and context effects on participants' target RTs was not observed. A three-way interaction between trial type, group, and context effects on target accuracies was not observed, nor was an interaction between distance, group, and context effects on participants' accuracies observed. Finally, trial type, distance, group, and context did not interact to influence participants' performance accuracy.

The separate effects that trial type and flanker distance had on participants' RTs to targets did not vary across the three blocks of the flanker task. A trend for reduced filtering abilities over time was evidenced by an almost-significant interaction between trial type and test block in the target accuracy data, however, $F(2,74) = 2.76$, $p = .07$. The FCE in participants' accuracies appeared largest in the third test block. The influence that flanker distance had on participants' target accuracies also varied throughout the three test blocks, $F(4,148) = 2.95$, $p = .02$. A visual assessment of the data suggests that participants were most accurate on trials with near flankers (relative to trials with middle and far flankers) in Block 2 but least accurate on these trials in Block 3. Post hoc paired *t*-tests completed on all pairs of least squares means within each test block, however, did not show these effects to be significant.

The trial type, test block, and task context variables did not interact to influence participants' target RTs nor did the combination of the flanker distance, test block, and task context variables interact to influence the RTs. In contrast with the RT data, the combined effects of the trial type and test block factors on participants' target accuracies did vary across task context, $F(2,74) = 3.32$, $p = .04$. The difference in the size of the FCE in the two contexts appeared to be largest in the third test block, with a larger FCE in the traditional context than in the video game context. Post hoc paired t-tests completed on the data from each block confirmed no difference in FCE size between the two contexts in Blocks 1, $t(128) = 1.34, p = .18$, and 2, $t(128) = -1.04, p = .30$. A very slight trend (especially when Bonferroni corrections are applied to the critical p-value of .05) was shown for the FCE to be larger in the traditional relative to video game context in Block 3, $t(122) = 1.76, p = .08$. Flanker distance, test block, and task context did not interact to influence performance accuracy on the flanker task.

Group differences were observed in the participants' abilities to maintain interference control on the flanker task throughout the three test blocks. Specifically, interactions occurred between the effects of trial type, distance, test block, and group on participants' target RTs, $F(4,144) = 3.26, p = .01$, and target accuracies, $F(4,148) = 2.75$, $p = .03$. These interactions are beyond the scope of this project and are therefore not discussed any further.

Effects of context order. The order in which the children completed the two attention batteries did not have a main effect – or an interactive effect with group - on their processing speed on the flanker task. Context order also did not interact with flanker distance to influence participants' target RTs. It did, however, differentially influence the impact that trial type had on the RT data, $F(1,36) = 4.70, p = .04$. The FCE was larger for participants who completed the traditional attention battery prior to the video game battery (relative to those who completed the batteries in the reverse order) by 33.24 ms ($SE = 8.38$). A four-way interaction between context order, trial type, and flanker distance effects on target RTs was not observed. Regarding target accuracies, context order was shown not to elicit a main effect. Context order also did not influence the main effects that participant group, trial type, flanker distance – or the interaction between trial type and flanker distance variables - had on participants' target RTs accuracies.

The nature of the interaction between the trial type and context order variables differed across the participant groups within their RT data, $F(1,36) = 5.22, p = .03$. The children with ADHD who completed the video game attention battery first experienced a smaller FCE than their same-group counterparts who completed the traditional battery first, t(303) = 3.26, $p < .01$. On the other hand, the control children's FCE did not change as a function of the order in which they completed the attention batteries, t(460) = 0.39, $p = .70$. Similar to the RT data, the interaction shown between the trial type and context order variables came close to differing across the groups within their accuracy data, $F(1,37) = 3.73$, $p = .06$; the nature of the interaction appeared the same as in the RT data.

Context order differentially influenced the effect that test block had on each group's RTs on the flanker task to an almost-significant level, $F(2,72) = 2.81$, $p = .07$. Beyond that, the variables of trial type, context, and context order interacted in their influence on participants' RTs, $F(1,36) = 5.16$, $p = .03$, as did the variables of trial type, group, context, and context order, $F(1,36) = 5.75$, $p = .02$. Context and context order interacted to influence participants' target accuracies on the flanker task, $F(1,37) = 4.93$, $p = .03$. Additionally, an interaction among trial type, distance, context, test block, and context order effects almost significantly influenced participants' target accuracies on the flanker task, $F(4,148) = 2.35$, $p = .06$. The final interaction of effects including context order was the interaction of trial type, flanker distance, group, context, and context order on participants' mean target accuracy, $F(2,74) = 3.60$, $p = .03$. These interactions are beyond the scope of this project and are therefore not discussed any further.

Stop-Signal Task

To assess the effects that ADHD and experimental context had on focusing (specifically, the subcomponents of processing efficiency and response inhibition) and sustained attention (specifically, the subcomponent of performance stability), as measured on the stop-signal task, repeated measures ANOVAs were computed on participants' go RTs, *SD*s of the go RTs, go accuracies, and $P(I \mid S)$. Each of these ANOVAs included group and context order as between-subjects factors. The within-subjects factors included test block and context.

Go trials. The groups did not differ in their overall target RTs on the go trials of the stop-signal task, although the children with ADHD demonstrated more variability in their RT data from that task (by means of a larger *SD*) than did the controls, $F(1,35) = 12.02$, $p < .01$. All participants were slower to respond to target stimuli in the video game context relative to the traditional context, $F(1,35) = 18.22$, $p < .01$) but equally variable in their response speed in each of the contexts. No interactions were found between the group and context variables on participants' target RTs or *SD*s of target RTs. As with their RTs, the groups did not differ in their overall rate of target accuracy on the go trials of the stop-signal task. Furthermore, all participants were equally accurate in both contexts. Group and context did not interact to influence participants' performance accuracy.

The test block variable did not have a main effect on participants' target RTs or the variability in their target RTs on the stop-signal task. Additionally, no group differences in the pattern of participants' RTs over time were found, although a group difference existed in the pattern of RT variability over the three test blocks, $F(2,70) = 3.25$, $p = .04$. Post hoc paired *t*-tests on the least squares *SD* means for each group demonstrated only one significant effect. Specifically, the control children were shown to be significantly more variable in their response speed in the second test block of the stop-signal task relative to the first ($t(44) = -3.31$, $p < .01$. The test block variable did not have a main effect on participants' target accuracies nor did it interact with group to influence these accuracies.

Only one performance measure was shown to vary as a function of test block, participant group, and task context in the entire second experiment of this project. It was participants' target accuracy on the go trials of the stop-signal task, $F(2,70) = 4.60$, $p = .01$. The data suggest that the traditional and video game contexts did not have a different influence on the control children's mean target accuracy in either test block of the stop-signal task. Conversely, the children with ADHD appeared to be less accurate in the video game context than in the traditional context in the first test block, equally accurate in the two contexts in the second test block, and more accurate in the video game context relative to the traditional context in the third and final test block. Post hoc paired t-tests confirmed that the control children were equally accurate (in their target identification) in the two contexts in all three of the test blocks, $t(22) = -0.55, p = .59$, $t(22) = -0.41, p = .69$, and $t(22) = 1.52, p = .14$ respectively. Similar t-tests completed on the data from the ADHD group failed to demonstrate statistical significance for the differences in target accuracies in the first and third test blocks, $t(15) = 1.90$, p = .08 and $t(15) = -1.96, p = .07$ respectively.

Stop trials. The children with ADHD inhibited responses on an average of 65.2% ($SE = 0.01$) of the stop trials in this experiment.[34] This proportion was not significantly different from that of the control children, $F(1,51) = 0.17, p = .68$, but was significantly higher than the expected 50% rate, $t(31) = 10.86, p < .01$. By contrast with the data from control participants and as shown in the bottom right panel of Figure 8, the ADHD group's P(I | S) was not a linear function of stop delay. In other words (and contradictory to expected results), the children with ADHD did not – on average – become increasingly worse at response inhibition with increasingly longer stop delays on the stop trials of the stop-signal task. This finding suggests a general lack of inhibitory control on all stop delays, regardless of length.

Neither task context nor test block had main effects on participants' probabilities of response inhibition on the stop-signal task. Similarly, participants' P(I | S) did not change as a function of context by test block, group by test block, context by test block, or group by context by test block. An interaction did occur between context and test block for this variable, however, $F(2,51) = 3.28, p = .05$. Specifically, participants inhibited an increasing percentage of stop trial responses with each new test block in the video game context but a decreasing percentage in the traditional context. This interaction was qualified by the stop delays, however. The increase in P(I | S) over the test blocks in the video game context was correlated with shorter stop delays on the stop trials, $r = 0.41, p = .02$. On the other hand, the decrease in P(I | S) in the traditional

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[34] With regards to calculating response inhibition rate on the stop-signal task, data for the ADHD group was organized in the same fashion as in Experiment 1 and for control children in Experiment 2 (see earlier discussions and Figure 8).

context was not correlated to the length of the stop delay (thus reflecting a genuine decrement in participants' inhibitory control; $r = -0.24$, $p = .20$).

Effects of context order. Context order did not have a main effect on participants' target RTs or the variability in their RTs on the go trials of the stop-signal task. It also did not influence the role that participant group or test block played on these dependent variables. As with their RTs, context order did not have a main effect on target accuracies nor did it influence the effect that test block had on performance accuracy. The two groups demonstrated different degrees of accuracy according to their context order, however, $F(1,35) = 4.77$, $p = .04$. A post hoc *t*-test showed that the control children who completed the traditional attention battery before the video game attention battery were, on average, more accurate than their counterparts who completed the batteries in the opposite order, $t(136) = 3.21$, $p < .01$. A similar post hoc *t*-test computed on the data from the children with ADHD showed a slight trend for the opposite effect, $t(94) = -1.80$, $p = .08$.

The combined effects of test block and context order on participants' RT variability on the stop-signal task was significantly different for the children with ADHD relative to their control counterparts, $F(2,70) = 4.39$, $p = .02$, and was significantly different in the traditional context relative to the video game context, $F(2,70) = 3.58$, $p = .03$. Context order also interacted with actual context to impact participants' RT variability on go trials of the stop-signal task, $F(1,35) = 5.43$, $p = .03$. These interactions were beyond the scope of this project and are therefore not discussed any further. To reduce data in the analyses of inhibition rates on the stop-signal task, no split was made for context order (see earlier discussion in Part I of Results). Thus, its potential effect on participants' overall response inhibition rate was not analyzable.

Blink Task

The effects of ADHD and context on children's blink task performance in Experiment 2 was established through repeated measures ANOVAs that were run on participants' T1 accuracy, T2 | T1 accuracy, and blink magnitude. Group and context order were entered into these ANOVAs as between-subjects factors whereas test block and context were entered therein as within-subjects factors.

Effects of ISI. Relative to their control counterparts, the participants with ADHD correctly identified a smaller proportion of initial targets on the blink task, $F(1,32) = 18.40, p < .01$. They were also less proficient in identifying T2 | T1, $F(1,31) = 4.22, p = .05$. The length of the ISI between T1 and T2 did not differentially influence the groups in their abilities to identify T1 or T2 | T1. A plot of T1 accuracy as a function of ISI length is provided for each participant group in the top panels of Figure 9. The same for T2 | T1 accuracy is provided in the bottom panels of the same figure. Although less proficient in identifying targets on the blink task, the children with ADHD experienced the same magnitude of attentional blink as their control counterparts.

Relative to the traditional version of the blink task, the video game version effectively worsened all participants' abilities for accurate T1 identification, $F(1,32) = 11.06, p < .01$. Context did not, however, have a main effect on participants' abilities for T2 | T1 identification. Furthermore, the contexts of the attention batteries did not differentially influence the participant groups in terms of their T1 or T2 | T1 performance, nor was an interaction observed between the effects of participant group, context, and ISI among the T1 or T2 | T1 data. Although context did not have a main effect on the magnitude of participants' attentional blinks, it demonstrated an interaction with the group variable, $F(1,31) = 5.94, p = .02$. Specifically, the children with ADHD experienced a larger blink in the traditional context than in the video game context, $t(40) = 1.98, p = .05$. Conversely, a post hoc paired *t*-test confirmed that the control participants demonstrated the same size of blink in both contexts, $t(65) = -1.33, p = .18$. Furthermore, unpaired *t*-tests show that the children with ADHD had a larger blink in the traditional context relative to the control children, $t(106) = 2.96, p < .01$, but (quite interestingly) the same size of blink in the video game context, $t(105) = -0.75, p = .45$.

Participants' T1 performance on the blink task decreased over the test blocks, $F(2,64) = 7.51, p < .01$. Planned contrasts showed that the decrease in proportion correct from the first to second test block was statistically significant, $F(1,64) = 6.71$, $p = .01$, whereas the decrease from the second to third test block was not, $F(1,64) = 1.50$, $p = .23$. Similarly, participants' encoding capacity for T2 | T1 decreased over testing time, $F(2,62) = 3.74$, $p = .03$. Planned contrasts showed that the decrease in proportion correct from the first to second test blocks was statistically significant, $F(1,62) = 5.68$, $p = .02$, whereas the decrease from the second to third test blocks was not. Participants' attentional blinks did not change in magnitude over time.

A significant interaction between the effects of test block and group did not occur on participants' T1 performance but did occur on their T2 | T1 performance, $F(2,62) = 4.05$, $p = .02$. The plot of these data in the bottom panels of Figure 9 suggests that the children with ADHD identified a greater proportion of T2 | T1 in the first test block relative to the second and third test blocks whereas the control children appeared to identify equal proportions in the first two test blocks and a smaller proportion in the third test block. In other words, a delayed fatigue effect appeared among the control children. Post hoc paired *t*-tests on all least squares means, however, failed to demonstrate statistical significance for these effects. No interactions occurred between the test block and context factors – or between the test block, group, and context factors - in either the T1 or T2 | T1 data. Furthermore, test block and group effects did not interact to influence the magnitude of participants' attention blink, nor did test block and context, or test block, group, and context interact to influence blink magnitude.

Effects of context order. The order in which children completed the traditional versus video game test batteries did not have a main effect on the capacity limit of their attentional resources for rapidly presented visual icons, as measured by T1 accuracy and T2 | T1 accuracy. Notably, an interaction between context and context order effects approached significance on the T1 accuracy data, $F(1,32) = 3.68$, $p = .06$. Similarly, context order did not have a main effect on blink magnitude but influenced the effect that test block had on blink magnitude, $F(2,62) = 3.37$, $p = .04$. These interactions are beyond the scope of this project and are therefore not discussed any further.

CPT

To determine the effects of ADHD and task context on the measures of focused and sustained attention that were recorded on the CPT, a repeated measure ANOVA was separately computed on all participants' block means for target RT, hit rate, false alarm rate, A', and B". Between-subject factors included participant group and context order. Within-subjects factors included test block, context, and, for the false alarm data, distracter type. Regarding the latter, responses to distracter trials were thought to be prepotent on the basis that, in all but the [All Random] case, the distracter trials included cards from the target sequence and thus pulled for hit responses. A false alarm was therefore viewed as a failure to inhibit a prepotent response and a participant's false alarm rate was considered to be an overall measure of his/her inhibitory control.

Target card sequences. Overall, the two participant groups responded to target card sequences on the CPT with equivalent RTs. All participants also responded to targets with equivalent mean RTs in the traditional and video game contexts. Interactions between the context and group variables were not observed in the RT data. In contrast with the RT data, a group effect was shown for participants' hit rates, $F(1,36) = 6.17$, $p = .02$. As hypothesized, the participants with ADHD detected a smaller proportion of the [7H/AS] target card sequences relative to the control children. Furthermore, the video game context effectively worsened all participants' abilities for target detection, $F(1,36) = 4.34$, $p = .04$. An interaction between the context and group effects on participants' hit rates was not observed.

Participants' target RTs changed over time on the CPT, $F(2,72) = 4.77$, $p = .01$. Planned contrasts showed that participants responded with equal motor speed in the first and second test blocks, $F(1,72) = 2.24$, $p = .14$, as well as the second and third test blocks, $F(1,72) = 2.19$, $p = .14$, but were ultimately faster in the first test block relative to the last, $F(1,72) = 8.86$, $p < .01$. The main effect of time on participants' RTs was not modified by an interaction with the group, context, or combination of group and context variables. The fatigue effect in the RT data was supported by the pattern in participants' hit rates. Specifically, participants' overall hit rate decreased over time, $F(2,72) = 6.90$, $p < .01$, although this main effect of test block was not detectable from the control children's target detection data alone (see Part I of Results). A planned contrast on all participants' data showed that participants' hit rate was larger in the first test block relative to the final two blocks, $F(1,72) = 15.08$, $p < .01$. No interactions between the test block and group, test block and context, or test block, group, and context combinations of variables on participants' hit rates were observed.

False alarm card sequences. As hypothesized, the mean overall false alarm rate shown by the children with ADHD was higher than that of the control children, $F(1,32) = 7.49$, $p = .01$. When the data were subdivided across the four types of distracter trials, the pattern of false alarm rates differed across the two groups, $F(3,96) = 8.54$, $p < .01$. As illustrated in Figure 10, the ADHD group responded more frequently to the [7H Alone] trials than to the remaining three types of distracter trials, $F(1,36) = 24.38$, $p < .01$. The control children responded equally to each distracter type, as shown by a repeated measures ANOVA computed only on their data, $F(3,60) = 1.34$, $p = .27$.[35]

The manipulation of experimental context did not impact participants' false alarm rates nor did it differentially influence their false alarm rate on each type of distracter trial. The effects of task context and group did not interact in their influence on participants' false alarms, nor did they interact to produce different false alarm rates for each group across the distracter types. Finally, participants' rates of false alarms - as a whole and by distracter type - did not vary as a function of time nor did the group or context variables interact with the time variable (separately or together) to change participants' tendencies to make false alarms.

All card sequences. As hypothesized, and relative to non-target sequences, the children with ADHD were not as sensitive as the control children to the [7H/AS] card sequence

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[35] Readers may recall that this finding for the control group was highlighted in the initial (task reliability) portion of Experiment 2 Results.

that constituted hits, $F(1,35) = 10.91$, $p < .01$; this result can also be viewed as the ADHD group demonstrating poorer response inhibition.[36] The target sensitivity of the full sample of children was not differentially influenced by the traditional and video game contexts, nor were the two groups differentially influenced by the context manipulation. Participants' response bias did not differ across the two groups of children nor did it differ across the traditional and video game contexts. An interaction between group and context effects on participants' response bias was significant, however, $F(1,35) = 4.73$, $p = .04$. The ADHD group tended to be more liberal in their response pattern on the video game version relative to the traditional version of the task whereas the control group appeared to be equally liberal on both versions. Post hoc paired t-tests confirmed that the control children were equally liberal in the two contexts, $t(67) = 0.80$, $p = .43$, and showed a very slight trend (statistically speaking and especially when the p-value is corrected for multiple comparisons) for the between-context difference in the ADHD group (uncorrected p-value: $t(50) = -1.90$, $p = .06$). Further post hoc t-tests showed that, relative to the control children, the children with ADHD were more conservative in their response style on the traditional version of the CPT, $t(117) = -2.35$, $p = .02$, but equally as liberal on the video game version of the task, $t(118) = 0.30$, $p = 0.77$.

When the ADHD data was combined with the control data, a repeated measures ANOVA on participants' target sensitivity revealed a main effect of test block that was not detected when only the control data were analyzed, $F(2,70) = 4.26$, $p = .02$. A planned contrast on all participants' data showed that all participants were significantly more sensitive to the target card sequence in the first test block relative to the final two test blocks, $F(1,70) = 8.79$, $p < .01$. The change in sensitivity over time did not vary as a function of group, context, or the combined variables of group and context.

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[36] As discussed in introductory chapters in this manuscript, A' is traditionally defined as a measure of perceptual discrimination. This conceptualization of the A' index is arguably not applicable to the current task paradigm because it used visually distinct playing card stimuli and target/distracter card sequences. Given this task paradigm – and the ADHD versus control group framework used herein – the reader is reminded here that A' has been categorized in this project as a measure of response inhibition.

Participants' response bias changed over time, $F(2,70) = 5.01$, $p < .01$, although, as with target sensitivity, a test block effect on response bias was not found when only the control data were analyzed (likely due to a lack of power, $F(2,40) = 1.14$, $p = .33$; see Part I of Results). Planned contrasts revealed no significant difference in response bias from the first to second test block, $F(1,70) = 2.16$, $p = .15$, or second to third test block, $F(1,70) = 3.27$, $p = .07$, but did show participants' mean overall bias in the third test block to be significantly more liberal than that in the first test block, $F(1,70) = 10.76$, $p < .01$. As with target sensitivity, participants' response bias did not vary over time as a function of group, context, or the combined variables of group and context.

Effects of context order. The order in which participants completed the video game and traditional versions of the CPT did not directly influence their processing speed on hit trials (i.e., their hit RTs). Context order also did not interact with the group or test block variables to influence hit RTs. Notably, it did interact with context to significantly influence participants' response speed, $F(1,36) = 33.84$, $p < .01$. As with their RTs, participants' hit rates were not directly influenced by context order or indirectly influenced by context order via an interaction with the group or test block variables. Again, as with their RTs, context order and context interacted to influence participants' hit rates, $F(1,36) = 8.05$, $p < .01$. Participants' false alarm rates – overall and by type of distracter trial – did not demonstrate a main effect of context order, an interaction between context order and group, or an interaction between context order and test block. Context order and context showed a strong trend for interacting in their influence on participants' overall false alarm rates, $F(1,32) = 3.97$, $p = .06$, but not their pattern of false alarm rates across the four distracter types.

Regarding participants' target sensitivity (i.e., A'), context order did not demonstrate a main effect or an interaction with either the group or test block variables on this measure of perceptual discrimination / response inhibition. Nonetheless, as with participants' target RTs, hit rates, and (via a trend) false alarm rates, context order did interact with context to significantly influence participants' levels of target sensitivity, $F(1,35) = 6.41$, $p = .0160$, on the CPT. Finally, context order did not have a main effect on response bias, nor did it interact with participant group or test block to influence this variable. The interactions that were shown with the context order variable were beyond the scope of this project and are therefore not discussed any further.

Chapter 13. Experiment 2 Discussion

General Overview

The purpose of Experiment 2 was to first investigate several different components of attention in typically developing children as compared to children with ADHD and, second, to establish the vulnerability (or robustness, as the case often was) of these components to a manipulation of context within the children's environment. The battery of computerized attention tasks that was administered to the 30 university students in the separate condition of Experiment 1 was administered to all child participants in Experiment 2. Each child completed the tasks within a traditional lab environment and within a non-traditional, visually enhanced lab environment that incorporated video game features into the attention battery.[37] The test batteries were administered in a counterbalanced order to all children approximately one week apart.

Embarking on a project that aims to investigate several components of attention in two fundamentally different participant groups and in each of two different contexts is an ambitious proposition. A comprehensive framework of attention was therefore sought to give perspective to the many components of attention relative to each other and to the construct of attention as a whole. A model of neural networks proposed by Posner and Raichle (1994) was most relevant. On the basis of an extensive review of empirical research, Posner and Raichle assigned alertness, orienting, and executive control to each of three distinct neural networks within the human brain. Notably, past research on ADHD has long alluded to the construct of alertness and, more recently, to response inhibition (an aspect of executive control) as core deficits in the disorder (e.g., see review of related literature in Chapters 3 through 6). Given its thoroughness and relevance,

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[37] Pilot data from children suggested that younger individuals might have trouble with the blink task that was administered to the adults in Experiment 1. Thus, to make the task easier, the targets were given longer (and the masks, shorter) display times (see Chapter 8 for details). This was the only task-specific modification made to the attention battery for Experiment 2.

Posner and Raichle's framework was chosen to lend structure and organization to this project.

The components of attentional expectancy, encoding, and sustained attention - all of which were chosen for study in this project – were considered to be processes eliciting and/or requiring alertness. Alternately, focusing, filtering, and their combination - interference control - were thought to elicit/require executive control.[38] As indicated in Table 1, these six components were assigned subcomponents – each of which was directly measured in the tasks administered to the children. Before addressing first- and second-order effects of the group and context variables on these attention (sub)components, this chapter will first address the issue of task reliability in children.

Task Reliability in Children

As was shown for the adults in Experiment 1, the five tasks designed for use in this project proved to be reliable measures of attention in the control children in Experiment 2. For example, the Simon task tapped into children's abilities for cognitively filtering an irrelevant target attribute (i.e., its location) as they responded to visual stimuli that were presented in rapid succession. Whereas the response-interference (i.e., the Simon) effects took the form of a 13.94 ms ($SE = 2.91$) increase in RT and a 2.1% ($SE < 0.01$) reduction in target accuracy on incompatible relative to compatible trials in the adults, they comprised of a 32.69 ms ($SE = 4.71$) effect in RT and a 3.8% ($SE < 0.01$) effect in accuracy in the children. The Simon effects on both the children's RTs and accuracies were statistically significant.

Beyond isolating attentional filtering, the Simon task effectively incorporated warning tones to increase children's alertness on a subset of trials. As was exactly the case for the adults in Experiment 1, the control children in Experiment 2 demonstrated shorter RTs

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[38] The conceptualization used in this project of the attention components and how they relate to each other (e.g., interference control viewed as an integration of focusing and filtering) is explained in Chapter 2 and incorporated into the discussion of each experiment (including the current discussion on Experiment 2).

and a coinciding speed-accuracy trade-off on the trials with the shortest warning intervals (50, 100, and 200 ms) relative to the trials with no tones and those with the longest warning intervals (400 ms and 800 ms). Although statistically significant in adults, the speed-accuracy trade-off was not statistically significant in the child sample. Shorter RTs and more frequent errors are typical alertness effects (Posner, Klein, Summers, & Buggie, 1973). The cue sensitivity indicated by the interval-induced variation in task performance was considered an aspect of attentional expectancy. Thus, warning the control children of an imminent target and the corresponding need for a response – by means of a brief auditory tone - facilitated their speed of processing.

The finding that short warning intervals for alerting tones facilitated the speed of the participants' motor responses and not their S-R mapping or response planning is somewhat curious.[39] It seems that the difference must be due to the type of cognitive/ behavioural process involved. A speeded response to a beeping sound that signals an imminent target (as was the case on the trials with short warning intervals) arguably has a motorically reflexive component to it. The process of quickly pressing a key on a computer keyboard in response to an alerting tone might be paralleled – on a much larger scale - to jumping out of one's seat upon hearing a fire alarm (although clearly the motivation to do the latter is much greater!). By contrast, S-R mapping and response planning are cognitive processes. Perhaps the behavioural event of a motor reflex is more attuned to auditory cuing than the cognitive events associated with S-R mapping and response planning.

Whereas the Simon task captured children's capacities for filtering and attentional expectancy, the flanker task effectively measured their proficiency for interference control. As previously indicated, interference control was conceptualized in this project as the integration of the abilities for focusing and filtering. The flanker task showed how well the children could narrow (i.e., focus) their attention beam upon a flanked visual target in order to successfully filter irrelevant cues from nearby visual distracters (i.e., the

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[39] Facilitated S-R mapping would have taken the form of a reduced Simon effect whereas facilitated response planning would have been evidenced by improved target accuracies.

flanker identities). Firstly, the data showed overall FCEs on the order of 12.71 ms (SE = 6.21) in RT and 1.30% (SE < 0.01) in target accuracy (versus 14.63 ms (SE = 4.13) and 1.00% (SE < 0.01) for the adults in Experiment 1). Secondly, the FCE in RT was smaller on trials with flankers further away from (rather than close to) the target. The FCE was 32.54 ms (SE = 9.65) on trials with flankers nearest to the targets, 0.46 ms (SE = 11.81) on trials with flankers at a middle distance from the targets, and 5.14 ms (SE = 10.61) on trials with flankers furthest from the targets (the latter two FCEs were statistically equivalent in magnitude and also statistically equivalent to zero).

As was exactly the case for the adults, then, the children could narrow their attention beam within the 5.50° that spanned the minimum flanker-to-flanker distance on middle-flanker trials more effectively than they could narrow it within the 2.86° that spanned the equivalent distance on near-flanker trials. Furthermore, the children's ability to visually focus their attention – and thus facilitate their cognitive filtering of nearby visual distracters – was no greater when the flanker-to-flanker separation distance was extended to 8.36° as it was on far-flanker trials from the 5.50° that it was on middle-flanker trials. A corresponding interaction of the trial type and flanker distance factors on children's target accuracies was not statistically significant. Nonetheless, the RT findings are remarkable for three reasons. Firstly, the data suggest a parallel in the focusing efficiency of children (aged 7 through 11 years) with that of university-aged adults. Secondly, the data imply an improvement in the children's ability for interference control as the spatial expanse separating task-relevant from task-irrelevant stimuli increased. Thirdly, the presence of an FCE in the context of an interference-free expanse that extends 5.50° and, even more impressively, 8.36°, appears to contrast with the conventional wisdom that a person's visual attention beam can be narrowed to as little as 2° in width (Miller, 1991). These findings are respectively discussed in the next paragraph.

To place the findings from the flanker task in context with related past literature, it will first be useful to convert the minimum flanker-to-flanker separation distances on each trial type to the corresponding minimum target-to-flanker separation distances. In that regard (and as reported in the methods for this project; see Chapter 8) the minimum edge-to-edge separation between the target and a flanker was 0.77° on near-, 2.09° on middle-, and 3.52° on far-flanker trials. The finding that both the children and adults demonstrated more efficient interference control in the case of the 2.09° target-to-flanker separation distance relative to the 0.77° separation distance is not surprising. Related research has demonstrated general improvements in filtering on the flanker task among individuals in the 5- through19-year-old age range as the separation distance between targets and flankers increased from 0.5° to16°. Not surprisingly, the children in this research demonstrated less control over their visual attention beams than adults. Furthermore, the children's focusing deficiency was most evident at the smaller degrees of separation within the 0.5° to 16° range that was tested (likely separations less than 2.09°; Enns and Akhtar, 1989).

The implication in this study that the children's ability for interference control improved as distracters were distanced from visual targets is, like the parallel finding among adults in Experiment 1, interesting but not necessarily accurate. Rather, it may have been that – as the peripheral flankers were distanced from the central targets – the children needed less interference control. In turn, a reduced need for interference control (rather than an improvement in interference control) may have accounted for the faster but equally accurate target processing on far- relative to near-flanker trials. Regardless of its interpretation, the finding demonstrates the ability of the flanker task to isolate the attention component of interference control.

The production of an FCE on a task display with 0.77° separating targets from flankers is very much in line with past research. For example, Eriksen and Eriksen (1974) found a lag in participants' mean target RT on target + flanker trials relative to that on target-alone trials when the flankers were distanced from the targets by each of three lengths – namely, 0.06°, 0.5°, and 1°. Additionally, at least one researcher has demonstrated the presence of an FCE in the case of 1.9° of separation between targets and flankers and an additional pair of researchers have produced the FCE wherein 2° separated targets and flankers. Notably, the FCE produced with 1.9° of separation between targets and flankers was only produced when the flankers slightly preceded targets (Miller, 1991).

Miller (1991) extended upon early work with the flanker task and, in so doing, produced the FCE in the case of target-to-flanker separation distances approaching 1° and even 5°, respectively. To avoid acuity problems, Miller repeated his experiment using smaller targets but same-size flankers (thus ensuring that the amount of raw sensory input from the flankers was not compromised as a function of the target-to-flanker separation distance). Miller was impressed by the persistence of the flanker effects in both scenarios in this second experiment and concluded that, because the FCE is obtained with separations of nearly 5° (and possibly even larger distances) between targets and flankers, limited spatial resolution must not be the sole cause of the FCE. Herein lies justification for the view adopted in this project; specifically, it is indeed likely that imperfect visual focusing *combines with* imperfect *cognitive filtering* to produce the FCE on the flanker task. It seems reasonable that neither component of attention can be isolated on the flanker task and the definition of interference control used in this project (i.e., the interaction of focusing and filtering abilities) is indeed suitable as a description of the attentional processes tapped by the flanker task.

The stop-signal task was included in the attention battery used in this project to isolate children's abilities for response inhibition. Response inhibition, in turn, was thought to reflect focused attention and to be an integral part of the executive control network in Posner and Raichle's (1994) model of attention. The stop-signal task used herein did capture children's abilities for response inhibition, although not in the way intended (and as was shown by the adults in Experiment 1). The percentage of stop trials on which the children successfully inhibited responses was significantly greater than the desired 50%. Thus, a "stopping time," or SSRT, could not be calculated in the intended manner (i.e., using the formula [mean go RT] – [mean stop delay], as outlined in previous literature (Logan et al., 1997); see Chapter 5 for details). Although an SSRT was not calculated for participants, the results from the stop-signal task demonstrated an unexpected – but not surprising - discrepancy between the control and ADHD participant groups in terms of the relationship each demonstrated between the stop delays and their subsequent ability to inhibit responses on stop trials. Whereas the control children demonstrated a clear pattern of poorer response inhibition on trials with longer stop delays, the children with ADHD did not. Rather, a clear or consistent relationship did not develop between stop delay length and probability of response inhibition among the children with ADHD. Their increased variability was, in turn, interpreted as a relative lack of motor control.

To substantially impede response inhibition and have the probability of inhibition stabilize at a much lower rate than was shown in this study, the visual stop signal should have occurred much later after target onset than the 250 ms delay that was used on the initial stop trials in this project. A longer stop delay to decrease the likelihood of response inhibition makes sense (and is indicated by the bottom panels of Figure 8) to the extent that the attention battery in this project increased cognitive demands and distractions over traditional stop-signal tasks - and thereby slowed children's processing speed. The likelihood that a child had processed a stimulus by 250 ms post-target-onset to the extent required to make a go response was quite low. Thus, the stop process "beat" the go process more than half of the time when the stop delay was approximately 250 ms in length. If the stop delay were lengthened such that the stop and go processes could be more competitive with each other, the likelihood of response initiation and follow-through would be markedly increased and, in turn, the probability of response inhibition would hover more closely around 50%.

Past studies have successfully used the tracking algorithm (as was used in this study) with an initial stop delay of 250 ms to produce inhibition rates very close to 50% in both children with ADHD and controls (e.g., Stevens et al., 2002). The difference between these past studies and the current one lies in the type of stop signal used. Whereas the past studies have typically used short beeps as the stop signal, the current study employed a visual stop signal of a white computer screen. Perhaps, then, children take longer to process targets in the context of possible visual stop signals than in the context of possible auditory stop signals. Rubia et al.'s (1998) study with the airplane and man holding a stop sign as go and stop signals, respectively, support this conjecture. Rubia et al. used a stop delay of 250 ms on a subset of trials in one of their experiments. The associated P(I | S) was on the order of 70-75% for children with ADHD and 95-100% for control children. Not surprisingly, processing an image of an airplane and deciding it is in the absence of a stop sign icon takes much longer than processing a simple illustration of a heart or diamond and deciding it is not covered by a white screen. Thus, with the go process so elongated, Rubia et al. demonstrated a stopping rate even higher than that observed in the current project.

The demands of the blink task used in this project effectively overwhelmed the children's attentional resources for the patterned stimuli it presented in a rapid and serial fashion on the computer screen. The task thus permitted quantification of the same. Given the child-friendly modifications outlined in a footnote in the methods chapter (see Chapter 8), the children performed similarly to the adults. The children accurately identified 75.9% ($SE = 0.01$) of the T1s and 80.9% ($SE = 0.01$) of the T2 | T1s whereas the adults accurately identified 81.5% ($SE = 0.01$) of the T1s and 79.0% ($SE = 0.01$) of the T2 | T1s. Although the children's performance was not optimal, it was much better than chance (i.e., 25%) for each subset of targets and – most importantly in terms of task reliability – reflected the children's increasing ability to recover cognitive resources as the time lag between the two targets increased. The magnitude of the children's attentional blink was calculated in the same manner as that of the adults in Experiment 1 yet, somewhat surprisingly, was about two-thirds of its size (0.29 ($SE = 0.06$) versus 0.44 ($SE = 0.06$)).[40] Whereas T1 accuracy was taken as a measure of focused attention, T2 | T1 accuracy and blink magnitude were considered measures of an encoding limit, or encoding capacity for rapidly presented visually patterned stimuli.[41]

[40] The finding of an attentional blink being smaller in children than adults on the same task is somewhat curious and must be a product of the target and mask manipulations (see referenced footnote).

[41] The reader is reminded here that details regarding the measures of T2 | T1 accuracy and blink magnitude – and their appropriateness as measures of encoding capacity – are provided in both Chapters 2 and 8.

The component of attention that was best isolated by the CPT was that of sustained attention. Children's alertness decreased, as expected, on this task. The decrease in alertness was reflected by longer RTs to the target card sequences and decreased hit rates as testing progressed (although the latter effect did not reach statistical significance). Surprisingly, the fatigue effects did not extend to the children's rate of false alarms, sensitivity to targets, or response bias. When the data from the control children were combined with that from the children with ADHD, however, results did indicate that all children's target sensitivity decreased over testing time – just as their response bias became increasingly liberal over time. A main effect of test block was likely not detected in the control children's data due to insufficient statistical power. The lack of a test block effect on children's proportion of false alarms persisted in the complete (control + ADHD) dataset and remains somewhat of an anomaly. The lack of an effect is not likely due to a ceiling effect as the overall means (2.70% ($SE < 0.01$) for the control group and 8.50% ($SE = 0.01$) for the ADHD group) were larger than that demonstrated by the adults in the separate condition ($M = 1.1\%$ ($SE < 0.01$)) and, yet, the data from the adults showed an increase in false alarm rate over time.

The component of focused attention, required on all five tasks administered in this project, has not been discussed to the full extent that it was investigated in this project. The largest subcomponent of focused attention that was measured was participants' processing efficiency. It was reflected by all measures of reaction time and accuracy, as well as the variability of children's reaction times on the stop-signal task (a variable of particular interest in children with ADHD). Children's target sensitivity, response bias, and rate of false alarms on the CPT were also thought to be measures of focused attention. In different ways, children's response bias and false alarms were thought to reflect their general ability for response inhibition. A third measure of response inhibition was children's SSRT on the stop-signal task (which, as discussed, was ultimately assessed indirectly via the relationship between the stop delays and probability of response inhibition). The measures of focused attention were simply the overall means of the variables indicated; they should not be confused with the patterns these means demonstrated over time – which, in and of themselves, were measures of sustained attention.

Thus far, this discussion has detailed how all six components of attention studied in this project were measured on the computer tasks. To review, the influence of S-R spatial incongruence on children's performance on the Simon task was identified as a measure of filtering whereas the influence of warning tones on the same task performance was highlighted as a measure of attentional expectancy. The interaction of the trial type and flanker distance effects on flanker task performance was identified as a measure of interference control whereas means of the overall response speed, accuracy, and probability of response inhibition (when cued) on the stop-signal task were introduced as measures of focused attention. Focused attention was also assessed on the Simon, flanker, blink, and continuous performance tasks by various measures of processing efficiency, target sensitivity, and response inhibition. The compromise in target identification subsequent to visual masking on the blink task was recognized as a measure of encoding capacity and, lastly, the patterns over time of children's target detection rate, reaction time, sensitivity, response bias, and false alarm rate on the CPT were acknowledged as measures of sustained attention. As points of comparison for sustained attention on tasks other than the CPT, children's performance stability on several other measures within the battery was reviewed and is discussed in the following subsection.

Effects of ADHD on Task Performance

It seems that the simplest way to begin a discussion of the group effects that were shown in this study is to detail the attention components for which the groups were expected – and did – demonstrate equivalent performance profiles. There were three: (1) attentional expectancy, (2) filtering, and (3) interference control. Deficits in the attention profile of the ADHD group relative to the control group were hypothesized for the remaining components of encoding capacity, focusing, and sustaining focus. The results provide partial support for the conjecture that ADHD entails a deficit in encoding capacity, much support for a deficit in focused attention, and very little support for a deficit in sustained attention. As will be revealed, the deficits in focusing were shown on each of the subcomponents that were studied - processing efficiency, target sensitivity, and inhibitory control for motor responses. The limited support for a deficit in sustained attention contrasts with a long-held notion in the ADHD field but is in congruence with a recent shift in thinking about the disorder (e.g., Barkley, 1997a, 1997b).

Relative to the control children, the children with ADHD were shown to identify significantly fewer of the second targets (for which initial targets were correct) in the TM-TM stream on the blink task in this project. To the extent that the T2 | T1s could not be processed due to a shortage in attentional resources, this finding indicates a smaller capacity for encoding visually patterned stimuli that are presented in rapid succession at the same location in space. Two corresponding findings must also be taken into account here, however. The first is that the children with ADHD did not, on average, demonstrate a larger attentional blink than their control counterparts and the second is that they identified fewer of the initial targets on the task. Thus, the apparent deficit in encoding capacity may be a function of the poor focus they demonstrated at the outset of each trial and/or poor recall of the items from short-term memory, rather than a relative reduction in the size of the memory store that is tapped during a trial on the blink task. If the deficit in encoding capacity was genuine – and not a byproduct of poor focused attention or short-term memory – the T1 performance would not necessarily be diminished and the blink - measured independently from T1 performance – would be larger. In summary, then, the diminishment of T1 performance and equivalence in blink magnitude among the ADHD group relative to the control group argues against a genuine deficit in encoding capacity among children with ADHD.

Related to the issue of a possible ADHD-specific deficit in encoding capacity is an investigation of the contextual effects shown among the data (and discussed in greater detail in the next subsection of this chapter). The data show that the children with ADHD demonstrated a larger blink than the control children in the traditional context but a blink of equal magnitude as the control children in the video game context.

Furthermore, the ADHD group's blink in the traditional context was larger than their blink in the video game context. Thus, contrary to the indications outlined in the previous paragraph, herein lies at least partial support for the hypothesis of an encoding capacity deficit in children with ADHD relative to control children.

As previously indicated, a curious positive correlation was shown between ISI length and T1 accuracy for both the adult and child participants in this project. This has been shown, albeit inconsistently, in one of the two previous studies that have used TM-TM paradigms (McLaughlin et al., 2001) and may have occurred as a result of a participant's automatic cognitive pairing of T1 with T2 | T1 to form one analyzable unit (versus two separate units). Although the ability for processing the targets as one unit should have been limited by the presence of the intermediary mask (e.g., Chun & Potter, 1995; Hollingsworth et al., 2001), perhaps there was something unique about the target and mask features used herein that allowed such pairing to occur. Notably, their colour features were matched. The masks constituted a mosaic of overlapping segments of the four possible target shapes (i.e., heart, diamond, spade, and club). Additionally, each mask was square-shaped and of a size such that if either of the targets was laid over it, only the target's most external edges would intersect points on the square's perimeter. If T1 and T2 | T1 were indeed processed as one unit, the longer the "blank screen" interval (as occurred with the longer ISIs) that occurred between them, the more likely a participant would have been able to parse T1 from T2 | T1. In turn, the participant would have been increasingly able to accurately identify T1 and, thus, the positive correlation that occurred between ISI length and T1 accuracy is explained.

Beyond their processing inefficiency on the initial targets in the visual streams on the blink task, the children with ADHD demonstrated deficits in focused attention on each of the remaining four tasks. Relative to the control group, the ADHD group was slower and less accurate in their performance on both the Simon and flanker tasks. They were also more variable in their RTs to the go trials on the stop-signal task and made fewer hits on the CPT. Also relative to the control children, the children with ADHD demonstrated lower target sensitivity and more frequent false alarms on the CPT. Notably, within their false alarms, the ADHD group made disproportionately more anticipatory responses to the [7H Alone] distracter trials (versus other distracter types such as [AS Alone] and [7H/R/AS]) than the control children – thereby evidencing poorer response inhibition. In addition to their higher false alarm rate on the CPT, the ADHD group's lack of sensitivity to differential stop delays on the stop-signal task (discussed in the previous subsection of this chapter) is indicative of poorer inhibitory control.

Despite the overwhelming evidence for a deficit in the component of focused attention, the children with ADHD did perform "up to par" on some measures of focused attention in this experiment. For example, they responded to targets on the stop-signal task and CPT with the same overall speed as control children and, additionally, correctly identified the same overall proportion of targets on the go trials in the stop-signal task. Furthermore, although it was hypothesized that the ADHD group's expected problems with inhibitory control would translate into a more liberal response bias on the CPT (relative to the control group), such was not the case. A group difference in response bias on the CPT, although suggested by its association with response inhibition and the related notion that response inhibition is a core deficit in ADHD, has not always been found in past research. For example, a group difference in response bias was not shown by Losier et al. (1996) in their meta-analysis of the CPT nor by Corkum, Schachar, and Siegel (1996) in their rewards-based study of the task.

All children showed several fatigue effects in their performance throughout the battery of attention tasks, but none that were clearly exaggerated for the children with ADHD relative to the controls. Thus, contrary to that hypothesized, the children with ADHD did not demonstrate a deficit in sustained attention. One of the many fatigue effects shown by all children was on the Simon task and took the form of slower RTs and increasingly worse performance accuracy as testing time progressed. All children also slowed in their responses on the flanker task and demonstrated a statistical trend for an increased FCE in their target accuracy at the end of testing relative to the beginning. Throughout the blink task, all children became increasingly worse in their ability to identify T1 and T2 | T1, just as they slowed in their responding and became increasingly less sensitive to the target card sequence over the three test blocks of the CPT. Corresponding to their decreased sensitivity on the CPT, the children's hit rates decreased and their response bias became more liberal as testing time progressed.

Although the lack of evidence for a sustained attention deficit in the ADHD group is convincing, there was indeed one statistical trend to suggest otherwise. Specifically, a statistical trend on the blink task suggested that the ADHD group became fatigued earlier than the control group. This was shown on their T2 | T1 performance but did not extend to a larger decrement overall. One other trend for a group difference in performance over time was on the stop-signal task. An interaction was shown between the group and test block factors on the children's pattern of variability in their RT data. However, as discussed in the results, the interaction was not easily interpretable.

Thus far, evidence has been reviewed for a decrement in sustained attention in all children on four of the five tasks that were completed. Notably, neither of the participant groups demonstrated a change over time in processing speed or accuracy on the go trials of the stop-signal task. A change in RT variability or the relationship between the stop delays and probability of response inhibition was also not observed for either group on that task. Finally, all children remained stable in their target accuracy on the flanker task, their blink magnitude on the blink task, and their false alarm rate on the CPT. Because the children's blink magnitude remained stable over time, it is likely that the decrease in their T2 | T1 performance over time was, again, the function of a similar decrease in their T1 performance and not a reduced capacity for registering and recalling the visual stimuli. The pattern of fatigue effects on some, but not all, measures of focused attention is indeed curious and perhaps is the function of task complexity, concurrent attention demands, and limits in statistical power.

Effects of Context on Task Performance

A cursory review of the published literature on children's functioning and how it is influenced by contextual factors would provide the general impression that enhancing a child's environment holds guaranteed potential for eliciting optimal behaviour and, at least in some instances, cognitive performance. These enhancements can take many forms but certainly in the intervention literature on ADHD primarily involve increased structure, reward contingencies, and response costs (e.g., see review by Miranda, Jarque, & Tárraga, 2006). Intuitively at least, making an environment child-friendly by putting posters on the walls, using bright colours in the décor, and having toys available for easy access helps to establish rapport with a child and elicit his/her compliance with rules and requests.

As reviewed in Chapter 4 of this manuscript, Zentall (1975) capitalizes on the phenomenon of environmental stimulation in his theory of ADHD. His theory purports that hyperactive children (for reasons that remain speculative) need more stimulation than their control counterparts to function "normally" so turn to self-stimulation by means of motor overactivity to maintain optimal functioning in everyday ("under-stimulating") environments. In a related vein, the entire field of industrial/organizational psychology is committed to maximizing employee satisfaction and productivity by means of contextual manipulations within the workplace. The phrase "situational engineering" has been used to describe these manipulations (Wright & Cropanzano, 2004).

Given this initial foray into the research world of rewards and enhanced contexts - not to mention the clinical world and anecdotal reports of children sitting for hours "glued" to television screens and video games despite their ADHD (Tannock, 1997) - it seemed quite reasonable to expect the video game context in this study to facilitate task performance in all child participants and especially those with ADHD. However, as the results have already revealed, the forthcoming discussion ultimately shows how the contextual manipulation clearly had deleterious rather than beneficial effects on several aspects of children's cognitive functioning. This discussion will first address the main effects of the contextual manipulation on all children's task performance before turning to the differential effects that it had upon the two participant groups.

The results of this study indicate that all of the child participants were slower to respond to targets in the video game versions of the Simon, flanker, and stop-signal tasks relative to the traditional versions. Although this might be viewed as a benefit for the children with ADHD (who, by definition, are hyperactive), slowed responding on reaction time tests arguably reflects slower cognitive processing rather than improved motor control. In addition to effectively slowing their processing on the Simon, flanker, and stop-signal tasks, the video game context also distracted both groups of children such that, relative to their performance in the traditional context, they accurately identified fewer of the initial targets on the blink task and detected fewer of the [7H/AS] target card sequences on the CPT. The contextual manipulation had an interesting effect on the degree of response interference caused by the flankers in the flanker task. In particular, the video game context slowed - and the lack of video game features hastened - participants' responses on the near-flanker trials more so than on the middle- and far-flanker trials. (As the next subsection of this chapter reveals, the overall pattern of interference in target RT on the flanker task due to the video game features was unique to the control children.)

The RT data from all children on the flanker task showed an interaction between the context and test block factors, indicating that the "strength of the manipulation" was limited. In particular, the increase in children's RTs on the video game version of the flanker task (relative to the traditional version) was more pronounced in the first test block than in the last test block. The increased interference of the video game features on children's general processing speed (i.e., RT) in the first test block seemed to transfer to a larger FCE in accuracy by the third test block. Specifically, the data showed the FCE in participants' target accuracies to be equivalent in the two contexts for the first two test blocks but larger in the video game (versus traditional) context in the third test block. It is granted here that the interaction effect was statistically significant but a post hoc test on the data from the third test block merely reflected a slight trend.

Beyond affecting the children's processing efficiency on the Simon, flanker, and stop-signal tasks – and their cognitive filtering of task-irrelevant stimuli on the flanker task - the experimental context influenced all children's probability of response inhibition on stop trials of the stop-signal task. The children demonstrated an increase in their percentage of inhibited responses over time in the video game context but a decrease over time in the traditional context. Notably, the increase in the video game context was a function of shorter stop delays. The decrease in the traditional context did not correlate with the length of the stop delays, however. Thus, the improvement in participants' inhibitory control appears to be a direct result of the video game context. This is the first piece of evidence reviewed to indicate a benefit of the video game context and suggests that, as the children were closer to finishing the traditional battery they became less inhibited whereas – perhaps given increased alertness in the anticipation of their reward – this did not occur on the video game battery.

As revealed in the results chapter, the order in which the children completed the two attention batteries in this project influenced their performance on several of the performance measures. It did not have a direct influence on any of the attention measures recorded in this project (see Table 1); rather, the influence that context order had on children's attentional functioning was through interactions with other variables. For example, the influence that context order had on the children's processing speed on the Simon task was mediated by the test blocks and its impact on the children's performance accuracy on the stop-signal task was mediated by the presence/absence of ADHD. These interactions were beyond the scope of this project but, especially given their quantity and complexity, confirm the vulnerability of several components of attention in children to contextual manipulations. The components that were influenced by context order were the same as those directly influenced by context – that is, focusing and filtering. The subcomponents of focused attention that were influenced were those of processing efficiency on all timed tasks, target sensitivity on the CPT, and response inhibition on both the stop-signal task and CPT (i.e., false alarm rate).

Differential Effects of Context on Each Group's Task Performance

As already indicated, the results provide extensive evidence to suggest that the unique features of the video game context (relative to their lack in the traditional context) disrupted several components of attention in both participant groups in this study. Given this evidence, it is not surprising that the ADHD group did not demonstrate (with one exception) a performance level parallel to that of the control group. Nonetheless, the statistically significant interactions that were shown between the group and context factors by omnibus inferential tests could be classified into three categories, the first two of which indicate a benefit of the video game features for the children with ADHD relative to the controls. The three categories into which the findings can be classified are: (1) a relative benefit with statistically significant post hoc tests, (2) a relative benefit with non-significant post hoc tests, and (3) a relative cost with non-significant post hoc tests. Notably, the fourth corresponding category (a relative cost with statistically significant post hoc tests) did not contain any findings. To the extent that statistical power accounts for the nonsignificant post hoc tests despite significant interactions in the omnibus tests ([2] and [3]), these results are especially intriguing.

The first indication of a differential influence of the traditional and video game contexts on the participant groups was discovered on the flanker task. The children with ADHD were slower to respond to targets by 10 ms in the video game context relative to the traditional context. The difference was not statistically significant. Conversely, the control children were slower by 76 ms in the video game context – a difference that was statistically significant. Although the ADHD group experienced a relative benefit of the video game features, their fastest RT (i.e., in the traditional context) still lagged behind the slowest RT shown by the control group (i.e., in the video game context) by a matter of 93 ms. A second relative benefit was shown for the ADHD group on the blink task. Whereas the control children demonstrated the same size of blink in both the traditional and video game contexts, the children with ADHD experienced a larger blink in the traditional context than in the video game context.[42] Furthermore, the children with ADHD had a larger blink than the control children in the traditional context but the same size of blink in the video game context.

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[42] Note that this is the first indication in the results of a genuine deficit in encoding for the children with ADHD and that it was only apparent in the traditional context.

Beyond less interference in their processing speed on the flanker task and less interference in stimulus encoding on the blink test, the children with ADHD – relative to the controls – experienced a pattern of improved accuracy on the stop-signal task which is directly attributable to the video game features. The control children were equally accurate in their target identification on the stop-signal task in the two contexts and in all three of the test blocks. By contrast, the children with ADHD appeared to be less accurate in the video game context than in the traditional context in the first test block, equally accurate in the two contexts in the second test block, and more accurate in the video game context relative to the traditional context in the third and final test block. It could be reasoned that, given their novelty, the video game features were distracting in the first test block. The novelty appears to have waned by the middle test block yet the children's alertness increased again in the third test block – possibly in anticipation of trading in their virtual coins for a tangible reward. Although an intriguing interpretation and possible given the statistically significant interaction between the group, context, and test block factors on this variable, post hoc tests failed to approach significance after accounting for the multiple comparisons that were made.

A fourth interaction between the group and context factors was on participants' response bias on the CPT. The control children demonstrated an equally liberal response bias in both contexts whereas the ADHD group tended to be more liberal in their response pattern on the video game version relative to the traditional version of the task. Although the overall interaction was statistically significant, the follow-up post hoc *t*-test on the ADHD group's data failed to demonstrate a significant difference in their biases across the two contexts. Nonetheless, a between-group *t*-test showed that the children with ADHD were more conservative than the control children in the traditional context but equally as liberal in the video game context. To the extent that a person's response bias on the CPT reflects inhibitory control, the finding that the ADHD group demonstrated more motor control than the control group in the traditional context is unusual and indicative of a relative benefit from simple, non-distracting surroundings.

A final interaction between group and context effects that was statistically significant overall but failed to demonstrate significance in post hoc tests was the second interaction to indicate a relative cost of video game features on the functioning of the children with ADHD. In particular, the contexts differentially influenced the effect that trial type had on each group's processing speed in the flanker task. Whereas the control children demonstrated an FCE of the same magnitude in both contexts, the children with ADHD appeared to demonstrate a larger FCE in the video game context. To the extent that the ADHD group was more vulnerable to distractions and less able to cognitively filter flanker cues, this finding was likely not spurious and failed to demonstrate significance due to limited statistical power.

Summary & Conclusions

Independent of the contextual manipulation in this project, the results indicated parallel profiles in the two participant groups for the attention components of expectancy, filtering, and interference control. As hypothesized – and relative to the control children, the children with ADHD showed many compromises in their profile of focused attention and, possibly as a result of their problems with focusing, a deficit in the proportion of rapidly presented visual stimuli that they could effectively process (i.e., their encoding capacity). Contrary to hypotheses, a deficit in sustained attention was not observed in the ADHD group.

The manipulation of the lab environment in this project was designed to facilitate children's performance on the attention tasks that were administered. Several hypotheses of performance facilitation were made on the basis of theory (Zentall, 1975), neuropsychology (e.g., Koepp et al., 1998), and empirical research (e.g., Zentall & Zentall, 1976). These hypotheses were qualified by evidence from past studies that showed a limit to the beneficial capabilities of reward (e.g., Barber et al., 1996; Douglas and Parry, 1994) and appetitive stimulation (Lee, 1999; Zentall & Zentall, 1986). Ultimately, the results indicated a mix of effects. The variability was a function of the attention component studied and the presence/absence of ADHD.

To summarize, one of the six attention components that were studied (filtered attention) demonstrated clear sensitivity to the contextual manipulation made to the lab environment in this project; specifically, filtering was disrupted by the video game features in the children with ADHD *and* their control counterparts. A second component of attention (focused attention) demonstrated both robustness and sensitivity to the manipulation; the variability in results varied according to the exact subcomponent and participant group being assessed. In particular, all children's processing efficiency (i.e., target reaction time and accuracy) was disrupted by the video game context – although there was some evidence to suggest that the ADHD group improved the accuracy of their target processing on the stop-signal task as a direct result of the video game features. The video game context also appeared to interfere with the ADHD (but not the control) group's response inhibition (at least, relatively so) on the CPT - yet facilitated all children's response inhibition on the stop-signal task. A third subcomponent of focused attention (beyond processing efficiency and response inhibition) – target sensitivity – was not impacted by the contextual manipulation used in the project. A third attention component that was studied – encoding capacity – was beneficially influenced by the video game context in the ADHD, but not the control, group. Finally, the remaining three attention components that were studied - expectancy, sustained attention, and interference control - were robust to the manipulation.

The disruption in focused attention as a result of the video game features was evidenced by a general slowing of all participants' processing speed on the Simon and stop-signal tasks, and a slowing of the control children's processing speed (but not that of the children with ADHD) on the flanker task. Notably, the slowed processing speed among the control children was time-limited on the flanker task and most apparent during context novelty (i.e., first test block). Regardless, the detriment of the video game context for the control children persisted into the third test block; specifically, their lag in reaction time was replaced by an exaggerated FCE in target accuracy (and, thus, poorer attentional filtering) in the third test block. Additional disruptions in all children's focused attention (in particular, their processing efficiency) as a function of the video game features were evidenced by the reduced accuracy in identifying the initial targets on the blink task and the detection of fewer target card sequences on the CPT.

The children with ADHD showed a fluctuation in their target accuracy on the stop-signal task that was suggestive of interference in the video game context due to its novelty (and thus, potential for distraction) but – after time – a facilitation by the video game features (notably, as the attainment of a toy reward was imminent). In contrast, the control children were equally accurate in their target accuracy on the stop-signal task in both contexts and all test blocks. The data provided an interesting indication of a more liberal response bias on the CPT (arguably, poorer inhibitory control) in the ADHD group as a function of the video game context – although the group was, oddly, more conservative than the control children in the traditional context and no more liberal in the video game context. Finally, just as there was evidence for disruption in the control children's filtering on the flanker task, the data indicated a possible compromise in the ADHD group's ability to filter interference due to the flankers on the flanker task as a function of the contextual manipulation. Specifically, a statistical trend was demonstrated for a larger FCE (in target RT) within the video game relative to traditional context for the ADHD group; by contrast, the control children demonstrated FCEs in their RTs that were of equivalent magnitude in each of the two contexts.

Whereas the video game features appeared to disrupt all children's processing efficiency and cognitive filtering (as tested on the flanker task), the video game features did facilitate all children's response inhibition on the stop-signal task (viewed, like processing efficiency, to be a subcomponent of focused attention). The benefit of the context manipulation upon participant's response inhibition was demonstrated to the extent that all participants became increasingly better at inhibiting responses over time on the stop-signal task in the video game but not traditional context. Additionally, the children with ADHD experienced a relative benefit in their encoding capacity for the visually masked targets on the blink task as a result of the introduction of video game features – even to the extent that their encoding limit (as reflected by their blink magnitude) paralleled that of the control children in the video game context (whereas their blink was significantly larger than that of the control children in the traditional context). To reiterate, a larger attentional blink is suggestive of a reduced encoding capacity for the targets shown on the blink task to the extent that difficulty in processing T2 | T1 occurs as a result of a limitation in attentional resources (or, alternately, a smaller memory store for the on-line targets). The implications of these results are discussed in the next chapter.

Chapter 14. General Discussion

> Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seems several simultaneously possible objects or trains of thought. Focalization, concentration, of consciousness are of its essence. (p. 3)
>
> - William James, 1890

As a forerunner of attention research, James (1890, as cited in Hartley, 1992) created a legacy that continues to be active over 115 years later. The inspiration for this project stemmed from James' legacy and, hopefully, will serve to broaden its scope. At least to the author's knowledge, this project provided the first look at several components of attention simultaneously and with consideration for their differential sensitivity to an environmental manipulation. As set out in its rationale, the project has revealed similarities and differences between the attention profiles of typically developing children relative to those with ADHD. It has identified components of attention that are robust to enhancements in context and those that are sensitive to such manipulations. Ultimately, it has shown that – not only are the components of attention differentially influenced by environmental context – the influence of the context can change as a function of the population studied.

Although the greatest focus of this project was on the "malleability" of attention in children, the collection of data from adults in Experiment 1 permitted the development of two conclusions that are important to the field of human cognition. Firstly, a key finding in Experiment 1 was that participants in the integrated condition demonstrated worse interference control on the flanker task than those in the separate condition. This finding implies that a person's attention beam automatically responds to the nature of the visual stimuli being attended and does so in a way that maintains maximal processing efficiency. This is an impressive, although not entirely surprising, example of how flexible the human brain is and how well adapted it is to the visual world. Secondly, the task effects that were shown by the adults in Experiment 1 were replicated in the child sample from Experiment 2 – using exactly the same tasks. The replicated effects included an alerting effect using auditory cues, the Simon effect, the FCE, an attentional blink, and a vigilance decrement on a simple detection task. The replication suggests that several basic components of attention operate similarly in children as they do in adults and, thus, are likely developed quite early in life. Furthermore, the impressive similarity even in the magnitude of many of these effects suggests that, developmentally, it is adaptive for the attention system to establish adult-like efficiency at an early age.

Just as it is useful to compare the attention profile of children with that of adults, it is useful to compare the profile of typically developing children with that of children with ADHD. The reader may recall from earlier in this manuscript that there is a general convergence of opinion in several bodies of literature regarding the core deficits that typify ADHD. The literature encompasses theory, etiology (particularly as it relates to neuroanatomy), and empiricism, and suggests that children with ADHD are most compromised in their levels of arousal, behavioural inhibition, and working memory.[43] When related to the taxonomy of attention used in this project, these findings translate into hypothesized deficits in the processes of encoding (in particular, the capacity limit for such), focusing, and sustaining focus.

Initially, the results of this study appear to support the conjecture that ADHD entails a deficit in encoding capacity. Closer inspection, however, reveals the caveat that the deficit is a byproduct of deficient focused attention – at least to the extent that the ADHD group's poorer T1 performance on the blink task corresponded to their poorer T2 | T1 performance. Whether their failure to correctly identify the first target in the TM-TM stimulus streams was a function of impaired focus or impaired short-term memory remains unclear, although the former was further implicated on several other measures in

[43] See Chapters 3 through 6 for detail and Chapter 7 for a summary of this literature. The corresponding references are provided therein.

this project. Notably, the children with ADHD experienced a larger attentional blink than their control counterparts in the video game context so, possibly, ADHD entails an encoding deficit under certain circumstances (such as those with increased stimulation, cognitive demands, and/or sources of distraction). It is not likely a coincidence that the lack of clarity in the data maps directly onto a debate of this exact nature in published literature on ADHD (see Chapter 4 for further detail and related references).

Although the data are mixed regarding a deficit in encoding capacity in ADHD, they are much clearer regarding focused attention. Of the three components hypothesized to be deficient in ADHD, the data provide the most support for a deficit in this domain. The deficits in focused attention were shown on the subcomponents of processing efficiency, target sensitivity, and inhibitory control for both ongoing and prepotent motor responses. In surprising contrast to a long-held notion in the ADHD field – but in congruence with growing empirical evidence and a recent shift in thinking (Barkley, 1997a, 1997b) – the data provided very little evidence for a deficit in sustained attention in the ADHD group.

In terms of equivalent profiles of attention components, the children with ADHD were as proficient as their control counterparts in their ability to be alerted by the cueing tones on the Simon task (i.e., their attentional expectancy). Additionally - just as McLaughlin (2003) found in her study - the ADHD group studied herein were as proficient as the control group in cognitively filtering (or not, as the case was) the incongruence in the S-R spatial maps on the Simon task. Furthermore, just as McLaughlin (2003) found and Jonkman et al. (1999) demonstrated with RT data, the ADHD group paralleled the control group in its ability to control the interference from cues delivered by multi-distanced flankers surrounding central targets on the flanker task. This finding contrasts with Barkley's (1997a, 1997b) tenet that difficulty with interference control is a core feature of ADHD, yet supports Nigg's (2001) lack of confidence in the same. Considered together, the results – as hypothesized - indicate that there are aspects of alertness and executive control that do not fit the symptom profile of ADHD.

Only one of the six studied components (i.e., focused attention) demonstrated a clear vulnerability to the passage of time. The results indicated clear evidence that all children were not able to fully sustain their capacity for processing efficiency on four of the five tasks nor were they able to sustain their target sensitivity or conservative response bias on the CPT. The degree of vulnerability was the same for the two groups of children and not all-encompassing, as several measures of processing efficiency (target accuracy on the flanker and stop-signal tasks as well as target RT and its *SD* on the stop-signal task) and response inhibition (overall false alarm rate and false alarm rate as a function of distracter type) remained stable over time. A trend was shown for children's filtering to become worse over time but only on one of several measures (the FCE in RT data from the flanker task). The components of attentional expectancy, encoding capacity, and interference control did not change as a function of testing time.

The results of the contextual manipulation on the components of attention in each of the two participant groups were reviewed in great detail in Chapter 13 and will not be re-reviewed here. Nonetheless, there is a general body of evidence to implicate interference in the children's attentional performance by the introduction of colourful stimuli, reward contingencies, and a video game storyline into their environment as they complete a series of reaction time (and similar) lab tasks. As foreshadowed in Chapter 6 and summarized in Chapter 7, there are two likely reasons for interference of the contextual manipulation. The first is competition for attentional gaze and the second is cognitive overload. Perhaps these two factors explain the discrepancy in the field regarding the potential of contextual manipulations to reduce ADHD symptomatology.

Just as the peripheral computer monitor displaying a cartoon show pulled children's attention away from the task they were completing in Lee's (1999) study, the graphics of a path and animal characters on the bottom half of the computer monitor and the collection of possible rewards on a nearby table in the current project likely diverted the children's visual gaze from the task displays. Secondly, a unique goal and ongoing possibilities for task outcome probably served to overload the children's working memory in the video game context. For example, the children may have been keeping in mind the end goal of "traveling" the entire gravel path (in the video game display on the computer monitor) and thereby becoming the ruler of the virtual "animal world." They may have regularly monitored their point tally and used it to gauge their progress, or to estimate the time remaining before task completion. Alternately, the children may have periodically observed the virtual bridge in the graphics display (reaching the bridge signaled the end of that task). The overload of demands on children's executive functions in stimulation-rich events such as playing video games or walking through a zoo has been implicated in previous research (Lawrence et al., 2002; Tannock, 1997).

A review of literature on emotion and how it relates to neuropsychology brings to light the likelihood that the anticipation of toy rewards in the video game context improved the children's moods. In turn, the positive affect may have produced cognitive intrusions regarding if and when rewards would be obtained, what rewards should be chosen,[44] and how each would be enjoyed. It might also have elicited reflection on how pretty the poster of the piggy bank and coins looked on the wall, or exactly what the Bart Simpson © poster said about not liking school. A recently proposed neuropsychological theory relating positive affect to cognition (Ashby, Isen, & Turken, 1999) and a growing body of empirical research (e.g., Bartolic, Basso, Schefft, Glauser, & Titanic-Schefft, 1999) indicate that a happy mood can facilitate cognitive flexibility such as the skills for creative problem solving and verbal fluency. Conversely, a happy mood interferes with other types of cognition. A study that investigated the influence of induced mood states on executive functions showed participants in a happy mood to demonstrate worse performance on the Stroop task than those in a neutral mood state (Phillips, Bull, Adams, & Fraser, 2002). Phillips et al. (2002) suggested that the discrepancy in performance effects is a function of the intrinsically motivating qualities (or lack thereof) that are inherent to the tasks used.

It could be argued that the tasks used in the current project were not intrinsically motivating. Thus, it makes sense that - to the extent that the children were put in a happy

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[44] The reader may recall that children could choose a larger prize worth the 200 coins that they earned or could choose a collection of prizes that totaled a worth of 200 coins.

mood by the video game context - their executive functions suffered. The mediator in the mood-performance relationship, as mentioned, was likely intruding thoughts about the reward and stimulation. Indeed, a study that used the CPT in children with ADHD showed methylphenidate to improve sustained attention whereas rewards and response costs did not; both interventions (unlike the contextual manipulation used herein) improved target sensitivity, however (Solanto, Wender, & Bartell, 1997). Solanto et al. (1997) concluded that stimulation of brain centers associated with reward (via dopaminergic transmission) only partially mediate improvements in attention.

Regarding the relative benefit of the video game features on children with ADHD and not the control children on the measures of processing speed in the flanker task, performance accuracy in the stop-signal task, and encoding capacity in the blink task, it may be that – as alluded to in project hypotheses - the neurophysiology of ADHD implicates greater potential for afflicted children to benefit from an increase in dopaminergic neurotransmission (as was presumably elicited in the video game context). The converse indication that the video game features detrimentally impacted their ability for cognitive filtering on the flanker task more so than the control children is especially interesting because problematic filtering does not appear to be a characteristic of ADHD. The finding may be related to the concurrent demand for visual focusing and resultant increase in cognitive load.

The many findings from this study can be placed into the context of several different models of ADHD. For example, Chapter 4 in this manuscript outlined three such models: Zentall's (1975) underarousal theory, Barkley's (1997a, 1997b) theory of deficient behavioural inhibition, and Douglas' (1983, 1988, 2005) model of impaired self-regulation. The results contradict Zentall's proposal that a visually exciting environment can calm hyperactive children to the extent that they can function at the same level as typically developing peers. In fact, the results from this study provide evidence to the contrary. In particular, it seems that visually enhancing a hyperactive child's physical workspace produces interference in his/her ability to attend to events and fulfill task demands within that environment. Support is garnered, however, for Barkley's theory of

ADHD. The results that map most clearly onto Barkley's model are those from the stop-signal task wherein the children with ADHD demonstrated (what was interpreted as) a general lack of motor control. To the extent that the results suggested a deficit in encoding capacity among the children with ADHD (as indicated by their reduced ability to identify the second targets on the blink task), the findings from this project tap into both Barkley's and Douglas' prediction of impaired working memory for these children. Notably, the conclusion for which most evidence is found – in particular, the notion of impaired focusing in children with ADHD – fits most neatly into Douglas' model wherein she describes children with this disorder as having great difficulty in regulating their levels of alertness and arousal.

Beyond confirming (and disconfirming, as the case may be) various models of ADHD, the results from this study add to the growing body of literature on the lack of fit between symptom criteria for a diagnosis of ADHD and the actual deficiencies that typify children who have been diagnosed with the disorder – namely, the lack of a deficit in sustained attention.[45] Fortunately, the tremendous quantity of research that exists on ADHD appears to be shifting in focus towards a more accurate view of ADHD – what it is, what does and does not belong in the symptom list, who should and should not be diagnosed with it, and how it can be most effectively treated. In that regard, the results of this study bring to light possible reasons for the failure of past researchers to facilitate improvements in the functioning of children with ADHD through the use of reward contingencies, and shows how important it is for intervention programs to be clear in terms of exactly which cognitive and/or behavioural difficulties are being targeted in a child with ADHD (or any child for that matter). Indeed, it may not be possible to target all components of attention through contextual manipulations but the ones that can be impacted require individual and careful analysis. Clinically, then, time must be taken to understand exactly the problems that a child does or does not have with visually focusing on objects/events versus ignoring nearby distraction, with remembering something they

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[45] Notably, data analyses conducted on the same participant sample, minus the four children with the PI subtype of ADHD, demonstrated the same general pattern of results as reported in this manuscript for all tasks, both groups, and both contexts.

just saw versus something that they have been (apparently) attending for several minutes, and with effectively responding to cues provided by sound alarms (… or parents!). In turn, options for intervention can be considered and chosen accordingly. Given the literature and experimental findings that are reviewed herein, it might – for example – be reasonable to use contextual enhancements to motivate children with ADHD to remember just-witnessed events but not to help them stay focused on a two-hour documentary about something of little interest to them.

The idea that contextual factors differentially influence the components of attention is not a new phenomenon. For example, it fits with the long-held practice of libraries encouraging quietness so that patrons may concentrate on their respective activities. Alternately, it explains why the sound of a baby crying might be particularly disruptive during a church service but less so at a busy playground. The ability to filter out these distractions undoubtedly varies according to the general noise level and nature of the environments. The ability to filter distraction is very likely compromised when a person's cognitive resources are devoted to a task that requires concentration – such as studying in the library for an upcoming biochemistry exam or listening to a sermon. Similarly, it makes sense that the extent to which a person can quickly and accurately complete a task or stop from running in front of an oncoming train depends upon the environment he/she is in. The ability to focus on these events will likely be facilitated by a lack of distracting sights and sounds. Finally, it makes intuitive sense that the capacity a person has for encoding information is a function of the setting. Things will likely be easier to encode if colourful, interesting, and relevant to the observer than if chromatically dull, irrelevant, and amidst more enticing stimuli.

Equally as interesting as the phenomenon of "contextually vulnerable" components of attention is its antithesis, although clearly even the components that are robust to contextual manipulations must be influenced by environmental extremes. Nonetheless, the idea that a person's attention can be cued by alerting sounds to the same extent in a multitude of environments has implications for many aspects of society. For example, civil engineers might have increased confidence in the widespread use of fire alarms, maybe even extending their use in areas where they are not currently used (such as outdoor recreational facilities). Alternately, the notion that a person's ability to sustain alertness or executive control is at least partially independent from his/her surroundings holds promise for employers, television programmers, and air traffic controllers (but not teachers!). Finally, interior designers and architectural engineers might enjoy greater freedom, for example, given the implication that a person's surroundings are not likely to have a strong influence on his/her ability to attend to an object or event despite being in close quarters with other objects and events.

Its controlled nature and the finite aspect of the resources that can be committed to it inherently limit an experimental research study. This study is no exception to that phenomenon. Perhaps this study's greatest limitations lie in the fact that no attention component can ever be fully isolated by any manipulation of tasks or environmental contexts. Their interdependent nature is especially remarkable for sustained attention as it can be tapped for any length of time and always entails the waxing and waning of alertness, orienting, and executive control. The other components are momentous phenomena and, at least theoretically, one can be isolated to a greater extent than any other at any point in time (van Zomeren & Brouwer, 1987).

Beyond the limited ability to isolate any component of attention, the current project was limited by the failure of the stop-signal task to elicit in the child participants a 50% probability of response inhibition on stop trials, the "impurity" of the ADHD sample due to its inclusion of children with different subtypes of the disorder, and – in its initial design phase - a lack of appreciation for the mediating role that stimulus intensity appears to play in the behaviour-environment relationship in children. Even with the results analyzed and an acknowledgement of research from biological, psychological, and cognitive realms, the dynamics by which the experimental manipulation produced the effects it did remain speculative. A self-report questionnaire was administered to each child regarding his/her feelings toward the video game context. The data from these questionnaires have yet to be analyzed but hold potential for quantifying the degree of positive affect and, related to that, motivation that was elicited by the video game features of the attention battery. With this knowledge, clarity should be gained regarding the mechanisms of the contextual and group effects. Even without this clarification, however, the study still forms a solid basis for further research on attention in children and the relevance of the environments to which they attend.

The possibilities for future research in this area are limitless. Ideas for applied research in this area are especially exciting and suggest the potential to some day uncover ways to teach people how to improve their attentional skills. Great value would be offered by research that entailed attention components not studied herein, contextual manipulations on a different scale (smaller or larger) and in different settings than that used in this lab–based study, a range of participant ages including children and adults, and activities of a different nature than highly controlled computer tasks.

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Table 1

Experiment 2: Neural Networks, Components, Subcomponents, Tasks, and Performance Measures of Attention Studied in this Project

NETWORK **Component**	**Subcomponent**	**Task**	**Performance Measure(s)**
ALERTNESS			
Expect	Cue sensitivity	Simon	Target RT & accuracy ▪ effect of warning interval
Encode	Capacity limit	Blink	T2 | T1 accuracy ▪ overall ▪ effect of ISI Blink magnitude ▪ overall
Sustain	Performance stability	Simon	Target RT & accuracy ▪ effect of test block ▪ effect of warning interval * test block ▪ effect of trial type * test block
		Flanker	Target RT & accuracy ▪ effect of test block ▪ effect of trial type * test block ▪ effect of distance * test block ▪ effect of trial type * distance * test block
		Stop-signal	Target RT & accuracy [go trials] ▪ effect of test block

			Variability in target RT [go trials] ▪ effect of test block SSRT [stop trials] ▪ effect of test block
		Blink	T1 & T2 | T1 accuracy ▪ effect of test block ▪ effect of ISI * test block Blink magnitude ▪ effect of test block
		Continuous performance	Hit RT, hit rate, A', & B" ▪ effect of test block False alarm rate ▪ effect of test block ▪ effect of distracter type
EXECUTIVE CONTROL			
Focus	Processing efficiency	Simon	Target RT & accuracy ▪ overall
		Flanker	Target RT & accuracy ▪ overall
		Stop-signal	Target RT & accuracy [go trials] ▪ overall Variability in target RT [go trials] ▪ overall
		Blink	T1 accuracy ▪ overall

		Continuous performance	Hit RT & rate ▪ overall
	Target sensitivity	Continuous performance	A' (nonparametric d') ▪ overall
	Response inhibition (prepotent responses)	Continuous performance	False alarm rate ▪ overall ▪ effect of distracter type
	Response inhibition (ongoing responses)	Stop-signal	SSRT [stop trials] ▪ overall
	Response bias[46]	Continuous performance	B" (nonparametric β) ▪ overall
Filter	Sensitivity to S-R spatial congruence	Simon	Target RT & accuracy ▪ effect of trial type
Interference control	Visual distractibility	Flanker	Target RT & accuracy ▪ effect of trial type ▪ effect of flanker distance ▪ effect of trial type * flanker distance

[46] As discussed in the text of the manuscript, this measure is closely related to the response inhibition subcomponent of focused attention.

Table 2

Experiment 1: Participant Means (*SE*) of Performance Measures Across Conditions

Task	**Performance Measure**	**Condition**	
		Separate	Integrated
Simon	Target RT (ms)	480.63^{A} (2.13)	664.84^{B} (6.63)
	Target accuracy	94.9^{A} (<0.01)	98.3^{B} (<0.01)
Flanker	Target RT (ms)	446.18^{A} (3.29)	698.74^{B} (10.07)
	Target accuracy	97.4^{A} (<0.01)	99.0^{B} (<0.01)
Stop-signal	Target RT (ms)	558.61^{A} (16.64)	679.16^{B} (22.99)
	Target accuracy	98.4^{A} (<0.01)	98.6^{A} (<0.01)
	SSRT	278.33^{A} (8.61)	255.19^{A} (8.66)
	P(I | S)	52.1^{A} (0.02)	53.7^{A} (0.02)
Blink	T1 accuracy	81.5^{A} (0.01)	86.7^{A} (< 0.01)
	T2 | T1 accuracy	79.0^{A} (0.01)	79.0^{A} (0.01)
	Blink magnitude	0.44^{A} (0.06)	0.56^{A} (0.07)
Continuous performance	Hit RT (ms)	322.33^{A} (4.25)	330.12^{A} (5.39)
	Hit rate	98.4^{A} (<0.01)	98.7^{A} (<0.01)
	False alarm rate	1.1^{A} (<0.01)	1.0^{A} (<0.01)
	A'	0.99^{A} (<0.01)	0.99^{A} (<0.01)
	B"	-0.18^{A} (0.07)	-0.18^{A} (0.06)

^{A} and ^{B} used to denote statistical equivalence/difference at $p < .05$.

Table 3

Experiment 1: Participant Means (*SE*) of Performance Measures Across Conditions and Test Blocks

Task	Performance Measure	Test Block		
		1	2	3
		SEPARATE CONDITION		
Simon	Target RT (ms)	491.76^{A} (3.74)	480.41^{B} (3.82)	469.72^{C} (3.45)
	Target accuracy (%)	95.4^{A} (< 0.01)	94.0^{B} (<0.01)	95.4^{A} (<0.01)
Flanker	Target RT (ms)	464.77^{A} (6.11)	436.33^{B} (5.02)	437.46^{B} (5.70)
	Target accuracy (%)	97.4^{A} (<0.01)	97.8^{A} (<0.01)	97.0^{A} (<0.01)
Stop-signal	Target RT (ms)	532.63^{A} (19.95)	557.68^{AB} (27.71)	585.52^{A} (36.55)
	Target accuracy (%)	98.8^{A} (<0.01)	98.1^{A} (<0.01)	98.4^{A} (<0.01)
	SSRT	271.71^{A} (10.47)	270.03^{A} (13.27)	293.26^{A} (19.62)
	P(I | S) (%)	51.2^{A} (0.06)	55.0^{A} (0.03)	50.2^{A} (0.03)
Blink	T1 accuracy (%)	77.9^{A} (0.02)	83.1^{B} (0.02)	83.3^{B} (0.02)
	T2 | T1 accuracy (%)	73.7^{A} (0.02)	79.9^{B} (0.02)	83.4^{B} (0.02)
	Blink magnitude	0.61^{A} (0.12)	0.47^{AB} (0.10)	0.25^{A} (0.10)
Continuous performance	Hit RT (ms)	312.24^{A} (7.12)	317.14^{A} (6.76)	337.61^{B} (7.54)
	Hit rate (%)	100.0^{A} (<0.01)	96.9^{B} (0.01)	98.2^{AB} (<0.01)
	False alarm rate (%)	0.9^{A} (<0.01)	0.1^{A} (<0.01)	2.3^{B} (<0.01)
	A'	1.00^{A} (<0.01)	0.99^{B} (<0.01)	0.99^{B} (<0.01)
	B"	-0.21^{A} (0.08)	0.18^{B} (0.09)	-0.51^{C} (0.12)

INTEGRATED CONDITION

Simon	Target RT (ms)	654.64^{A} (9.41)	671.22^{A} (12.59)	668.65^{A} (12.19)
	Target accuracy (%)	98.5^{A} (<0.01)	98.3^{A} (<0.01)	98.2^{A} (<0.01)
Flanker	Target RT (ms)	677.97^{A} (13.75)	704.54^{A} (18.83)	713.71^{A} (19.21)
	Target accuracy (%)	98.6^{A} (<0.01)	99.3^{A} (<0.01)	99.0^{A} (<0.01)
Stop-signal	Target RT (ms)	662.21^{A} (31.28)	686.14^{A} (44.28)	689.12^{A} (43.91)
	Target accuracy (%)	98.6^{A} (<0.01)	98.6^{A} (<0.01)	98.6^{A} (<0.01)
	P(I | S) (%)	53.0^{A} (0.03)	53.9^{A} (0.03)	54.1^{A} (0.04)
	SSRT (ms)	251.85^{A} (12.39)	261.46^{A} (17.37)	252.26^{A} (15.34)
Blink	T1 accuracy (%)	82.9^{A} (0.02)	88.7^{B} (0.01)	88.5^{B} (0.01)
	T2 | T1 accuracy (%)	73.9^{A} (0.02)	79.5^{B} (0.02)	83.7^{C} (0.02)
	Blink magnitude	0.82^{A} (0.12)	0.54^{B} (0.12)	0.30^{B} (0.09)
Continuous performance	Hit RT (ms)	324.88^{A} (9.84)	324.22^{A} (9.92)	341.25^{B} (8.08)
	Hit rate (%)	99.0^{A} (<0.01)	99.5^{A} (<0.01)	97.6^{A} (0.01)
	False alarm rate (%)	0.3^{A} (<0.01)	0.1^{A} (<0.01)	2.7^{B} (<0.01)
	A'	1.00^{A} (<0.01)	1.00^{A} (<0.01)	0.99^{B} (<0.01)
	B"	-0.04^{A} (0.09)	0.00^{A} (0.06)	-0.51^{B} (0.13)

^{A}, ^{B}, and ^{C} used to denote statistical equivalence/difference at $p < .05$.

Table 4

Experiment 2: Demographic Information of Participant Families

Demographic Variable	Mother	Father
Gross Yearly Income (in thousands of dollars)		
▪ 0-10	8	0
▪ 10-25	12	4
▪ 25-40	15	7
▪ 40-55	4	11
▪ 55-75	3	11
▪ Over 75	2	3
▪ Not reported	1	9
Highest Level of Education		
▪ Completed a post university program	5	7
▪ Graduated from university	11	10
▪ Graduated from university and technical school	0	2
▪ Graduated from technical school, community college, etc.	7	12
▪ Completed at least one year of college, university or specialized training (e.g., technical school, community college)	14	6
▪ Graduated from high school or earned GED	6	3
▪ Completed some high school	2	2
▪ Not reported	0	3

Table 5

Experiment 2: Participant Means (*SE*) of Performance Measures Across Groups

Task	Performance Measure	Group: Control	Group: ADHD
Simon	Target RT (ms)	740.92^{A} (3.76)	839.76^{B} (5.39)
	Target accuracy (%)	94.4^{A} (< 0.01)	88.4^{B} (0.01)
Flanker	Target RT (ms)	713.95^{A} (5.49)	852.91^{B} (8.10)
	Target accuracy (%)	95.2^{A} (< 0.01)	90.6^{B} (0.01)
Stop-signal	Target RT (ms)	753.92^{A} (11.66)	825.84^{A} (17.50)
	SD of target RT	38.09^{A} (1.21)	51.10^{B} (1.71)
	Target accuracy (%)	96.6^{A} (< 0.01)	94.6^{A} (0.01)
	P(I | S) (%)	67.8^{A} (0.02)	65.2^{A} (0.01)
Blink	T1 accuracy (%)	75.9^{A} (0.01)	61.8^{B} (0.01)
	T2 | T1 accuracy (%)	80.9^{A} (0.01)	75.0^{B} (0.01)
	Blink magnitude	0.29^{A} (0.06)	0.40^{A} (0.08)
Continuous performance	Hit RT (ms)	462.14^{A} (9.56)	499.29^{A} (13.52)
	Hit rate (%)	86.8^{A} (0.01)	77.8^{B} (0.02)
	False alarm rate (%)	2.70^{A} (< 0.01)	8.50^{B} (0.01)
	A'	0.96^{A} (< 0.01)	0.89^{B} (0.01)
	B"	0.31^{A} (0.05)	0.19^{A} (0.07)

^{A} and ^{B} used to denote statistical equivalence/difference at $p < .05$.

Note that data from both contexts were used for calculations in table.

Table 6

Experiment 2: Participant Means (*SE*) of Performance Measures Across Contexts

Task	Performance Measure	Context	
		Traditional	Video Game
Simon	Target RT (ms)	756.64^{A} (4.66)	810.98^{B} (4.50)
	Target accuracy (%)	91.5^{A} (< 0.01)	92.1^{A} (< 0.01)
Flanker	Target RT (ms)	742.61^{A} (7.20)	795.47^{B} (6.63)
	Target accuracy (%)	93.2^{A} (0.01)	93.5^{A} (< 0.01)
Stop-signal	Target RT (ms)	745.47^{A} (13.98)	821.38^{B} (14.02)
	SD of target RT	42.79^{A} (1.51)	44.07^{A} (1.56)
	Target accuracy (%)	96.0^{A} (0.01)	95.5^{A} (0.01)
	P(I | S) (%)	66.6^{A} (0.02)	66.5^{A} (0.02)
Blink	T1 accuracy (%)	73.7^{A} (0.01)	67.2^{B} (0.01)
	T2 | T1 accuracy (%)	78.3^{A} (0.01)	78.9^{A} (0.01)
	Blink magnitude	0.35^{A} (0.06)	0.31^{A} (0.07)
Continuous performance	Hit RT (ms)	487.30^{A} (10.39)	468.55^{A} (12.21)
	Hit rate (%)	85.0^{A} (0.02)	81.0^{B} (0.02)
	False alarm rate (%)	5.7^{A} (0.01)	4.6^{A} (0.01)
	A’	0.94^{A} (0.01)	0.92^{A} (0.01)
	B”	0.23^{A} (0.06)	0.29^{A} (0.06)

^{A} and ^{B} used to denote statistical equivalence/difference at $p < .05$.

Note that data from both participant groups were used for calculations in table.

Table 7

Experiment 2: Participant Means (*SE*) of Performance Measures Across Test Blocks

Task	Performance Measure	Test Block		
		1	2	3
Simon	Target RT (ms)	752.32^{A} (5.22)	801.84^{B} (5.82)	797.15^{B} (5.85)
	Target accuracy (%)	93.1^{A} (< 0.01)	91.6^{AB} (<0.01)	90.7^{B} (0.01)
Flanker	Target RT (ms)	753.98^{A} (7.95)	787.04^{B} (8.39)	766.75^{B} (9.22)
	Target accuracy (%)	94.0^{A} (0.01)	93.5^{A} (0.01)	92.6^{A} (0.01)
Stop-signal	Target RT (ms)	783.11^{A} (17.16)	790.03^{A} (18.16)	777.13^{A} (17.79)
	SD of target RT	42.20^{A} (1.97)	44.93^{A} (1.80)	43.16^{A} (1.86)
	Target accuracy (%)	95.6^{A} (0.01)	96.0^{A} (0.01)	95.6^{A} (0.01)
	P(I | S) (%)	65.6^{A} (0.02)	66.7^{A} (0.02)	67.3^{A} (0.02)
Blink	T1 accuracy (%)	74.3^{A} (0.01)	69.9^{B} (0.01)	67.1^{B} (0.01)
	T2 | T1 accuracy (%)	80.8^{A} (0.01)	78.2^{B} (0.01)	76.7^{B} (0.01)
	Blink magnitude	0.31^{A} (0.07)	0.36^{A} (0.08)	0.33^{A} (0.08)
Continuous performance	Hit RT (ms)	455.46^{A} (11.89)	478.51^{AB} (15.01)	499.81^{B} (14.32)
	Hit rate (%)	87.3^{A} (0.02)	80.9^{B} (0.02)	80.8^{B} (0.02)
	False alarm rate (%)	5.1^{A} (0.01)	5.8^{A} (0.01)	4.5^{A} (0.01)
	A'	0.95^{A} (0.01)	0.92^{B} (0.01)	0.93^{B} (0.01)
	B"	0.09^{A} (0.08)	0.27^{AB} (0.07)	0.42^{B} (0.07)

^{A} and ^{B} used to denote statistical equivalence/difference at $p < .05$.

Note that data from both participant groups were used for calculations in table.

Table 8

Experiment 2: Summary of Group and Context Effects

KEY

GE = group effect ✓ = $p < .05$ ____ = context order effect ($p < .05$)
CE = context effect ✗ no effect _ _ _ = context order trend ($p > .10$)
* = interaction

Component *Subcomponent*	**Task**	**Performance Measure(s)**	**GE**	**CE**	**GE* CE**
Expect					
Cue sensitivity	Simon	Target RT			
		▪ effect of warning interval	✗	✗	✗
		Target accuracy			
		▪ effect of warning interval	✗	✗̲	✗
Encode					
Capacity limit	Blink	T2 | T1 accuracy			
		▪ overall	✓	✗	✗
		▪ effect of ISI	✗	✗	✗
		Blink magnitude			
		▪ overall	✗	✗	✓
Sustain		See Table 9			
Focus					
Processing efficiency	Simon	Target RT			
		▪ overall	✓	✓	✗
		Target accuracy			
		▪ overall	✓	✗	✗

	Flanker	Target RT			
		▪ overall	✓	✓	✓
		Target accuracy			
		▪ overall	✓	✗̲	✗
	Stop-signal	Target RT			
		▪ overall	✗	✓	✗
		Target RT variability			
		▪ overall	✓	✗̲	✗
		Target accuracy			
		▪ overall	✗̲	✗	✗
	Blink	T1 accuracy			
		▪ overall	✓	✓̲	✗
	Continuous performance	Hit RT			
		▪ overall	✗	✗̲	✗
		Hit rate			
		▪ overall	✓	✓̲	✗
Target sensitivity	Continuous performance	A'			
		▪ overall	✓	✗̲	✗
Inhibition of prepotent responses	Continuous performance	False alarm rate			
		▪ overall	✓	✗̲	✗
		▪ distracter type	✓	✗	✗
Inhibition of ongoing responses	Stop-signal	P(I | S)			
		▪ overall	✗	✗	✗
Response bias	Continuous performance	B"			
		▪ overall	✗	✗	✓

Filter					
Sensitivity to S-R spatial congruence	Simon	Target RT			
		▪ effect of trial type	✗	✗	✗
		Target accuracy			
		▪ effect of trial type	✗	✗̲	✗
Interference control					
Visual distractibility	Flanker	Target RT			
		▪ effect of trial type	✗̲	✗̲	✓̲
		▪ effect of flanker distance	✗	✓	✗
		▪ effect of trial type * flanker distance	✗	✗	✗
		Target accuracy			
		▪ effect of trial type	✗̲	✗	✗
		▪ effect of flanker distance	✗	✗	✗
		▪ effect of trial type * flanker distance	✗	✗	✗̲

Table 9

Experiment 2: Summary of Group, Context, and Test Block Effects

KEY

TBE = test block effect ✓ = $p < .05$ ____ = context order effect ($p < .05$)
GE = group effect (✓) = $p < .10$ _ _ _ = context order trend ($p > .10$)
CE = context effect ✗ no effect
* = interaction

Component *Subcomponent*	**Task**	**Performance Measure(s)**	**TBE**	**GE* TBE**	**CE* TBE**	**GE* CE* TBE**
Expect						
Cue sensitivity	Simon	Target RT				
		▪ effect of warning interval	✗	✗	✗	✗
		Target accuracy				
		▪ effect of warning interval	✗	✗	✗	✗
Encode						
Capacity limit	Blink	T2 | T1 accuracy				
		▪ overall	✓	✓	✗	✗
		▪ effect of ISI	✗	✗	✗	✗
		Blink magnitude				
		▪ overall	✗	✗	✗	✗
Focus						
Processing efficiency	Simon	Target RT				
		▪ overall	✓̲	✗	✗	✗
		Target accuracy				
		▪ overall	✓	✗	✗	✗

	Flanker	Target RT				
		▪ overall	✓	(✓)	✓	✗
		Target accuracy				
		▪ overall	✗	✗	✗	✗
	Stop-signal	Target RT				
		▪ overall	✗	✗	✗	✗
		Target RT variability				
		▪ overall	✗	✓	✗	✗
		Target accuracy				
		▪ overall	✗	✗	✗	✓
	Blink	T1 accuracy				
		▪ overall	✓	✗	✗	✗
	Continuous performance	Hit rate				
		▪ overall	✓	✗	✗	✗
		Hit RT				
		▪ overall	✓	✗	✗	✗
Target sensitivity	Continuous performance	A'				
		▪ overall	✓	✗	✗	✗
Inhibition of prepotent responses	Continuous performance	False alarm rate				
		▪ overall	✗	✗	✗	✗
		▪ distracter type	✗	✗	✗	✗
Inhibition of ongoing responses	Stop-signal	P(I | S)				
		▪ overall	✗	✗	✓	✗
Response bias	Continuous performance	B"				
		▪ overall	✓	✗	✗	✗

Filter						
Sensitivity to S-R spatial congruence	Simon	Target RT				
		▪ effect of trial type	✗	✗	✗	✗
		Target accuracy				
		▪ effect of trial type	✗	✗	✗	✗
Interference control						
Visual distractibility	Flanker	Target RT				
		▪ effect of trial type	✗	✗	✗	✗
		▪ effect of flanker distance	✗	✗	✗	✗
		▪ effect of trial type * flanker distance	✗	✓	✗	✗
		Target accuracy				
		▪ effect of trial type	(✓)	✗	✓	✗
		▪ effect of flanker distance	✓	✗	✗	✗
		▪ effect of trial type * flanker distance	✗	✓	✗	✗

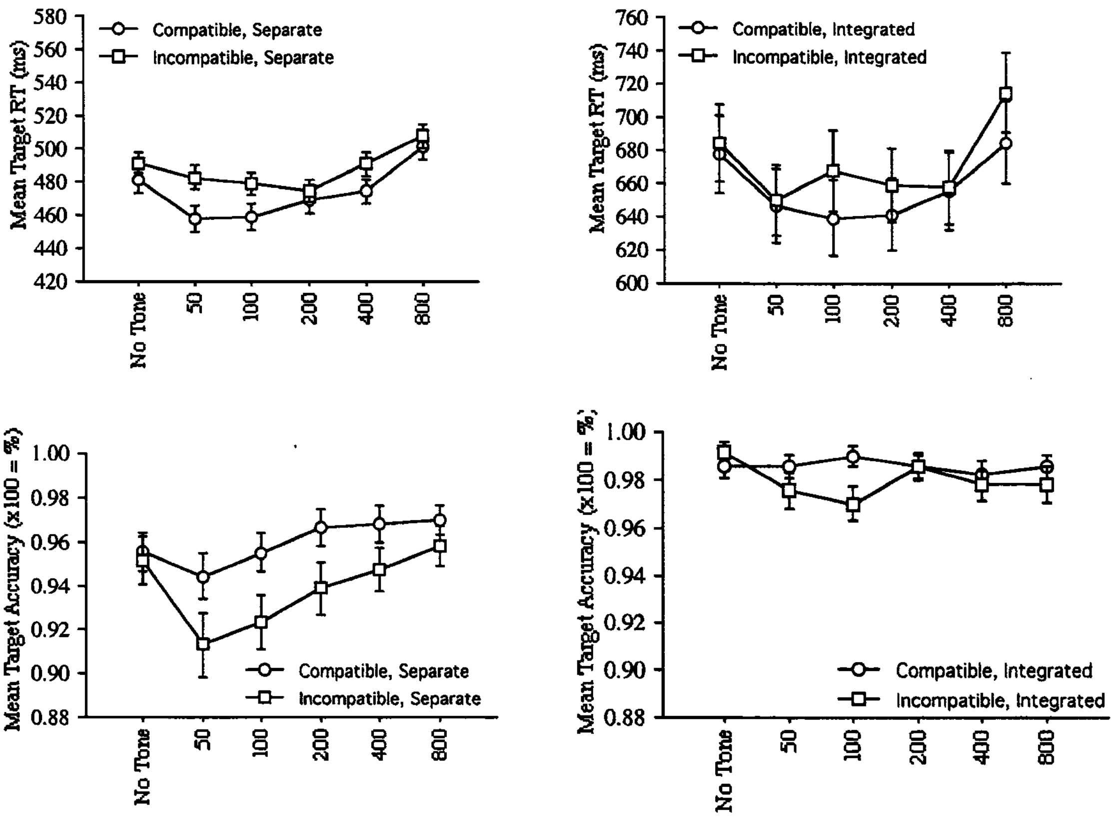

Figure 1. Experiment 1: Participants' mean target RT (± SE) and mean target accuracy (± SE) on the Simon task as a function of warning interval.

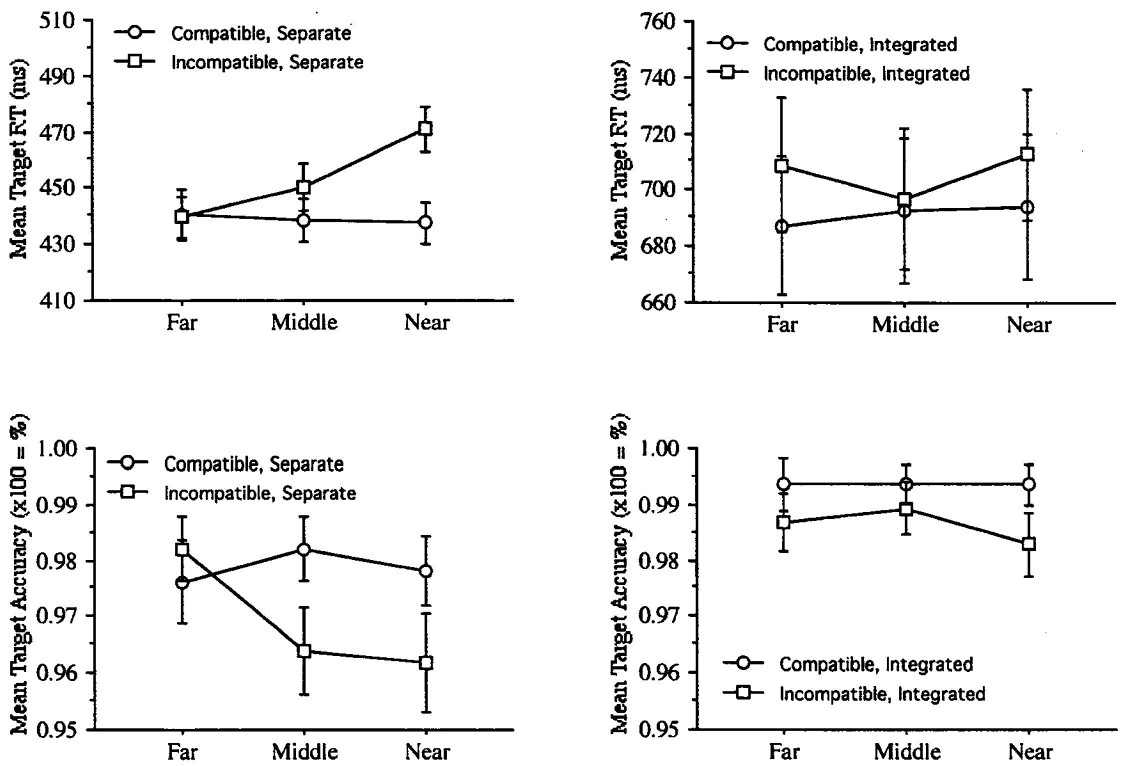

Figure 2. Experiment 1: Participants' mean target RT (± *SE*) and mean target accuracy (± *SE*) on the flanker task as a function of target-to-flanker distance.

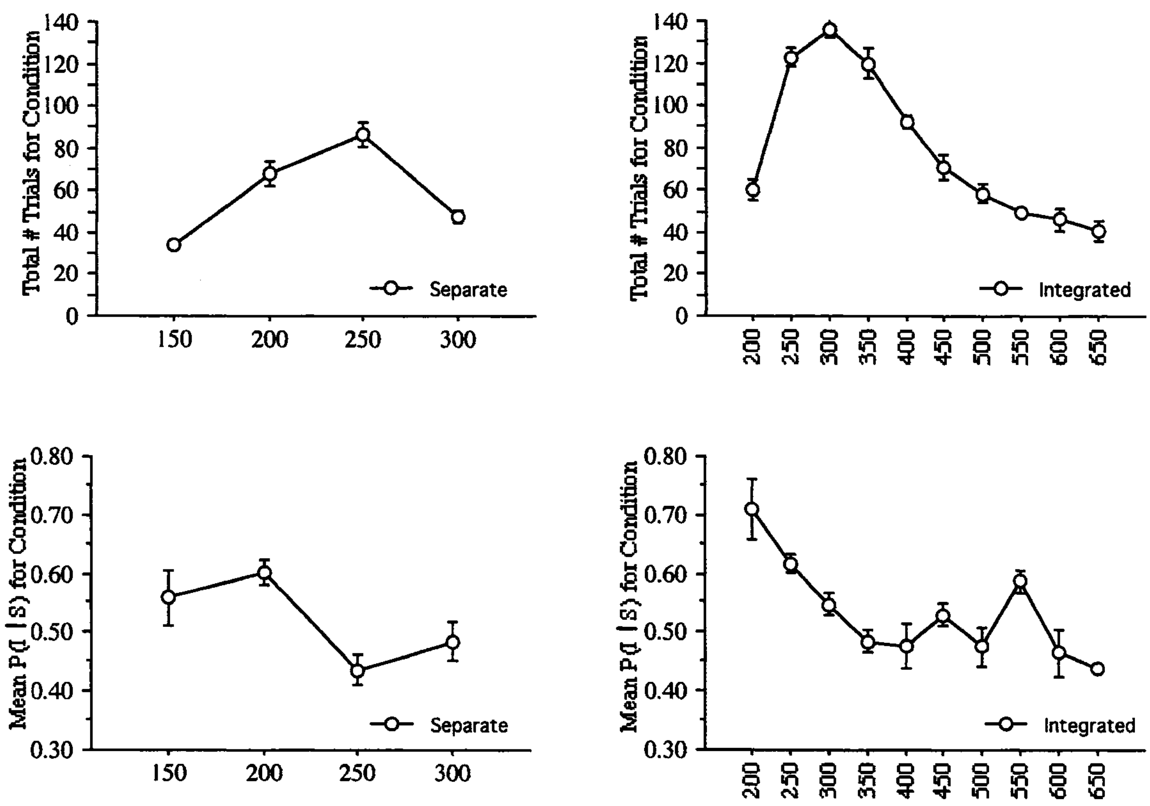

Figure 3. Experiment 1: Trial distribution (± *SE*) and mean P(I | S) (± *SE*) on the stop-signal task as a function of stop delay.

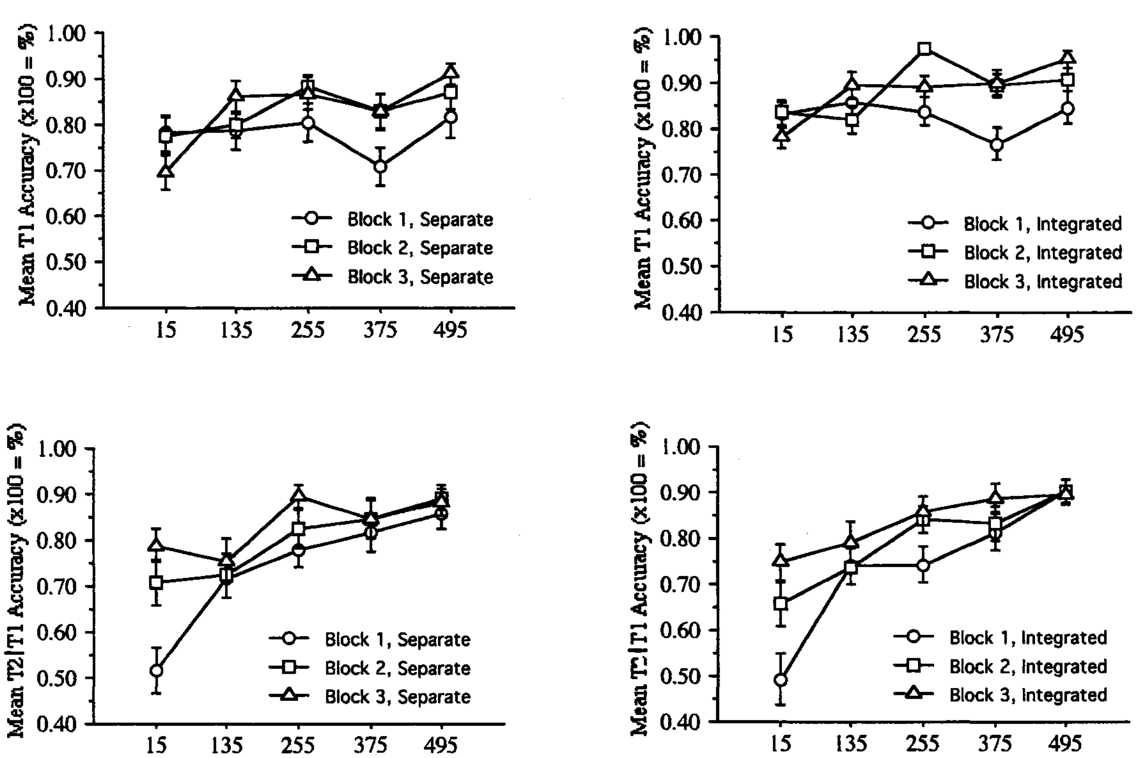

Figure 4. Experiment 1: Participants' mean target T1 accuracy (± *SE*) and mean T2 | T1 accuracy (± *SE*) on the blink task as a function of ISI.

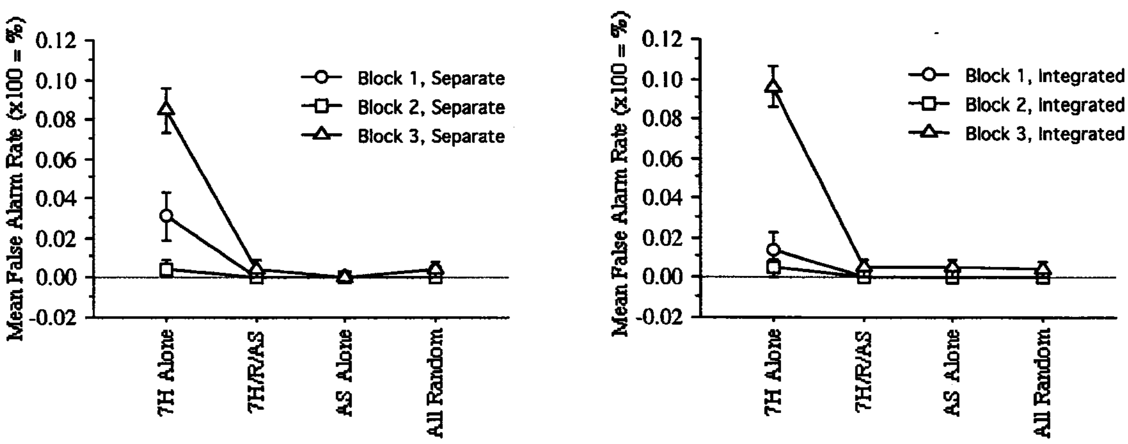

Figure 5. Experiment 1: Participants' mean false alarm rate (± *SE*) on the CPT as a function of distracter type.

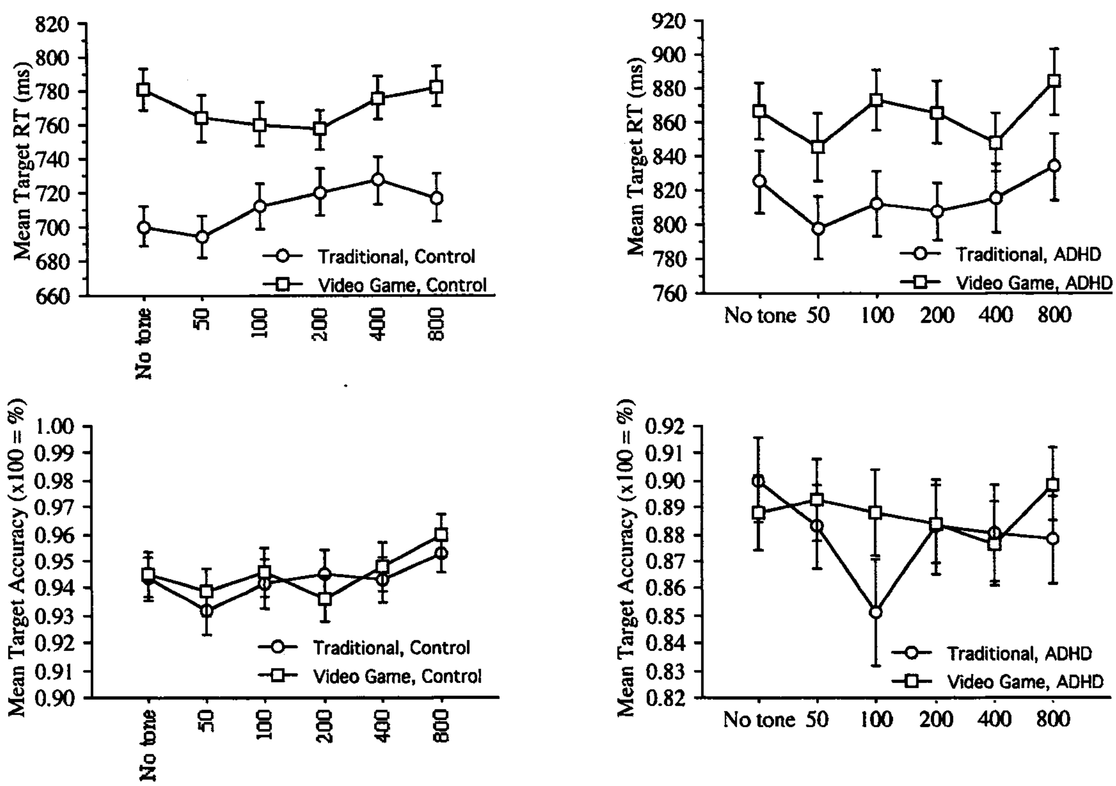

Figure 6. Experiment 2: Participants' mean target RT (± *SE*) and mean target accuracy (± *SE*) on the Simon task as a function of warning interval.

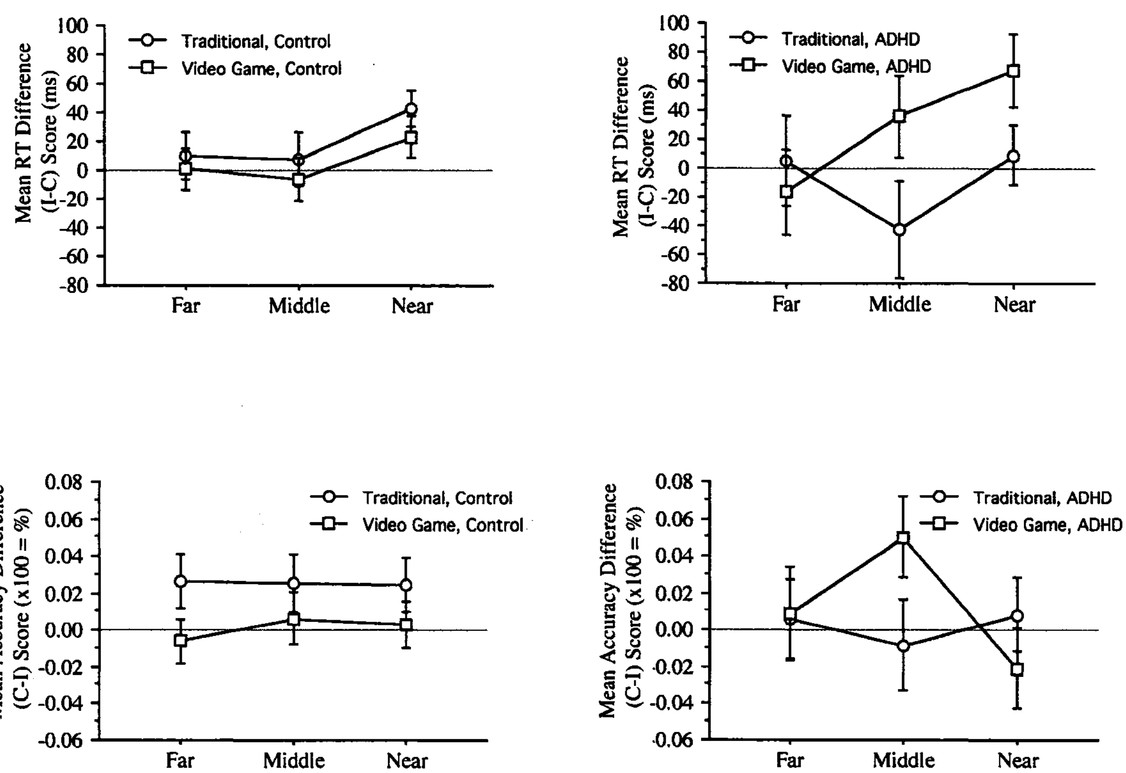

Figure 7. Experiment 2: Participants' mean flanker effect (± *SE*) and mean target accuracy (± *SE*) on the flanker task as a function of target-to-flanker distance. C = compatible trial, I = incompatible trial.

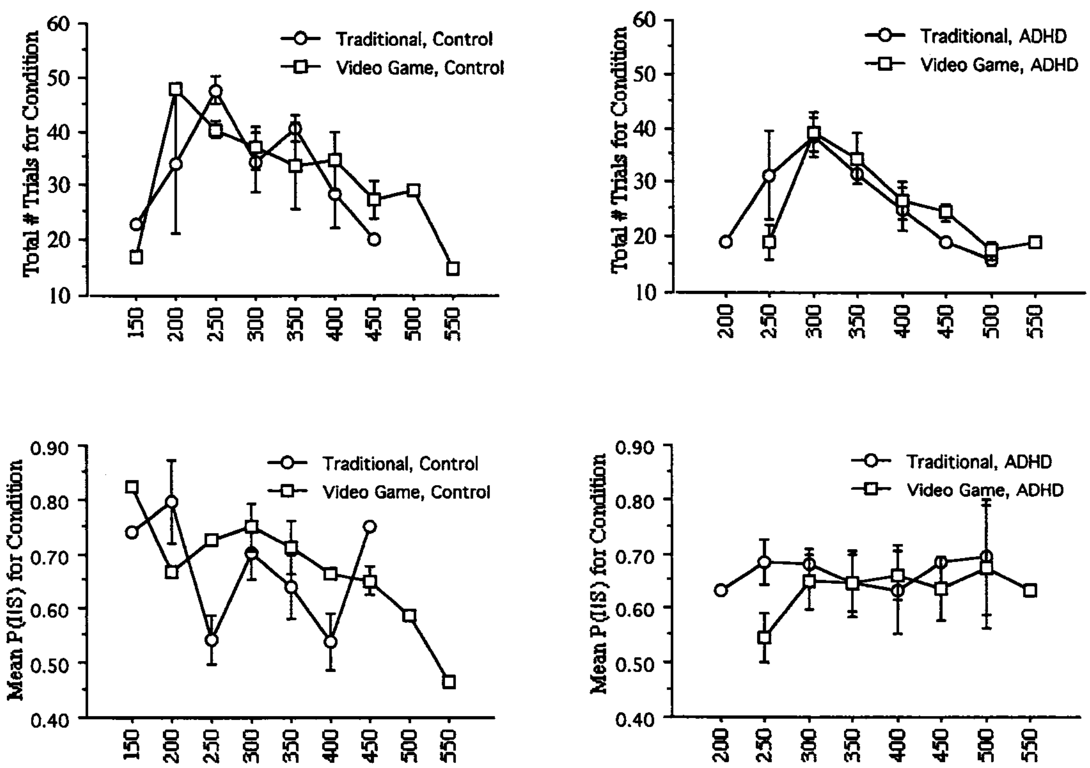

Figure 8. Experiment 2: Trial distribution (± *SE*) and mean P(I | S) (± *SE*) on the stop-signal task as a function of stop delay.

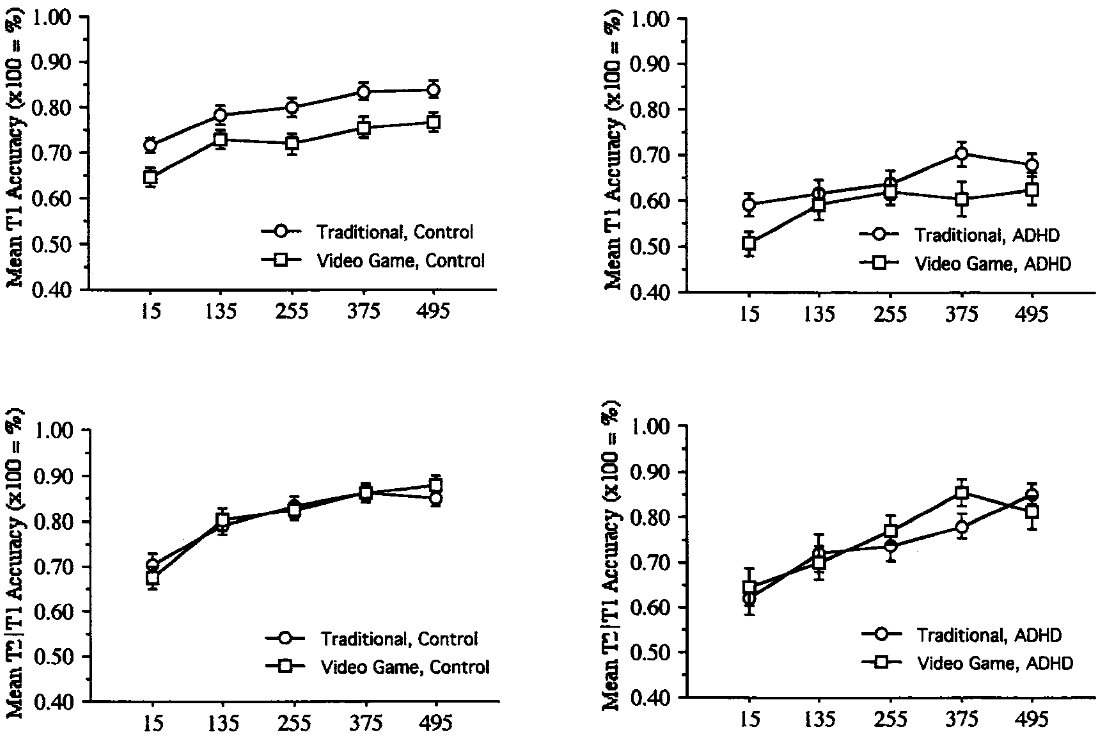

Figure 9. Experiment 2: Participants' mean target T1 accuracy (± *SE*) and mean T2 | T1 accuracy (± *SE*) on the blink task as a function of ISI.

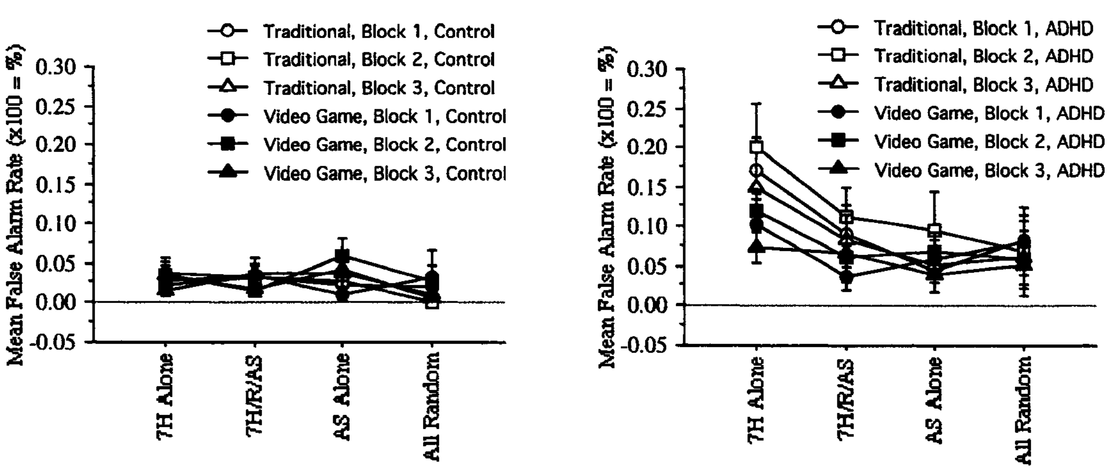

Figure 10. Experiment 2: Participants' mean false alarm rate (± *SE*) on the CPT as a function of distracter type.

Appendix A

Descriptions of Tasks

Simon Task

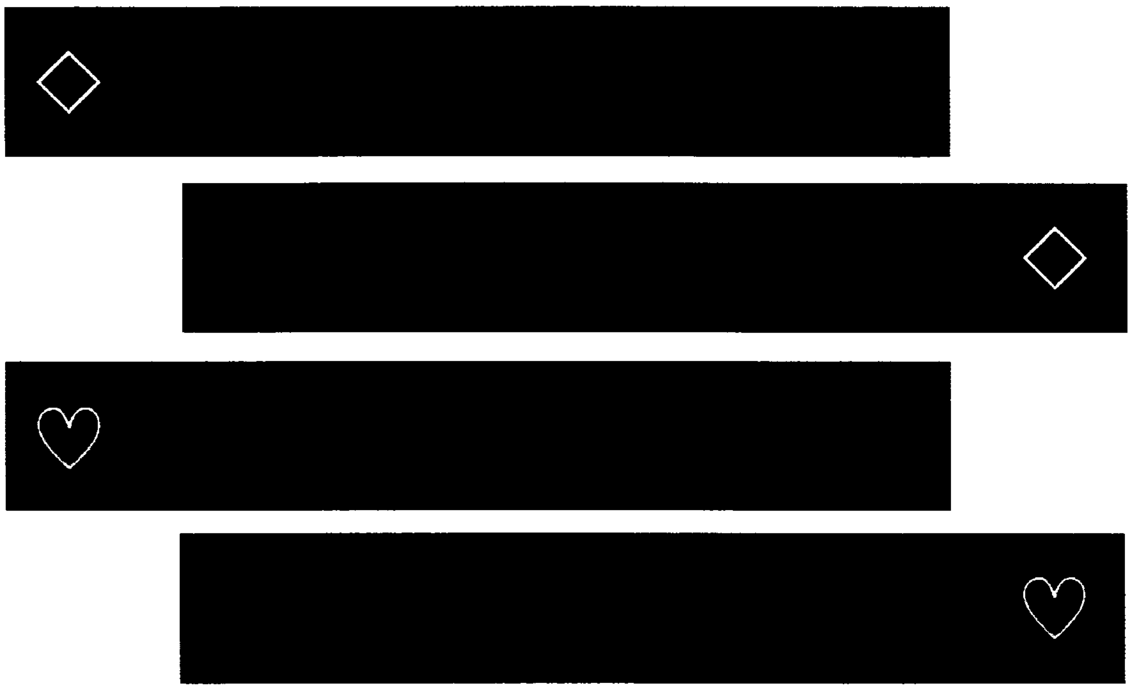

Figure A1. Depiction of the four possible trials on the Simon task. Targets are presented on the green background that filled the viewable portion of the computer screen. The first and fourth target displays represent incompatible trials whereas the second and third displays represent compatible trials. Scale is 1:1.

Trial Timing

A new trial was marked by a target onset 1000 ms following the response or time limit for the previous trial. Each target stimulus remained on the screen until a response was made or 2000 ms had passed.

Participant Instructions

Participants were instructed that they would see either a heart or a diamond on the screen on each trial and they were to press the response button corresponding with the shape they saw. Additionally, participants were told that they would hear "beeps" (the alerting tones) on some trials, and that each signaled an impending target. They were further instructed to make their responses as quickly as possible.

Flanker Task

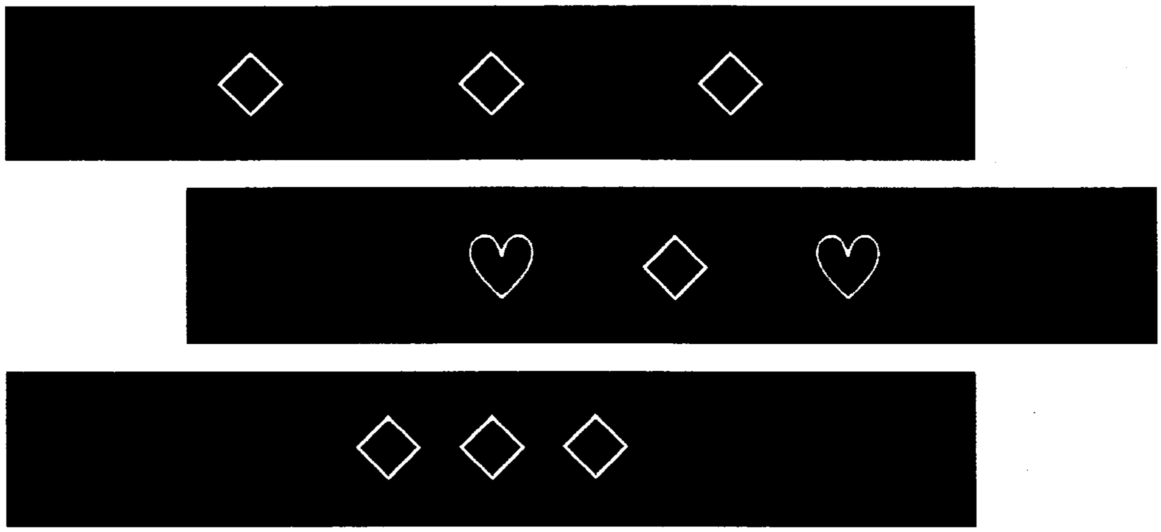

Figure A2. Depiction of three possible trials on the flanker task. Targets are presented on the green background that filled the viewable portion of the computer screen. The first and third target displays represent compatible trials whereas the middle display represents an incompatible trial. The displays demonstrate the far, middle, and near target-flanker separation distances respectively. Scale is 1:1.

Trial Timing

A new trial was marked by a target onset 1000 ms following the response or time limit for the previous trial. Each target stimulus remained on the screen until a response was made or 2000 ms had passed.

Participant Instructions

Participants were instructed that they would see several shapes on the computer screen on each trial. They were told to press the response button that corresponded with the shape (a heart or diamond) in the center of the array and to do so as quickly as possible on each trial.

Stop-Signal Task

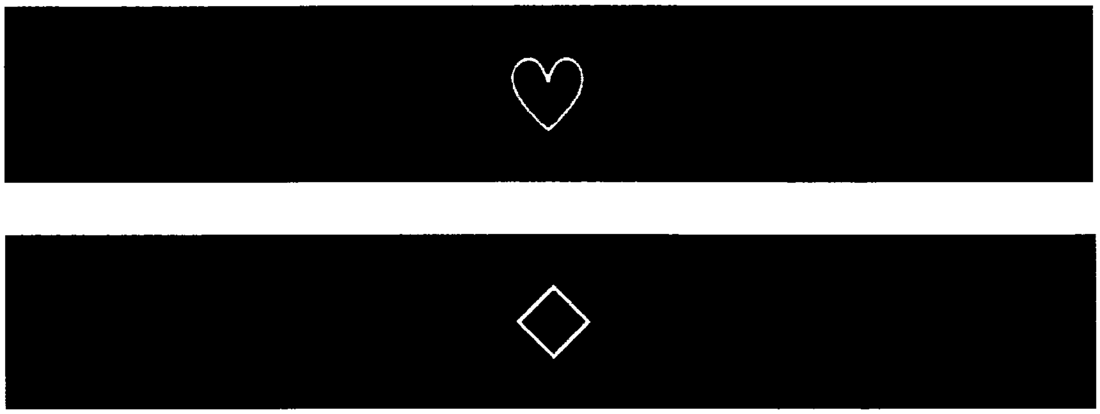

Figure A3. Depiction of the two possible go trials on the stop-signal task. Targets are presented on the green background that filled the viewable portion of the computer screen. The stop signal was a white computer screen that appeared after a delay (and momentarily covered the target) on a random selection of 25% of the trials. Scale is 1:1.

Trial Timing

A new trial was marked by a target onset 1000 ms following the response or time limit for the previous trial. Each target stimulus remained on the screen until a response was made or 2000 ms had passed.

Participant Instructions

Participants were instructed that they would see either a heart or a diamond on the screen and they were to press the response button according to the shape that appeared on each trial. They were told that the screen would turn white on some trials and that, if this happened, to try to not respond. They were also told that the white screen was random and not to wait for it. Participants were instructed to make their responses as quickly as possible.

Simon/Flanker/Stop (Integrated) Task

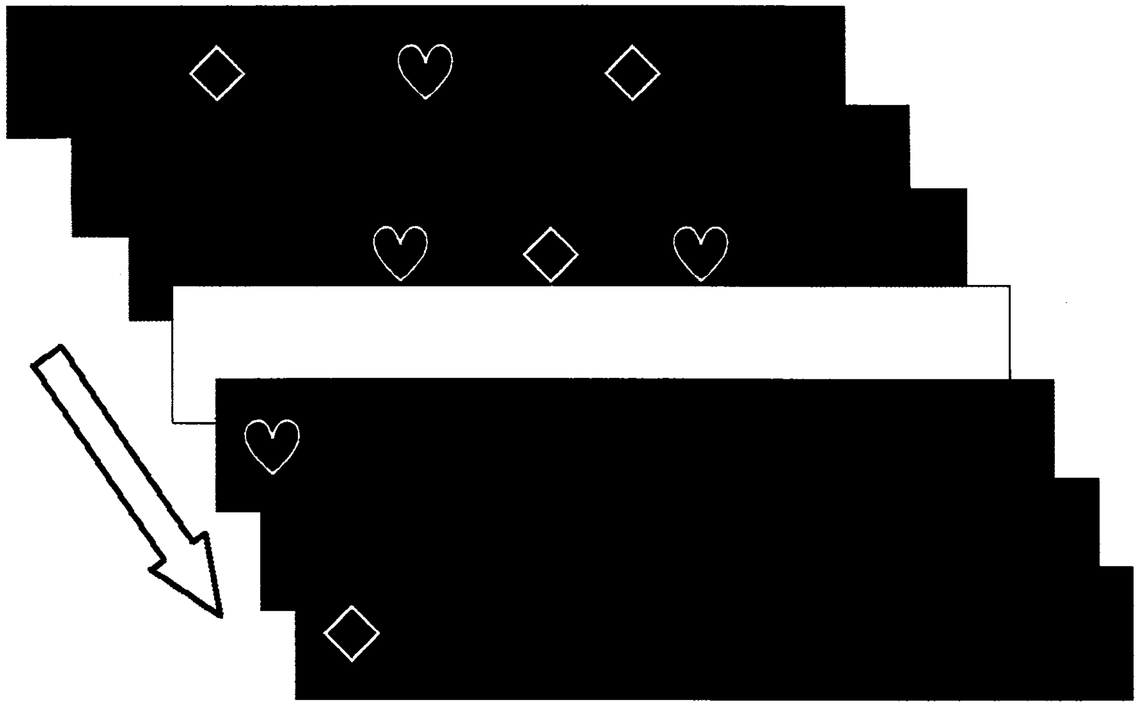

Figure A4. Depiction of six consecutive trials (randomly chosen) on the Simon/flanker/stop task. Top to bottom: incompatible flanker trial, incompatible flanker + stop trial, compatible Simon trial, incompatible Simon trial. Targets are presented on the green background that filled the viewable portion of the computer screen. The green boxes represent blank screens, the white box represents a stop signal, and the arrow represents the passage of time. Scale is 1:1.

Trial Timing

A new trial was marked by a target onset 1000 ms following the response or time limit for the previous trial. Each target stimulus remained on the screen until a response was made or 2000 ms had passed.

Participant Instructions

On the Simon/flanker/stop task (also referred to as the integrated task), participants were instructed that they would see either a heart or diamond on the computer screen. They were told to press the diamond response key if they saw a diamond and to press the heart response key if they saw a heart. Participants were further instructed on this task that, if they saw several shapes on one trial, to press the key that corresponded with the shape in the center of the array. They were also instructed that the screen would turn white on some trials and that, if this occurred, to try to not respond on that trial. Participants were told that the white screen was random and not to wait for it. Participants were instructed to make their responses as quickly as possible.

Blink Task

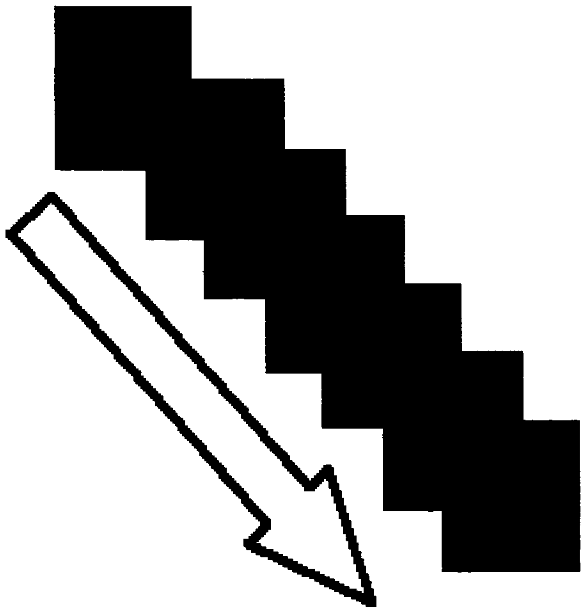

Figure A5. Event sequence for each trial on the blink task. In this example sequence, T1 = club and T2 = diamond. The arrow represents passage of time. The first and third "blank screens" (represented by green boxes) on each trial were 15 ms in duration, whereas the second blank screen was the ISI (15, 135, 255, 375, or 495 ms in duration). Scale is 1:1.

Trial Timing

Each new trial in the blink task began 1000 ms after the second response was made to the previous trial, with a total of 4000 milliseconds permitted on each trial for the presentation of the stimuli (T1, M1, T2, and M2) and the two responses.

Participant Instructions

Participants in both experimental conditions were instructed on the blink task that they would see a sequence of two card suit symbols (i.e., heart, diamond, club or spade) briefly presented on the screen, with a mask following each one. Their task was to report what the suits were, in the correct order, following presentation of the suit-mask-suit-mask array. Participants were further instructed that if they were not sure what suit was presented in one or both positions, they were to use what they did see to guess.

Continuous Performance Task (CPT)

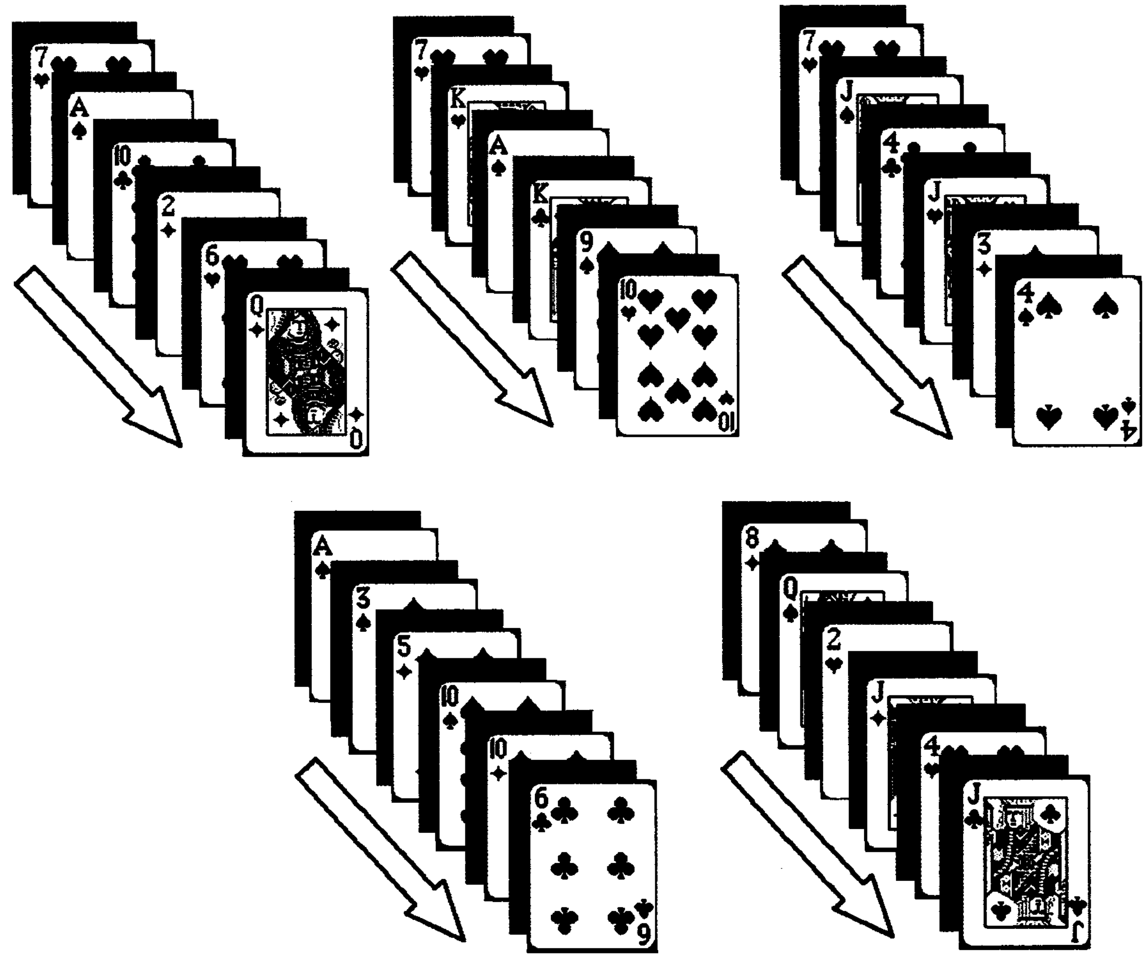

Figure A6. Depiction of the five possible "trial blocks" on the CPT. Top row (L-R): ([7H/AS], [7H/R/AS], [7H Alone]. Bottom row (L-R): [AS Alone], [All Random]. The arrows represent passage of time and the green squares between cards represent blank screens. The top left trial block represents the target sequence whereas all others represent the four types of distracter sequences.

Trial Timing

One card flashed on the computer screen at a time, with a display duration of 200 ms; an inter-stimulus interval of 750 ms was used. Responses to cards did not disrupt this trial timing.

Participant Instructions

Participants were instructed that they would see a sequence of cards and their task was to respond as quickly as possible when the target sequence (the seven of hearts card followed immediately by the ace of spades card) appeared on the monitor. They were further instructed not to respond in cases where only one of the two specified cards were presented or if they were presented close together but not one immediately after the other.

Appendix B

Extra Tables for Experiment 2

Table B1
Experiment 2: Participant Means (*SE*) from Simon Task Across Groups and Contexts

KEY

TB = test block
WI = warning interval
TT = trial type (C = compatible, I = incompatible)

TB	**WI**	**TT**	**Target RT (ms)** **Target Accuracy (%)**			
			Control		**ADHD**	
			Traditional	**Video Game**	**Traditional**	**Video Game**
1	No tone	C	664.64 (29.59) 93.2 (0.03)	751.52 (28.60) 97.2 (0.01)	756.15 (36.67) 92.1 (0.05)	855.56 (52.87) 94.7 (0.03)
		I	690.84 (29.71) 91.7 (0.02)	775.81 (29.43) 95.3 (0.02)	768.98 (28.67) 91.7 (0.02)	867.92 (34.15) 86.7 (0.05)
	50 ms	C	658.34 (24.14) 97.3 (0.01)	713.51 (25.23) 94.5 (0.02)	721.97 (39.70) 91.9 (0.03)	787.81 (40.71) 93.5 (0.03)
		I	650.80 (26.63) 91.3 (0.02)	743.74 (23.54) 94.3 (0.02)	793.50 (37.35) 89.3 (0.04)	861.21 (43.63) 91.5 (0.03)
	100 ms	C	671.43 (30.69) 98.5 (0.01)	718.07 (33.11) 97.3 (0.01)	776.96 (47.17) 89.8 (0.04)	847.90 (45.51) 98.2 (0.01)
		I	697.39 (30.10) 90.2 (0.03)	740.64 (26.16) 93.1 (0.02)	781.06 (38.90) 83.9 (0.07)	863.73 (35.28) 85.5 (0.04)
	200 ms	C	659.23 (27.24) 98.0 (0.01)	713.46 (23.38) 97.3 (0.01)	722.74 (32.08) 91.7 (0.03)	782.12 (36.56) 95.2 (0.02)
		I	692.00 (27.89) 95.3 (0.02)	728.69 (21.21) 89.9 (0.03)	825.05 (36.89) 91.7 (0.03)	887.38 (50.22) 84.5 (0.04)

	400 ms	C	667.92 (26.31) 95.3 (0.02)	757.98 (30.89) 96.7 (0.01)	755.67 (51.21) 93.0 (0.04)	800.83 (40.16) 92.8 (0.02)
		I	701.43 (27.83) 96.0 (0.02)	759.12 (30.37) 93.7 (0.03)	762.36 (43.27) 89.0 (0.06)	893.58 (42.72) 88.8 (0.03)
	800 ms	C	680.46 (26.89) 96.5 (0.01)	727.31 (27.96) 96.0 (0.02)	769.55 (30.14) 93.3 (0.03)	827.86 (54.80) 96.5 (0.02)
		I	712.39 (30.43) 96.0 (0.02)	772.93 (27.16) 94.0 (0.02)	796.55 (48.01) 87.2 (0.04)	873.63 (55.19) 85.2 (0.04)
2	No tone	C	683.72 (29.75) 97.3 (0.02)	758.96 (29.39) 97.1 (0.01)	847.20 (43.80) 91.4 (0.03)	820.80 (31.74) 93.9 (0.03)
		I	736.68 (28.79) 94.5 (0.02)	789.82 (29.41) 93.7 (0.02)	901.45 (44.61) 88.9 (0.04)	873.42 (43.29) 85.9 (0.03)
	50 ms	C	720.18 (31.53) 95.3 (0.02)	761.56 (39.67) 94.2 (0.02)	807.82 (50.88) 94.7 (0.03)	839.06 (38.35) 89.3 (0.03)
		I	731.40 (35.31) 88.7 (0.03)	803.98 (40.74) 92.0 (0.03)	868.33 (53.82) 83.2 (0.04)	945.52 (67.33) 87.4 (0.05)
	100 ms	C	712.53 (31.17) 96.5 (0.01)	753.64 (27.75) 96.7 (0.02)	804.54 (53.77) 90.0 (0.04)	884.99 (44.41) 86.3 (0.05)
		I	744.02 (37.40) 93.7 (0.02)	763.63 (24.10) 90.7 (0.03)	846.27 (46.99) 80.8 (0.05)	928.00 (59.18) 87.2 (0.04)
	200 ms	C	696.97 (30.66) 95.7 (0.02)	767.49 (28.64) 93.1 (0.02)	859.44 (43.19) 88.1 (0.04)	900.56 (44.60) 92.2 (0.03)
		I	768.97 (41.75) 89.4 (0.03)	766.03 (26.53) 89.3 (0.02)	871.94 (35.29) 84.1 (0.04)	862.19 (44.70) 84.6 (0.03)
	400 ms	C	739.81 (32.28) 95.9 (0.02)	775.20 (28.20) 97.7 (0.01)	826.31 (48.64) 90.2 (0.04)	861.68 (43.88) 89.3 (0.03)
		I	761.41 (37.05) 90.1 (0.02)	784.28 (34.32) 91.9 (0.03)	898.65 (40.81) 84.6 (0.03)	863.29 (55.41) 82.1 (0.05)
	800 ms	C	728.41 (36.87) 97.9 (0.01)	762.40 (28.27) 98.0 (0.01)	865.79 (43.05) 89.8 (0.04)	857.30 (38.87) 93.9 (0.03)
		I	748.12 (38.21) 95.3 (0.02)	817.36 (28.21) 96.7 (0.01)	853.71 (46.53) 87.0 (0.04)	892.42 (44.74) 89.1 (0.04)

3	No tone	C	672.03 (23.9) 96.5 (0.01)	772.62 (27.1) 97.2 (0.02)	829.24 (51.4) 92.2 (0.03)	901.72 (38.1) 88.9 (0.03)
		I	754.87 (29.56) 92.9 (0.02)	839.62 (34.82) 86.3 (0.03)	848.55 (53.59) 83.8 (0.05)	878.39 (43.3) 82.6 (0.04)
	50 ms	C	695.90 (30.31) 97.3 (0.02)	755.14 (34.39) 96.8 (0.02)	739.51 (32.86) 89.6 (0.05)	795.64 (44.25) 97.2 (0.02)
		I	710.47 (33.90) 89.2 (0.03)	807.20 (31.94) 91.3 (0.02)	857.02 (46.56) 80.9 (0.04)	844.41 (56.16) 76.9 (0.05)
	100 ms	C	703.29 (30.66) 97.0 (0.01)	753.01 (33.35) 96.9 (0.02)	799.42 (46.11) 89.0 (0.05)	835.39 (39.62) 92.8 (0.03)
		I	744.20 (35.88) 89.1 (0.03)	836.93 (40.61) 92.9 (0.03)	866.23 (50.08) 77.4 (0.05)	878.92 (36.25) 82.6 (0.05)
	200 ms	C	744.37 (40.63) 96.0 (0.02)	771.05 (33.75) 97.8 (0.01)	755.84 (53.43) 91.7 (0.05)	852.63 (41.49) 91.0 (0.04)
		I	760.76 (30.66) 92.7 (0.03)	799.05 (34.92) 94.6 (0.02)	811.84 (39.52) 82.5 (0.06)	910.78 (49.68) 82.9 (0.04)
	400 ms	C	716.81 (33.25) 94.3 (0.02)	769.10 (30.61) 94.0 (0.02)	835.51 (50.96) 87.6 (0.04)	806.48 (32.26) 86.9 (0.04)
		I	776.41 (37.57) 94.3 (0.03)	811.06 (29.80) 94.9 (0.03)	812.99 (52.50) 83.7 (0.04)	864.14 (43.12) 86.1 (0.04)
	800 ms	C	689.26 (34.26) 95.1 (0.02)	808.60 (26.34) 95.8 (0.02)	851.31 (56.55) 84.0 (0.05)	923.15 (50.59) 93.7 (0.02)
		I	744.49 (37.41) 90.9 (0.02)	809.35 (30.46) 95.1 (0.03)	867.83 (55.62) 85.4 (0.04)	929.50 (48.77) 80.9 (0.04)

All	No tone	C	673.46 (15.91) 95.7 (0.01)	760.87 (16.21) 97.2 (0.01)	810.86 (25.70) 91.9 (0.02)	859.36 (24.14) 92.5 (0.02)
		I	727.46 (17.01) 93.0 (0.01)	801.24 (18.06) 91.9 (0.01)	839.66 (25.73) 88.1 (0.02)	873.24 (22.96) 85.1 (0.02)
	50 ms	C	691.47 (16.69) 96.7 (0.01)	743.24 (19.30) 95.2 (0.01)	756.43 (24.22) 92.1 (0.02)	807.50 (23.54) 93.3 (0.02)
		I	697.56 (18.75) 89.7 (0.02)	784.67 (19.02) 92.6 (0.01)	839.62 (26.67) 84.5 (0.02)	883.71 (32.60) 85.3 (0.03)
	100 ms	C	695.75 (17.68) 97.4 (0.01)	741.42 (18.02) 97.0 (0.01)	793.64 (27.90) 89.6 (0.02)	856.09 (24.69) 92.5 (0.02)
		I	728.54 (19.87) 91.0 (0.02)	779.64 (18.22) 92.2 (0.02)	831.18 (26.29) 80.7 (0.03)	890.22 (25.75) 85.1 (0.02)
	200 ms	C	700.19 (19.41) 96.6 (0.01)	750.39 (16.67) 96.0 (0.01)	779.34 (26.01) 90.5 (0.02)	845.10 (24.15) 92.8 (0.02)
		I	740.58 (19.76) 92.5 (0.02)	764.12 (16.25) 91.2 (0.01)	836.71 (21.37) 86.1 (0.03)	886.78 (27.49) 84.0 (0.02)
	400 ms	C	708.18 (17.86) 95.1 (0.01)	767.40 (17.05) 96.1 (0.01)	805.83 (28.90) 90.3 (0.02)	823.00 (22.45) 89.7 (0.02)
		I	746.41 (19.97) 93.5 (0.01)	784.47 (18.17) 93.5 (0.02)	825.78 (27.10) 85.8 (0.03)	873.67 (26.97) 85.6 (0.03)
	800 ms	C	699.38 (18.92) 96.5 (0.01)	765.53 (16.17) 96.6 (0.01)	828.88 (25.90) 89.1 (0.02)	869.44 (28.04) 94.7 (0.01)
		I	735.00 (20.31) 94.1 (0.01)	799.75 (16.44) 95.3 (0.01)	839.36 (28.76) 86.5 (0.02)	898.52 (28.38) 85.1 (0.02)

Table B2

Experiment 2: Participant Means (*SE*) from Flanker Task Across Groups and Contexts

KEY

TB = test block
FD = flanker distance
TT = trial type (C = compatible, I = incompatible)

TB	FD	TT	Control		ADHD	
			Traditional	**Video Game**	**Traditional**	**Video Game**
			Target RT (ms) Target Accuracy (%)			
1	Near	C	616.27 (21.56) 94.9 (0.02)	737.70 (30.30) 96.1 (0.02)	827.95 (46.83) 96.1 (0.02)	827.07 (49.44) 86.4 (0.04)
		I	681.83 (28.93) 95.4 (0.02)	769.14 (30.02) 95.2 (0.02)	820.39 (46.43) 93.4 (0.02)	894.26 (40.82) 91.2 (0.04)
	Middle	C	639.21 (22.85) 94.1 (0.02)	753.65 (31.44) 93.6 (0.02)	830.26 (82.67) 91.0 (0.03)	773.28 (26.06) 94.9 (0.02)
		I	653.36 (27.34) 90.7 (0.04)	743.87 (33.86) 95.4 (0.02)	819.66 (49.67) 94.9 (0.02)	859.75 (44.54) 94.6 (0.03)
	Far	C	682.14 (25.01) 98.1 (0.01)	747.85 (29.46) 94.9 (0.02)	769.64 (53.82) 89.6 (0.03)	864.79 (42.17) 92.5 (0.03)
		I	687.77 (32.02) 93.3 (0.02)	769.76 (30.48) 97.2 (0.01)	793.73 (34.72) 93.9 (0.03)	831.49 (35.72) 93.3 (0.03)
2	Near	C	664.98 (27.45) 97.4 (0.02)	793.87 (35.01) 95.5 (0.02)	837.35 (46.98) 91.2 (0.03)	865.18 (47.24) 94.5 (0.02)
		I	688.64 (29.91) 95.1 (0.03)	801.56 (31.38) 93.1 (0.02)	839.89 (46.89) 93.6 (0.03)	929.70 (54.42) 94.1 (0.04)
	Middle	C	690.14 (33.34) 98.7 (0.01)	766.72 (36.12) 96.0 (0.02)	923.73 (52.09) 84.7 (0.06)	917.78 (44.41) 92.6 (0.02)
		I	735.53 (40.95) 93.6 (0.02)	760.65 (31.45) 94.3 (0.02)	807.20 (34.50) 89.9 (0.04)	910.82 (48.78) 87.7 (0.04)
	Far	C	719.00 (39.21) 95.4 (0.02)	736.81 (30.00) 95.2 (0.02)	806.33 (46.76) 88.2 (0.06)	840.91 (40.45) 94.9 (0.02)
		I	699.96 (29.23) 95.9 (0.02)	753.54 (28.48) 94.7 (0.02)	824.34 (49.04) 86.7 (0.05)	910.60 (44.44) 87.3 (0.04)

3	Near	C	623.52 (26.50) 97.2 (0.01)	742.42 (34.99) 92.9 (0.02)	851.31 (42.51) 87.4 (0.05)	808.42 (40.57) 86.5 (0.04)
		I	661.24 (33.34) 91.4 (0.02)	771.98 (34.76) 95.3 (0.02)	883.83 (43.21) 85.1 (0.04)	878.91 (51.68) 88.3 (0.04)
	Middle	C	683.84 (41.34) 93.6 (0.02)	736.36 (36.76) 96.1 (0.01)	912.05 (56.20) 93.2 (0.03)	799.63 (58.66) 95.9 (0.02)
		I	642.38 (31.58) 94.7 (0.02)	733.69 (35.76) 94.2 (0.02)	912.14 (48.32) 86.6 (0.03)	827.59 (46.69) 86.1 (0.04)
	Far	C	638.23 (28.22) 97.9 (0.01)	750.34 (38.85) 98.1 (0.01)	918.20 (56.83) 93.9 (0.03)	894.04 (75.41) 83.7 (0.06)
		I	683.24 (37.30) 94.2 (0.02)	714.01 (30.01) 97.9 (0.01)	882.26 (50.75) 89.2 (0.04)	807.69 (36.17) 87.8 (0.04)

All	Near	C	635.23 (14.60) 96.5 (0.01)	757.99 (19.31) 94.9 (0.01)	838.87 (25.77) 91.6 (0.02)	833.55 (26.18) 89.1 (0.02)
		I	677.66 (17.52) 94.0 (0.01)	780.89 (18.38) 94.5 (0.01)	848.04 (26.03) 90.7 (0.02)	900.96 (28.06) 91.2 (0.02)
	Middle	C	670.73 (18.94) 95.5 (0.01)	752.24 (19.91) 95.2 (0.01)	888.68 (37.28) 89.6 (0.02)	830.23 (27.00) 94.5 (0.01)
		I	678.00 (19.91) 93.0 (0.02)	746.07 (19.27) 94.6 (0.01)	846.33 (26.13) 90.5 (0.02)	866.06 (26.86) 89.5 (0.02)
	Far	C	680.89 (18.39) 97.1 (0.01)	745.00 (18.84) 96.0 (0.01)	831.89 (31.26) 90.6 (0.02)	866.58 (31.31) 90.4 (0.02)
		I	690.51 (18.70) 94.5 (0.01)	745.77 (17.11) 96.6 (0.01)	833.44 (26.21) 89.9 (0.02)	849.93 (22.91) 89.5 (0.02)

Table B3

Experiment 2: Participant Means (*SE*)^ from Stop-Signal Task Across Groups and Contexts

Test Block	**Stop Delay (ms)**	**Probability of Inhibiting Response**			
		Control		**ADHD**	
		Traditional	**Video Game**	**Traditional**	**Video Game**
1	150	.	.	.	.
	200	94.7	.	.	.
	250	58.7	74.4	73.3	59.1
	300	77.5	72.5	64.9	55.6
	350	69.8	78.9	67.9	55.3
	400	48.6	67.5	.	63.3
	450	75.0	67.7	.	57.7
	500	.	58.6	.	56.2
	550	.	46.7	.	.
2	150	.	.	.	.
	200	73.9	.	.	.
	250	45.5	71.1	71.8	50.0
	300	60.9	69.0	73.3	72.5
	350	.	72.2	54.3	62.5
	400	.	.	71.4	60.0
	450	.	.	80.0	69.6
	500	.	.	71.8	78.9
	550	.	.	.	63.2

3	150	73.9	82.4	.	.
	200	70.0	66.7	63.2	.
	250	58.5	72.5	60.0	.
	300	72.5	83.3	66.7	66.7
	350	57.9	62.2	71.9	76.0
	400	59.1	65.5	55.2	75.0
	450	.	62.5	68.4	.
	500	.	.	58.8	.
	550	.	.	.	.
All	150	73.9	82.4	.	.
	200	79.5 (0.08)	66.7	63.2	.
	250	54.2 (0.04)	72.7 (0.01)	68.4 (0.04)	54.5 (0.05)
	300	70.3 (0.05)	74.9 (0.04)	68.3 (0.03)	64.9 (0.05)
	350	63.8 (0.06)	71.1 (0.05)	64.7 (0.05)	64.6 (0.06)
	400	53.8 (0.05)	66.5 (0.01)	63.3 (0.08)	66.1 (0.05)
	450	75.0	65.1 (0.03)	68.4	63.6 (0.06)
	500	.	58.6	69.4 (0.11)	67.6 (0.11)
	550	.	46.7	.	63.2

^ Empty cells indicate that there were either no trials with that stop delay for the given test block, or the trials were so infrequent that they were excluded from analyses. Note, also, that these data were collapsed across participants so most cells reflect (raw) grand sample proportions and therefore do not have associated *SE*s. See Methods (Chapters 8 and 11) for further detail.

Table B4

Experiment 2: Participant Means (*SE*) from Blink Task Across Groups and Contexts

Test Block	ISI (ms)	T1 Accuracy (%)			
		Control		ADHD	
		Traditional	**Video Game**	**Traditional**	**Video Game**
1	15	76.4 (0.03)	70.9 (0.03)	57.9 (0.05)	51.4 (0.05)
	135	82.7 (0.04)	78.6 (0.04)	72.1 (0.04)	65.7 (0.06)
	255	80.9 (0.04)	76.8 (0.04)	62.1 (0.06)	63.6 (0.05)
	375	87.7 (0.03)	80.5 (0.04)	80.0 (0.04)	67.9 (0.07)
	495	90.0 (0.02)	75.0 (0.05)	70.7 (0.05)	61.4 (0.06)
2	15	72.7 (0.02)	63.2 (0.04)	55.7 (0.04)	51.4 (0.05)
	135	76.4 (0.03)	70.5 (0.04)	55.0 (0.05)	56.4 (0.04)
	255	82.3 (0.03)	71.4 (0.04)	62.1 (0.04)	63.6 (0.04)
	375	85.0 (0.03)	74.5 (0.04)	65.0 (0.05)	61.4 (0.05)
	495	85.9 (0.03)	80.0 (0.04)	66.4 (0.04)	62.9 (0.07)
3	15	65.9 (0.03)	59.5 (0.05)	64.3 (0.04)	49.3 (0.05)
	135	75.9 (0.05)	69.5 (0.04)	57.9 (0.06)	55.7 (0.07)
	255	76.8 (0.04)	67.7 (0.04)	66.4 (0.06)	59.3 (0.06)
	375	77.7 (0.03)	71.8 (0.04)	65.7 (0.04)	52.1 (0.07)
	495	75.9 (0.05)	75.0 (0.03)	66.4 (0.05)	63.6 (0.07)
All	15	71.7 (0.02)	64.5 (0.02)	59.3 (0.02)	50.7 (0.03)
	135	78.3 (0.02)	72.9 (0.02)	61.7 (0.03)	59.3 (0.03)
	255	80.0 (0.02)	72.0 (0.02)	63.6 (0.03)	62.1 (0.03)
	375	83.5 (0.02)	75.6 (0.02)	70.2 (0.03)	60.5 (0.04)
	495	83.9 (0.02)	76.7 (0.02)	67.9 (0.03)	62.6 (0.04)

		T2 | T1 Accuracy (%)			
1	15	74.0 (0.04)	69.6 (0.05)	59.2 (0.06)	65.4 (0.07)
	135	79.9 (0.04)	80.8 (0.05)	79.3 (0.05)	76.0 (0.06)
	255	85.1 (0.03)	81.2 (0.03)	78.9 (0.05)	84.0 (0.06)
	375	85.8 (0.03)	87.2 (0.03)	87.6 (0.04)	89.4 (0.04)
	495	87.7 (0.03)	90.6 (0.02)	87.8 (0.04)	79.1 (0.05)
2	15	71.1 (0.05)	69.2 (0.04)	66.1 (0.05)	66.1 (0.08)
	135	78.7 (0.04)	80.3 (0.04)	62.1 (0.08)	68.8 (0.07)
	255	85.7 (0.04)	84.6 (0.03)	74.7 (0.05)	72.1 (0.05)
	375	86.1 (0.03)	87.9 (0.04)	70.8 (0.05)	81.1 (0.06)
	495	90.8 (0.03)	87.7 (0.03)	76.9 (0.04)	81.6 (0.07)
3	15	66.7 (0.04)	63.8 (0.04)	61.2 (0.08)	62.2 (0.06)
	135	78.3 (0.03)	80.4 (0.04)	75.2 (0.07)	65.2 (0.05)
	255	78.7 (0.05)	81.2 (0.04)	67.5 (0.07)	75.8 (0.06)
	375	86.7 (0.03)	84.0 (0.04)	75.9 (0.05)	85.2 (0.05)
	495	77.2 (0.03)	86.0 (0.04)	90.8 (0.03)	82.4 (0.05)
All	15	70.6 (0.03)	67.5 (0.02)	62.1 (0.04)	64.6 (0.04)
	135	79.0 (0.02)	80.5 (0.02)	72.2 (0.04)	70.1 (0.04)
	255	83.2 (0.02)	82.3 (0.02)	73.7 (0.03)	77.3 (0.03)
	375	86.2 (0.02)	86.4 (0.02)	78.1 (0.03)	85.2 (0.03)
	495	85.2 (0.02)	88.1 (0.02)	85.2 (0.02)	81.0 (0.03)

Table B5

Experiment 2: Participant Means (*SE*) from CPT Across Groups and Contexts

Test Block	**Trial Type**	**Response Rate to Trial Type^ (%)**			
		Control		**ADHD**	
		Traditional	**Video Game**	**Traditional**	**Video Game**
1	7H/AS^^	442.77 (18.6) 89.1 (0.03)	426.11 (20.0) 90.3 (0.03)	495.17 (30.3) 89.9 (0.03)	472.62 (27.9) 77.9 (0.05)
	7H Alone	3.8 (0.02)	2.9 (0.01)	17.0 (0.04)	10.3 (0.03)
	7H/R/AS	3.3 (0.01)	3.5 (0.02)	9.1 (0.04)	3.8 (0.02)
	AS Alone	2.2 (0.01)	1.1 (0.01)	4.5 (0.03)	6.0 (0.02)
	All Random	2.0 (0.01)	3.4 (0.03)	8.3 (0.04)	8.2 (0.03)
2	7H/AS	466.15 (22.7) 88.7 (0.02)	464.68 (26.0) 82.1 (0.04)	505.24 (33.4) 76.3 (0.05)	487.21 (42.7) 73.4 (0.05)
	7H Alone	2.2 (0.01)	3.4 (0.02)	20.0 (0.06)	12.1 (0.03)
	7H/R/AS	3.3 (0.02)	1.6 (0.01)	11.2 (0.04)	6.2 (0.02)
	AS Alone	2.9 (0.01)	6.0 (0.02)	9.7 (0.05)	6.8 (0.03)
	All Random	0.0 (<0.01)	2.9 (0.02)	6.9 (0.02)	5.9 (0.04)
3	7H/AS	505.37 (24.9) 84.6 (0.03)	467.75 (26.4) 86.3 (0.03)	525.90 (23.1) 78.6 (0.05)	509.59 (40.6) 70.7 (0.06)
	7H Alone	3.4 (0.01)	1.6 (0.01)	14.9 (0.04)	7.5 (0.02)
	7H/R/AS	1.7 (0.01)	3.8 (0.02)	8.3 (0.03)	6.7 (0.04)
	AS Alone	4.2 (0.01)	3.8 (0.02)	5.3 (0.02)	4.0 (0.02)
	All Random	0.5 (0.01)	1.0 (0.01)	6.1 (0.05)	5.3 (0.03)
All	7H/AS	471.43 (13.0) 87.5 (0.02)	452.85 (14.0) 86.2 (0.02)	508.77 (16.6) 81.6 (0.03)	489.80 (21.4) 74.0 (0.03)

7H Alone	3.1 (0.01)	2.6 (0.01)	17.3 (0.03)	9.9 (0.02)
7H/R/AS	2.8 (0.01)	3.0 (0.01)	9.6 (0.02)	5.6 (0.02)
AS Alone	3.1 (0.01)	3.6 (0.01)	6.5 (0.02)	5.6 (0.01)
All Random	0.8 (<0.01)	2.4 (0.01)	7.1 (0.02)	6.5 (0.02)

^ Hit rate or false alarm rate, as applicable. Note that mean target RT (ms) is also included for the target trial type (i.e., the hits).

^^ Target trial type. (The remaining four trial types were distracters.)

The Anti-saccade paradigm

Papers

1. Munoz DP & Everling S (2004) Look away: The anti-saccade task and the voluntary control of eye movement. *Nature Reviews Neuroscience, 5,* 218-228.

2. Machado, L & Rafal R. D. (2004). Control of fixation and saccades during an anti-saccade task: an investigation in humans with chronic lesions of oculomotor cortex. *Experimental Brain Research, 156,* 55-63.

3. Kristjansson et al. (2001). Less attention is more in the preparation of antisaccades, but not prosaccades. *Nature Neuroscience 4,* 1037-42.

4. Everling S & Fischer B (1998) The antisaccade: A review of basic research and clinical studies. *Neuropsychologia 36,* 885-899

The controversy: The anti-saccade task is a very popular task particularly as an assessment tool for a wide range of disorders including stroke, ADHD, Schizophrenia etc. and there are also a number of groups looking at the neural basis of performance in this task. Part of the task's appeal is the apparent ability to tap into frontal/executive function and as a measure of voluntary and involuntary orienting systems.

Assignment: Try and find and read another paper that used this task as well as reading the ones about. What is the task really measuring? A large number of research groups are using this task – what are the strength and weaknesses of this? Why has it become so popular?