

The Development of Multitasking in Children Aged 7-11

by

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B.Sc., Queen's University, 2004

A Thesis Submitted in Partial Fulfillment of the  
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**ABSTRACT**

The purpose of this study was to examine the development of the ability to multitask in children along with other executive control processes that likely underlie goal-directed behavior in novel situations. 35 children, ages 7-11, completed an experimental multitasking paradigm, the Children's Multiple Activities Game (CMAG), and an existing measure, the Six Parts Test (SPT) as well as two working memory and inhibition tasks and a prospective memory task. Results indicated that multitasking ability improves across this age range and is related to a number of executive abilities. Performance on the CMAG was related to a number of executive abilities, while the SPT was unrelated to these measures. To our knowledge, this is the first study to investigate the development of this ability in children. Findings will be discussed in terms of how this ability develops in relation to cognitive processes that are crucial and account for its variation.

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## INTRODUCTION

The coordination and performance of multiple concurrent activities is a skill that is required frequently in daily living and has been described to lie at the very heart of competency in everyday life (Burgess, 2000). Many individuals' daily routines rely upon their ability to organize multiple 'future actions' such that they can complete multiple goals in a timely and efficient manner. Those individuals that have an impaired ability to organize multiple intended actions have been shown to have difficulty leading effective, independent lives (*e.g.*, Bechara, Tranel & Damasio, 2000; Burgess, Alderman, Evans, Emslie & Wilson, 1998; Burgess & Shallice, 1996; Shallice & Burgess, 1991; Wilson, Evans, Emslie, Alderman & Burgess, 1998). Furthermore, these individuals often require a significant amount of support in their daily lives (Evans, Emslie & Wilson, 1998; Manly, Hawkins, Evans, Woldt & Robertson, 2002). Yet, despite the seeming importance of this ability, very little research has examined its development in children.

Since the identification of individuals with the circumscribed deficits known as "strategy application disorder" due to frontal lobe damage (Baddeley & Wilson, 1988), there has been increased interest in researching the ability to organize multiple future actions (Shallice & Burgess, 1991, Levine, Stuss, Milberg, Alexander, Schwartz & Macdonald, 1998). Initial studies found individual clinical cases who in spite of having unimpaired IQ, memory, language, visuo-perceptual functions, and intact performance on a number of executive function tests, were unable to function effectively in the real world. They seemed to be unable to deal with complex real-life situations that required the ability to plan and organize multiple goal-directed behaviours in situations that are

relatively open-ended (Shallice & Burgess, 1991; Goldstein et al., 1993; Duncan, Burgess & Emslie, 1995). More specifically, these patients were impaired in their ability to successfully prioritize, organize and execute a number of different tasks within a limited amount of time also known as the ability to multitask (Burgess, Veitch, Costello and Shallice, 2000). Further research examining these impairments and their relationship to the executive functions that the ability to multitask would seem to rely on is an important step forward in understanding the nature of the cognitive deficits of these patients. The use of an existing cognitive model provides a theoretical blueprint of executive functions which are likely crucial to the ability to multitask.

### **The Supervisory Attentional System**

Norman and Shallice (1986) and Shallice (1982) proposed a cognitive model, the Supervisory Attentional System (SAS), to outline the processes that are hypothesized to be responsible for the executive control of goal-directed behaviour in novel situations (Norman and Shallice 1986, Shallice, 1982, 1988). These cognitive processes include goal initiation, strategy generation, decision-making, monitoring and evaluation of performance as well as schema activation and creation. While performing routine tasks, well-learned cues trigger previously formed 'schemas,' which are typically adequate to reach the goal effectively, and during which the SAS is not required. The SAS plays a critical role either in novel situations because previously developed schemas are unavailable or insufficient to reach the goal (as new sequences of behaviour need to be planned and monitored to achieve the goal), or when something changes and a previously formed schema is no longer effective in reaching the goal. It is suggested that most

*traditional* tests of executive function do not tap into the processes that the SAS is thought to control, as they are typically highly structured, short (in length), only require a single explicit problem be solved, and the task goals are clearly defined (Shallice and Burgess, 1991; Clark et al., 2000). Thus, many individuals with frontal lobe impairments can exhibit typical performance on traditional tests of executive function, despite suffering from an inability to organize the activities of their daily lives (Bechara et al, 2000, Shallice & Burgess, 1991).

Unfortunately, very little is known about the underlying cognitive abilities necessary to perform these more complex real life goal-directed behaviours. This is somewhat surprising considering that Penfield and Evans described these types of cognitive deficits as early as 1935 (in Burgess et al, 2006). They noted in some individuals that these types of deficits resulted in impairments such that they were often unable to even effectively carry out the various tasks involved in cooking a meal. Indeed, using a task analysis approach, cooking a meal requires a great number of steps or goal-states, including deciding on the materials needed, purchasing the correct ingredients while keeping in mind the individual preferences of those sharing the meal. This is followed by the food preparation, often cooking assorted dishes at the same time, all of which could require different cooking times and therefore have to be monitored and coordinated. Unexpected incidences might also occur, such as not having enough of an ingredient, resulting in the plan having to be altered, while still monitoring the food cooking and returning to each dish at the appropriate time. Patients having difficulty with real-life activities such as meal preparation, but who nonetheless perform normally on

typical executive function tasks, highlight the fact that the abilities for these types of activities are not captured by these traditional tests.

### **The Development of Multitasking Tests**

Few advances have been made in understanding the underlying cognitive mechanisms necessary to efficiently coordinate multiple activities. Likewise many of the traditional executive function tests, which Burgess and colleagues (2006) called ‘esoteric,’ continue to be used as the primary means of assessing this ability. Shallice and Burgess (1991) argued that truly ‘valid’ measures of executive function require that an individual access supervisory processes and therefore should be comparable to the open-ended problem solving situations that are encountered in daily life. In such measures, there should be a number of different possible approaches to achieving the goals, and the participants should decide themselves how they will allocate their time and effort. More specifically, Shallice and Burgess state that a valid measure of executive function requires self-monitoring, organization and decision-making while individuals carry out a novel (non-routine) task. Tasks that require all these abilities will necessitate the activation of the SAS.

In an attempt to develop a task which would truly assess executive function, Shallice and Burgess developed the Six Elements Test (SET) and the Multiple Errands Test (MET) (1991; Burgess et al, 1998). These measures are described as tests of ‘multitasking’ because they require the individual to prioritize, organize and carry out a variety of different tasks within a limited time period (Burgess et al, 2000). The SET is a laboratory-based test that entails presenting the participant with 6 tasks, each of which

should be attempted at least in part within a time limit and rules require that the tasks be interleaved. As a result the test more closely resembles the demands made in everyday life where carrying out multiple activities is interleaved as a result of environmental restrictions. Performing the test successfully therefore requires the participant to develop a simple plan including scheduling the tasks efficiently while monitoring the time they have left.

In the Shallice and colleague's study (1991), patients with frontal lobe impairments failed to perform the SET as efficiently as controls, executing relatively few task switches resulting in fewer tasks attempted and increased number of rule breaks. The key finding of studies in this area is individuals with frontal lobe impairments, who had shown normal or even above average performance on traditional measures of executive function, were found to perform poorly on the SET, corresponding with the difficulties these individuals exhibited in their everyday lives (Burgess et al, 2000).

The MET has received less attention than the SET and is a real-life based shopping task that takes place in a shopping center. In this test, participants are given money and instructions that require them to complete a number of simple tasks, which include purchasing various items, finding out certain information and arriving at a certain location at a designated time. The participant must complete these tasks while adhering to a number of rules that emphasize planning and prospective memory, such as not returning to a shop they have already been in (Burgess, Veitch, Costello and Shallice, 2000). Once again, patients with frontal lobe impairments were found to perform the test less efficiently than a healthy group of controls matched for age and IQ. Similar to the

findings with the SET, these patients displayed difficulties organizing their efforts, completed fewer tasks and broke more rules. These patients also made several errors not seen in controls including making a number of departures from social convention such as climbing onto a display of fruit outside a grocer's shop to peer through the shop window (Shallice and Burgess, 1991).

While, as previously discussed, a dissociation has been found between neuropsychological test performance and real-life multitasking ability, it is important to note that studies have indicated that there is a 'single dissociation' only (Levine, Stuss, Milberg, Alexander, Schwartz & MacDonald, 1998), as patients with multitasking problems may or may not show impairments on traditional executive function tests, but every individual that has failed a wide range of traditional executive function tasks has also shown deficits in their ability to multitask. Because a 'double dissociation' has not been found (e.g., all patients who can't multitask can perform EF tasks at a normal level) understanding more about the ability to multitask, its development and its relation to executive function, is crucial. Levine et al. (1998) suggested cognitive measures related to this ability, that measure additional processes such as working memory and interference control would aid in understanding the component processes that develop along with the ability to multitask. However, this appears to be an incomplete list of the cognitive components related to multitasking considering that "intentionality", or prospective memory (Ellis, 1996) has been found to be one of the most important abilities in the organization and execution of multiple activities (Knight, Alderman & Burgess, 2002).

While multitasking paradigms may provide a better and more ecologically valid measure of an individual's ability to function in everyday life, it is important to have an understanding of the role of other core cognitive control processes associated with executive function (e.g., working memory, inhibition, prospective memory) and the role they play in the execution of multiple concurrent activities.

### **Cognitive control process related to multitasking – Prospective Memory**

Intentionality or prospective memory involves the execution of delayed intentions. More specifically, it refers to the complex cognitive processes involved in retrieving and executing a previously formed intention at the appropriate time in the future (Kvavilashvili & Ellis, 1996). Burgess and colleagues (2000) found that the performance of subjects with circumscribed lesions on an analogue SET was closely associated with performance on tasks of prospective memory. Everyday examples of prospective memory in children include remembering to bring a book home from school that is necessary for their homework or remembering to prepare for a field trip they are taking the next day in school. Memory failure of this type is common in everyday lives and it has been found that nearly half of all memory failures involve the forgetting of intentions versus the forgetting of learned information (Crovitz & Daniel, 1984; Terry, 1988). It is hypothesized that the initial stage of prospective memory involves the formation of the intention or “marker creation” (i.e. “I will return to check on the cake in oven in 30 minutes”), which requires knowledge of the potential factors that could hinder performance (Burgess et al, 2000). Embedded in this stage is the encoding of the action to be carried out at the appropriate time and the generation of this plan requires

organizational ability (Carey, Woods, Rippeth, Heaton & Grant, 2006). The next stage involves a retention interval, during which attention resources are allocated to another task, precluding the continuous rehearsal of the encoded intention. During this time strategic monitoring may occur in order to assess whether the circumstances are appropriate for the performance of the action plan. The final stage involves the self-initiated retrieval of the intention and the subsequent execution of the action plan (Carey et al, 2006). This stage differs from retrospective memory tasks as it is performed without an external agent providing a reminder (Einstein, McDaniel, Thomas, Mayfield, Shank & Morrisette, 2005), as in conventional retrospective memory recall the experimenter prompts the search for recall. Prospective memory tasks require self-initiation to recall, which is considered by many to be the central feature of prospective memory (e.g., Knight, 1998). This stage of prospective memory may be difficult if an individual is dividing their attention among a number of activities (as in multitasking), as each cue event will receive less attention, and even retrieved intentions may be forgotten in the face of competing demands (McDaniel et al, 1998; Marsh & Hicks, 1998). Finally, assessment of the success of the realized intention is completed, again a defining feature in multitasking situations where individuals must decide whether the execution of the delayed intention was successful (Burgess, 2000).

The role of prospective memory in the ability to multitask is further evidenced by individuals with strategy application disorder and marked impairments in organizing their lives, who also typically display failures in prospective memory as a prominent concern.

These failures are typified by an inability to follow time constraints, meet deadlines and keep appointments (Burgess, 2000).

A number of the brain regions theorized to be involved in multitasking overlap with those which prospective memory is thought to rely on. Currently, evidence suggests that the anterior cingulate, Brodmann's area 10 and anatomically adjacent regions as well as right dorsolateral prefrontal cortex, each make contributions to aspects of multitasking performance. More specifically, Brodmann's area 10 has been found to provide the location for the coordination of information processing and transfer between multiple cognitive operations, a function that would seem to be highly related to multitasking (Ramnani & Owen, 2004), while the areas thought to provide prospective memory function include Brodmann's area 10, right dorsolateral prefrontal cortex and inferior parietal regions (Burgess, Quayle and Frith, 2001; Okuda et al, 2004).

While there is a growing body of research examining the cognitive processes underlying the ability to multitask in adults (i.e. Burgess et al, 2000; Kleigel, Martin, McDaniel & Einstein, 2002; Alderman, Burgess, Knight & Henman, 2003), very little is known about the way children organize multiple future activities and how this skill develops throughout childhood. While it is clear that children are not born with this skill, they do readily acquire the ability to multitask as they become older and more independent. In fact, it is likely that older school-age children regularly multitask, such as when they are doing their homework while watching television and using instant messenger on the computer. Even younger aged children are likely to display some

multitasking skills, for example making a collage that requires waiting for the glue to set while clipping out images, both of which can be interleaved with watching television.

Taking a developmental approach will provide an understanding of how the ability to multitask progresses in relation to the other cognitive processes related to this ability, as well as how these relationships change through development. The integration of these abilities can be conceptualized as occurring within the rubric of the SAS in which working memory, inhibition and prospective memory are considered to be the most integral components.

While some research on prospective memory has examined this ability in children, despite the growing interest in this field, a limited number of studies on the development of prospective memory have been undertaken. One study investigated the development of prospective memory on tasks in which the encoding modality was manipulated by comparing children aged 10 and 11 years old with children aged 7 and 8 years old (Passolunghi, Brandimonte, & Cornoldi, 1995). The results showed that, in general, prospective memory improves over this age range. Kerns (2000) used a computerized video-game style driving task to examine the development of prospective memory in children aged 7 to 12. In this study, the primary task was gaining points by 'driving' a vehicle while avoiding hitting other cars on the track. The concurrent prospective memory task was to monitor the fuel in the car, making sure to fill the fuel occasionally to avoid running out of gas, as this resulted in the loss of all points accumulated. Results from this study suggested improvement in prospective memory ability with increasing age with older children running out of fuel less frequently than

younger children. In addition, they also found that failures on the prospective memory task were significantly correlated with the number of errors on measures of working memory.

Review of these and other studies provide ample evidence supporting the relationship between multitasking performance and prospective memory ability, both which appear to be associated with working memory (Kerns, 1999; Einstein et al, 1997; Burgess, 2000; Ramnani & Owen, 2004; Burgess, Quayle and Frith, 2001; Okuda et al, 2004). For example, when comparing younger and older adults, no age-related differences were found when prospective memory tasks required little working memory, but marked age effects occurred as the demands on working memory increased (Kliegel, McDaniel, Einstein, 2000).

### **Cognitive control process related to multitasking – Working Memory**

Working memory is a limited-capacity resource for processing information that shows protracted growth during childhood (Awh, Smith & Jonides, 1995; Bayliss et al, 2003), with particularly rapid growth occurring in early childhood (6-8 years old), middle childhood (9-12) and adolescence (Brocki & Bohlin, 2004). For example, Hale, Bronik, and Fry (1997) found that the verbal and visuospatial components of working memory significantly improved in children from 8 to 10 years old. In this study, the verbal task required recalling a series of visually presented digits, while for the visuospatial task recall was for the location of X's in a series of matrices. The inclusion of different modalities is important as the executive system has been described as interacting with two systems that temporarily store different classes of information: the speech-based

phonological loop for auditory information and the visual-spatial sketchpad for visual information (Baddeley and Logie, 1999). The inclusion of tasks that measure both types of working memory is key to any study attempting to understand the relationship of working memory with other abilities.

Working memory is also affected by the performance of concurrent activities that divert attention resources (Conlin, Gathercole and Adams, 2005) and therefore is likely key in multitasking. Working memory has been conceptualized as being activated when there is competing information (Baddeley, 1990), such as during the simultaneous processing of multiple activities. The involvement of working memory in prospective memory tasks is also supported by the work of Smith (2003) who found that response times on a working memory task were slowed when a 'prospective task' demand was added to the task. The slowing of reaction time was also negatively correlated with working memory capacity. With respect to the involvement of working memory in prospective memory, when a prospective memory load is added to a task, a slowing of the response time for the ongoing activity trials has been found. This slowing has been found to be negatively correlated with working memory capacity (Smith, 2003). Dividing attention among tasks is also thought to increase the difficulty of selecting and retrieving delayed intentions by increasing the working memory demands (Einstein et al, 1997). Indeed, a recent study found that when measures of executive function were compared with performance on a children's version of the SET, a significant positive correlation was found between the number of tasks completed and working memory scores, even while controlling for age (Siklos & Kerns, 2004).

### **Cognitive control process related to multitasking – Inhibition**

While these findings point to the importance of working memory in multitasking tests, the development of working memory during childhood is dependent, at least in part, on increases in inhibitory control. This is particularly evident in complex situations where inhibition is required to keep irrelevant information from consuming the limited capacity of working memory (Dempster, 1993; Wilson, Kipp & Daniels, 2003). Evidence for this idea has been supported by the finding that a subset of the neural circuitry supporting working memory is activated during inhibitory control processes (Bunge et al, 2001). Inhibitory control is a suppression resource that prevents the entry into or maintenance of irrelevant information in working memory. Developmental gains in inhibitory control have been shown to occur in children up to the age of 12, with significant developmental shifts taking place between 7-8 and 9-12 years of age (Anderson, 2002; Levine et al, 1991; Anderson, 1998). More specifically, while children at the age of six are able to verbalise that a response should be inhibited, they are unlikely to actually be able to inhibit the response (Bell & Livesey, 1985). By age seven, children are more successful and clearly conceptually understand when to inhibit responses, but still are not totally successful in their behavioural performance (Dowsett & Livesey, 2000). There are again marked developmental gains around the ages of eight (Schacher & Logan, 1990) and 10 years (Stevens, Quittner, Zuckerman, & Moore, 2002) with children having greater success with speed of inhibition and reduction in the variability in response times on stop signal tasks with increasing age. Inhibition has also been implicated in prospective memory tasks that require a high level of strategic control

(Kliegel et al, 2002; Martin, Kliegel & McDaniel, 2003), particularly for children's prospective remembering. For instance, children find it easier to switch between tasks when a current task does not have to be interrupted to perform an intended task (Kvavilashvili et al, 2001). Furthermore, it has been suggested that inhibitory mechanisms are required to interrupt the performance of the ongoing task in order to allow for other intended actions to occur (Kerns, 1999) and that inhibition is required to interrupt performance numerous times in a multitasking paradigms in order to shift to other tasks. It is important to note that definitions for *inhibition* and concepts such as *resistance to interference* are broad and often used inconsistently across studies. Interference control has often been used interchangeably with inhibition but is distinguishable from it (Harnishfeger, 1995). This distinction is that inhibition is an active suppression process operating on the contents of working memory, whereas interference control prevents the entry of irrelevant or distracting stimuli into working memory through a gating mechanism Wilson and Kipp (1998). Given the close relationship between inhibition, prospective memory and working memory, it is likely that the development of the ability to multitask is dependent on inhibitory control processes. Given both the variability in definitions of inhibitory control and emerging evidence that there may be a number of differing types of inhibitory control, several tasks have been developed to tap these inhibitory processes (Nigg, 2001; Friedman & Miyake, 2004). Further clarifying the role of inhibition and the types of inhibitory control processes necessary for multitasking is crucial to understanding this ability.

## **The Current Study**

The purpose of the current study was to examine the development of the ability to multitask in children aged 7-11 years old, as well as the developmental trajectory of cognitive control processes important in the support of this ability including prospective memory, working memory and inhibition. The 7-11 age range captures a time period during which a number of developmental shifts occur in the executive control processes of interest. Very little research has been conducted on the ability to multitask in children, especially with regard to the relationship between its development profile and the cognitive control processes that are thought to be related to this ability. Given that many children with childhood disorders such as ADHD, FASD and autism have difficulty with various aspects of executive function (Siklos & Kerns, 2004; Clark, Prior & Kinsella, 2000) determining the development of these skills along with multitasking is crucial. Multitasking requires SAS function and it is hypothesized that these cognitive control processes develop over the age range studied and therefore relationships will be observed between multitasking paradigms and tasks of specific cognitive processes supporting the SAS including prospective memory, working memory, and inhibitory control.

## **METHODS**

### **Participants**

Thirty-five children, ranging in age from 7 to 11 years (mean age = 10.3; SD = 1.3; 19 boys, 16 girls) participated in this study. Participants were recruited from various schools throughout the Capital Regional District of Vancouver Island, from announcements to local parent groups and advertisements at local recreation centers.

Participant screening included a telephone interview, which queried about participants' incidence of birth complications and neurological, behavioral and educational histories. Volunteers with any prior history of significant neurological, psychiatric, developmental or learning difficulties were excluded from the sample. At the time of testing, written informed consent was obtained from the parents of each participant, as well as written or verbal assent from each participant.

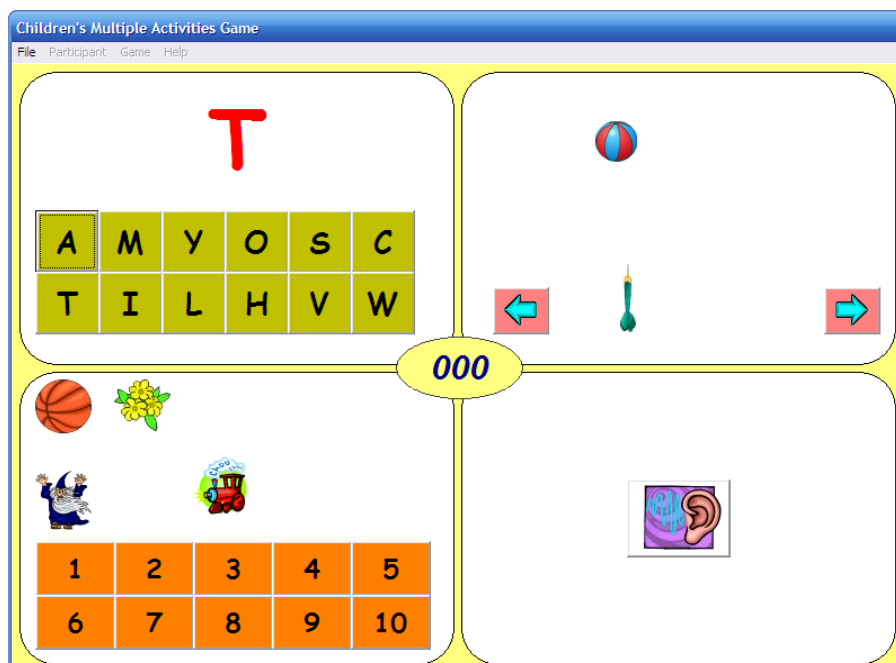
## **Measures**

### ***Multitasking Tests***

Two measures of multitasking were utilized in this study, a novel task called the Children's Multiple Activities Game (CMAG: McInerney & Kerns, 2003), and an existing modification of the SET developed for children, the 'Six Parts Test' from the Behavioural Assessment of the Dysexecutive Syndrome in Children (BADS-C: Emslie, Wilson, Burden & Wilson, 2003).

#### ***Children's Multiple Activities Game (CMAG)***

The CMAG is a novel task that was developed as a child friendly equivalent of SYNWORK, a computer program (Elsmore, 1994) designed to evaluate the multitasking abilities in adults. The CMAG (McInerney & Kerns, 2003) is a computerized task in which participants attempt to maximize points accumulated over a fixed amount of time by performing four different but simple tasks: a counting task, an auditory monitoring task, a visual monitoring task and a visual search task (see Figure 1).



*Figure 1:* A screen shot of all four tasks of the CMAG, visual search task in the upper left quadrant, visual monitoring task in the upper right quadrant, counting task in the lower left quadrant, and the auditory monitoring task in the lower right quadrant.

In this task, the computer screen is divided into four quadrants with one task located within each quadrant. In the middle of the four quadrants a “total score” box is displayed, showing the total number of points accumulated. Prior to beginning the CMAG, participants were told that they were going to do a task that had 4 separate games that they must complete to gain as many points as possible. Participants were then introduced to and practiced each of the four games individually to ensure comprehension and adequate performance. Once children were familiar with each game, the actual testing began for a total of five minutes. As the task began, the visual search game alone

was presented for the first minute of testing. Subsequently, the second game (visual monitoring) was also commenced so that on the second minute participants were playing 2 games simultaneously. At the third minute the counting game commenced and the auditory monitoring game in the fourth minute, and all games were simultaneously running for the final two minutes of performance.

The visual search game appeared in the upper left quadrant (see Figure 1) and required the participant to search a row of twelve letters (which appear in a random order) at the bottom of the quadrant for a target letter that is presented in the centre of the quadrant. For this task, the participants were required to click on the letter in the bottom row that matched the target within fifteen seconds of the appearance of the target. Ten points were awarded for each correct match and 5 points penalized for each incorrect match or lack of response within 15 seconds of the stimulus being presented.

The visual monitoring game appeared in the upper right quadrant (see Figure 1) and required participants to manoeuvre a 'dart' under a falling balloon such that the dart would pop the balloon. Participants controlled the horizontal movement of the dart across the quadrant changing the direction of the constantly moving dart by clicking the right or left arrow with the mouse. The balloon fell at a rate of once per twelve seconds and if popped, the computer produced a rewarding sound and awarded 50 points. If the balloon was missed, the computer produced an error sound and 25 points were deducted from the score.

The counting game appeared in the lower left quadrant (see Figure 1) and required participants to count the number of objects (cars, animals, etc.) that appeared on the

screen by clicking with the mouse on the corresponding number (1-10) found in a row at the bottom of the quadrant. Similar to the visual search task, for each correct match the participant is awarded 10 points and for each incorrect match, or when 15 seconds elapse without a response, the participant is penalized 5 points.

Finally, the auditory monitoring game appeared in the lower right quadrant (see Figure 1) and required participants to monitor a series of sounds. The sounds heard were either a distinct “click” or a “cuckoo”. The click sounds occurred consistently (every 2-3 seconds), while cuckoo sounds occurred at random intervals (but approximately one per 15 seconds). When the cuckoo sound was heard, the participant clicked a box in the center of this quadrant with the mouse. Fifty points were awarded for each correctly identified cuckoo sound, but no response to the cuckoo sound (within 15 seconds) or responding at an inappropriate time was penalized 25 points.

#### *Six Parts Test (SPT)*

The SPT from the Behavioural Assessment of the Dysexecutive Syndrome for Children (BADS-C), like the adult six elements test previously discussed, required dividing attention between a number of simple coloured-coded tasks (picture naming, arithmetic and sorting) while adhering to a set of rules. Each of the tasks had a part one and part two, such that there were two sets of materials for the picture naming, arithmetic tasks and sorting tasks even though the task demands were identical. Specifically, picture naming involved naming a series of simple line drawings, arithmetic involved counting a number of simple objects or performing simple arithmetic problems, and sorting involved sorting objects in two boxes, one containing multi-coloured and multi-shaped beads, and

the other a mixture of nuts, bolts, and washers. Children were instructed to attempt at least one item from all six parts of the task (2 parts for each of 3 tasks) over a five-minute period, while adhering to the restrictions on the order in which the parts could be attempted. Participants were told that they could not do the two parts of the same colour (task) immediately after each other. Throughout the task, a summary of the instructions, in simple language was available, placed in front of the child. After the child had been given the instructions, they were asked to repeat to the tester what they had been asked to do. Any errors were corrected and if necessary the child was asked to repeat again what they have been instructed to do. When the task commenced a timer was started which remained in full view of the child. Children's performance total score was based on the number of tasks attempted and the use of strategy (i.e. performing the tasks in sequential order and spending a similar amount of time on each task), while penalties were imposed for rule breaks (performing two tasks of the same colour in a row) and for dividing time unequally between tasks (i.e. participants should try and perform each of the first four parts for roughly one minute and spend half a minute on the last two parts).

### ***Executive Function Tests***

#### *Spatial Working Memory Task*

A computer based spatial working memory task developed for children based on a paradigm described by Owen and colleagues (1996) was used for the study. During this task, participants are presented with an array of boxes. For each trial the participant was required to find a token hidden in one of the boxes, clicking on the box with the mouse to open it. After the token was found, it was hidden again within the condition that it would

never be hidden in box in which it had already been found, and again participants were required to ‘find’ the hidden token. The number of trials (and hence tokens) for a given block equalled the number of boxes presented on the screen (e.g. 6 trials (and tokens) when an array of 6 boxes were presented). Participants completed a total of two blocks of 4, 6, and 8 trials each. Both the number of times a participant checked a box they had previously opened and found empty (within trial search errors) and the number of times a participant checked a box that previously yielded a token (between trial search errors) were tallied. These were then added together to produce a score of the total number of errors on this task.

#### *Digit Span Backwards (WISC-IV)*

This is a subtest from the Wechsler Intelligence Test for Children – 4<sup>th</sup> Edition (Wechsler, 1991) and required children to repeat ‘backwards’ or in the reverse order from that presented, increasingly long strings of digits (e.g., if presented with the string 1-3-5), the child would need to respond 5-3-1). There were two trials presented for each digit string length beginning with two digits and ending at nine digits for a total of 16 available trials. However, if a participant failed both trials at a given digit string length no further trials were presented and the task was discontinued. Participants were awarded 1 point for each digit string they responded to correctly, and the total score is used for analysis.

#### *Go/No-Go Task*

A computerized go/no-go task was used to tap the child’s ability to inhibit a prepotent response (Hrabok, Kerns & Mueller, 2007). It measured the child’s ability to rapidly differentiate between go and no-go stimuli. The child was instructed to respond

as quickly as possible by pressing the spacebar on the computer keypad each time a 'go' stimuli appeared on the screen, and to inhibit the response when a no-go stimulus was presented. The task was divided into four sessions consisting of 25 trials each. In order to develop a prepotent response (a response habit), the first session consisted of 25 trials of just the 'go' stimulus (a clip art image of a dog). In the second session participants were instructed that they should press the spacebar when they saw a koala and to withhold responding when they saw a dog. The third session reversed the go and no-go stimuli such that participants were to respond when they saw a dog and not a koala. Finally, the fourth session reversed the stimuli again. Prior to each session the participants were shown the image that they should be responding to for that particular session (either dog or koala). Each of the final three sessions consisted of 56% go trials and 44% no-go trials. This was designed for use with children with an increased number of no-go trials, which results in the task being easier (Logan, 1980). Scoring was based on the number of commission errors (incorrectly responding to a no-go stimulus) and omission errors (failing to respond to a go stimulus), which were each totalled for the last three blocks to provide summary scores for the total commission and total omission errors. In addition, reaction time data was collected for each trial from the baseline condition and provided a measure of processing speed.

### *Stroop Task*

The California Stroop Test, from the Delis-Kaplan Executive Function Scale, was also used a measure of response inhibition. This task has four conditions, each preceded by a practice trial. The conditions include: (1) colour patch naming (red, blue, green); (2)

word reading (the words *red*, *blue*, and *green* printed in black ink); (3) interference (naming the ink colour in which a discrepant colour word is printed, e.g. the word *red* printed in blue ink); and (4) set shifting. In the fourth condition, the examinee is asked to read a word aloud if a box surrounds it, or to identify the ink colour in which the word is printed if a box does not surround the word. A summary interference score was obtained by subtracting the amount of time (in seconds) on the colour-naming block from the interference block.

### *Prospective Memory*

#### *Cybercruiser*

This test was a modification of that developed by Kerns (2000) which provides a means to assess capacity to maintain both a primary and sub-goal activity, with the sub-goal activity being the prospective memory task. The task was designed to be engaging to children and ecologically valid, and involved playing a computer game that required *driving* a vehicle on a road with competing traffic. The 'car' was controlled through the use a joystick, and participants were required to manoeuvre around the other traffic without crashing into other cars. Participants were told that the primary goal of the game was to gain as many points as possible by passing other vehicles without hitting them (for which points are lost), and going faster on the road by pressing forward on the joystick (thus passing more cars). The child's moment-to-moment score was prominently displayed on the screen. The secondary (prospective memory) task involved monitoring the level of available fuel. The importance of this task was stressed by warning the children that if they ran out gas they would lose all points they had accumulated up to that

point. Participants could fill their car with gas whenever the gas station attendant was 'awake' and they could access the gas station attendant by pushing a button on the joystick. Pushing the button revealed a picture of a gas station attendant who was either 'sleeping' or 'ready to fill', but the picture remained visible on the screen for only 3 seconds. If the attendant was 'ready to fill' pushing the button another button would 'fill' their gas tank. The duration of the game was five minutes. The car would run out of gas after one minute of play if not filled, and could be filled after 50 seconds of play (though participants were not given this information). If the participant ran out of gas, an alarm sounded along with a flashing indicator that the tank was empty; the gas gauge then automatically refilled and the game restarted and the participant lost all points accumulated to that time. After participants completed the Cybercruiser they were asked to again describe what the goals and rules were in the task retrospectively. Participants who forgot or clearly misunderstood the prospective memory task were excluded from data analysis because their failures in performance could be explained by retrospective memory failures or by misunderstanding the task to be performed. The exclusion of this data is consistent with previous research in this area as the purpose of the task was to measure only prospective memory failures (Kidder, Park, Hertzog, & Morrell, 1997; Maylor, 1998). The scores generated by the Cybercruiser included the number of times participants ran out of gas, as a measure of failed prospective memory, and the number of checks on the gas gauge in the five minutes of play.

**Procedure**

Following completion of the informed consent, all participants were tested individually in a quiet room at the University of Victoria. The parents or caregivers were allowed to stay in the room where the testing took place, but were asked to remain quiet and in a part of the room not directly visible to the child. The tasks were administered during a 1- to 1.5 hour session in the following standardized order: (1) Spatial Working Memory task; (2) Behavioural Assessment of the Dysexecutive Syndrome –Children -Six Parts Test; (3) Digit Span Backwards; (4) Stroop task; (5) Go/No-Go task; (6) Children’s Multiple Activities Game; and (7) Cybercruiser. All computerized tasks were presented on an IBM-compatible laptop computer with a 15-inch monitor placed approximately 18 inches in front of the participant. The spatial memory working memory task, Go/No-Go task and the Children’s Multiple Activities game were programmed using Visual Basic, and the Cybercruiser was programmed in Java. Following completion of the testing, the children received a toy worth approximately \$5 for their participation.

**Data Analysis**

A series of correlation, partial correlation and regression analyses were conducted to determine the relationships between the multitasking measures and the executive function measures, assess the development of multitasking ability over the age range, and determine if age moderated any of the relationships. For some of the measures, positive scores were associated with better performance (accuracy), while for others the reverse was the case. Therefore, all scores were reflected so that higher scores represented better performance. To determine whether the relationship between executive function

measures and the multitasking measures varied across ages, age was tested as a moderator variable.

A series of separate regression analyses were performed with both the CMAG and the SPT scores as the dependent variables regressed onto age and each of the executive function measures with each the independent variable in separate analyses. In addition, an age by executive function measure interaction term was computed for each executive function measure and then the dependent measure scores were separately regressed on each executive function measure, age and the appropriate age by measure interaction term. Next, for the executive function tasks that were significantly related to multitasking performance, their ability to uniquely predict that multitasking score while controlling for the other executive function measures was examined by separately regressing each multitasking measure on all of the executive function measures (with and without controlling for age). Finally, the multitasking measures were each regressed onto reaction time (as measured from the first block of the go/no go task) and each executive function together in order to examine the relationships control for the effects of processing speed in the analysis. Given the small sample size and the resulting low power, findings at and around an alpha level of .05 were examined.

## **RESULTS**

Means and standard deviations for all measures separated by age are presented in Table 1. To assess the impact of development on multitasking, the measures were each regressed on age. Age was significantly related to both measures of multitasking [CMAG:  $r = .48$ ,  $ES = .23$ ,  $F(1, 34) = 9.61$ ,  $p = 0.004$ ; SPT:  $r = .38$ ,  $ES = .14$ ,  $F(1, 34) =$

5.460,  $p = 0.03$ ] with older children performing better than younger children, suggesting improvement in multitasking ability with increasing age. The performance on many of the measures of executive function also improved with age including the spatial working memory, colour-word interference, and the prospective memory tasks. Age was also significantly related to a number of the measures (presented below the diagonal on Table 3), including spatial working memory, prospective memory, colour-word interference, and reaction time, [spatial working memory:  $r = .54$ ,  $ES = .29$ ; prospective memory:  $r = .35$ ,  $ES = .12$ ; colour-word interference:  $r = .54$ ,  $ES = .29$ ; reaction time:  $r = .36$ ,  $ES = .13$ ].

TABLE 1  
*Means and standard deviations for multitasking and executive function measures*

Measure	Age (years)									
	7 (n=3)		8 (n=6)		9 (n=4)		10 (n=11)		11 (n=11)	
	<i>M</i>	<i>(SD)</i>	<i>M</i>	<i>(SD)</i>	<i>M</i>	<i>(SD)</i>	<i>M</i>	<i>(SD)</i>	<i>M</i>	<i>(SD)</i>
Go/No Go Commissions	4.67	(3.51)	2.5	(2.26)	4.25	(2.63)	3.55	(3.70)	4.18	(3.49)
Go/No Go Omissions	1.33	(1.15)	1.00	(1.55)	0.75	(1.5)	0.91	(1.38)	0.45	(0.52)
Spatial Working Memory	30.00	(5.20)	27.50	(18.15)	23.00	(16.15)	15.64	(13.08)	7.82	(6.21)
CMAG	1106.67	(294.80)	1129.17	(396.00)	1215.00	(377.96)	1605.46	(406.81)	1614.09	(404.33)
SPT	6.00	(2.00)	12.17	(4.17)	12.25	(3.86)	12.00	(2.53)	13.00	(3.43)
Cybercruiser	2.00	(1.00)	2.17	(1.47)	3.25	(1.50)	1.00	(0.77)	1.36	(0.92)
Colour-Word Interference	58.33	(17.90)	74.50	(24.93)	53.75	(17.93)	42.18	(15.90)	42.00	(14.14)
Digits Backwards	6.33	(2.08)	7.00	(1.79)	7.75	(2.50)	7.36	(1.36)	7.18	(1.72)
Reaction Time	319.49	(17.90)	357.58	(48.71)	301.49	(19.60)	310.22	(86.37)	274.38	(45.23)

To assess whether age moderated the relationships between multitasking performance and any of the measures of executive functions, both of the multitasking measures were separately submitted to first a regression onto age and each executive function measure, and the interaction term for age and the measure. These regressions were completed for each executive function measure separately. The results of these analyses are presented in Table 2, where the  $R^2$  change represents the addition of each executive functions interaction term to a regression of age and the executive function measure for each of the multitasking measures. The lack of any significant age by executive function measure interaction terms suggests that age did not significantly moderate (alter) the relationship between any of the executive functions measures and multitasking performance, even when a more liberal alpha level was examined. Therefore, the relationships between the executive function measures and the multitasking measures appear stable and do not significantly vary as a function of age (at least within the tested age range). As a result, no additional analyses included moderator effects even when age was statistically controlled.

TABLE 2

*Summary of addition of the age/executive function interaction term to Multiple Regression analyses predicting multitasking performance*

Multitasking Measure	Predictor	$R^2$ change	F-change	p-value
CMAG	Go/No Go Commissions x Age	0.008	0.367	0.549
	Go/No Go Omissions x Age	0.006	0.276	0.603
	Spatial Working Memory x Age	0.007	0.314	0.579
	Cybercruiser x Age	0.009	0.492	0.488
	Colour-Word Interference x Age	0.026	1.106	0.301
	Digits Backwards x Age	0.048	2.051	0.162
SPT	Go/No Go Commissions x Age	0.010	0.373	0.546
	Go/No Go Omissions x Age	0.029	1.105	0.301
	Spatial Working Memory x Age	0.001	0.035	0.852
	Cybercruiser x Age	0.063	2.461	0.127
	Colour-Word Interference x Age	0.052	2.067	0.161
	Digits Backwards x Age	0.005	0.173	0.681

**\* $p < 0.05$ . \*\* $p < 0.01$ . \*\*\* $p < 0.001$**

Regression analyses were performed to determine whether each executive function predicted performance on each of the multitasking measures. The relationships between all measures are presented in Table 3. Performance on the CMAG had a statistically significant proportion of variance predicted independently by two of the executive function measures [spatial working memory:  $r = .41$ ,  $ES = .17$ ,  $F(1, 34) = 6.657$ ,  $p = 0.015$ ; prospective memory:  $r = .59$ ,  $ES = .35$ ,  $F(1, 34) = 17.481$ ,  $p = 0.0001$ ], while colour-word interference and go/no go omissions approached significance at the 0.05 level [colour-word interference:  $r = .33$ ,  $ES = .11$ ,  $F(1, 34) = 3.953$ ,  $p = 0.055$ ; go/no

go omissions:  $r = .32$ ,  $ES = .10$ ,  $F(1, 34) = 3.724$ ,  $p = 0.062$ ]; better performance on each of these measures being related to better performance on the CMAG (see Table 3, below diagonal). Interestingly, SPT performance was not significantly predicted by any of the executive function measures, although a trend towards significance was seen for the correlation between CMAG and SPT performances [ $r = .29$ ,  $F(1, 34) = 3.121$ ,  $p = 0.09$ ]. To determine the relationships between each executive function measure and the multitasking measures while controlling for age, partial correlation coefficients were examined (see Table 3, above diagonal). When controlling for age, the relationship between the CMAG and the spatial working memory task was no longer significant ( $r = .21$ ,  $ES = .04$ ,  $p = 0.241$ ).

Table 3  
*Zero-order correlation coefficients and partial correlation coefficients (controlling for age) between all measures of multitasking and executive function*

Measure	1	2	3	4	5	6	7	8	9	10
1. Age										
2. Go/No Go Commissions	-0.09		0.46*	0.27	0.27	-0.12	0.20	-0.12	0.07	-0.07
3. Go/No Go Omissions	0.21	0.42*		0.44*	0.25	0.12	0.27	0.10	0.01	0.33
4. Spatial Working Memory	0.54**	0.05	0.48**		0.21	-0.04	0.20	0.06	-0.11	0.03
5. CMAG	0.48**	0.19	0.32	0.41*		0.14	0.51**	0.10	-0.03	-0.04
6. SPT	0.38*	-0.14	0.18	0.17	0.29		-0.06	-0.14	0.19	0.06
7. Cybercruiser	0.35*	0.16	0.32	0.34*	0.59***	0.08		0.34*	0.13	0.21
8. Colour-Word Interference	0.54**	-0.15	0.19	0.34*	0.33	0.09	0.46**		0.23	0.28
9. Digits Backwards	0.13	-0.06	0.04	0.02	0.03	0.22	0.08	0.26		0.09
10. Reaction Time	0.36*	-0.10	0.37*	0.22	0.14	0.19	0.14	0.42*	0.04	

*Note.* Zero-order correlation presented below diagonal (represented by shaded squares); partial correlation coefficients executive function are presented above the diagonal

\* $p < 0.05$ . \*\* $p < 0.01$ . \*\*\* $p < 0.001$

To determine which of the executive function measures were uniquely related to multitasking performance (above and beyond the variance accounted for by the other executive function measures), simultaneous regressions of the multitasking score onto all of the executive function measures was completed (with and without age included) for each dependent measure. The results of these multiple regression analyses are presented in Table 4 and Table 5 (with and without age included respectively). When age was not included, it was found that simultaneously all of the executive function variables account

for a significant amount of the variability in CMAG performance [ $R^2 = .41$ ,  $F(6, 34) = 3.257$ ,  $p = 0.015$ ], while prospective memory was the only measure which predicted statistically significant unique variance (above and beyond the other measures) [ $t = 2.724$ ,  $p = 0.01$ ], with better prospective memory performance predicting better CMAG performance. Including age in the regression, did not significantly improve the variance accounted for [ $\Delta R^2 = .051$ ,  $\Delta F^2(1, 27) = 2.579$ ,  $p = 0.120$ ], and prospective memory remained the only unique predictor [ $t = 2.671$ ,  $p = 0.013$ ]. The finding that only one of the variables is uniquely related to CMAG, despite significant bivariate relationships between the executive functions and CMAG, is not surprising due to the high intercorrelations among the measures of executive function, in conjunction with the relatively low power of the study.

TABLE 4  
 Summary of Simultaneous Multiple Regression analyses predicting multitasking performance from executive function measures without age included

Multitasking Measure	$R^2$	F	Predictor	t-statistic	p-value			
CMAG	0.411*	3.257	Go/No Go Commissions	0.600	0.553			
			Go/No Go Omissions	0.012	0.990			
			Spatial Working Memory	1.310	0.201			
			Cybercruiser	2.724*	0.011			
			Colour-Word Interference	0.139	0.891			
			Digits Backwards	0.392	0.698			
			SPT	0.160	0.892	Go/No Go Commissions	-1.507	0.143
						Go/No Go Omissions	1.116	0.274
Spatial Working Memory	0.413	0.683						
Cybercruiser	0.505	0.617						
Colour-Word Interference	0.689	0.496						
Digits Backwards	1.503	0.144						

\* $p < 0.05$ .

TABLE 5

*Summary of Multiple Regression analyses predicting multitasking performance from executive function measures with age included.*

Multitasking Measure	$R^2$	F	Predictor	t-statistic	p-value
CMAG	0.462*	3.317	Go/No Go Commissions	0.691	0.495
			Go/No Go Omissions	0.128	0.899
			Spatial Working Memory	0.516	0.610
			Cybercruiser	2.671*	0.013
			Colour-Word Interference	-0.424	0.675
			Digits Backwards	0.288	0.775
			Age	1.606	0.120
			SPT	0.281	1.510
			Go/No Go Omissions	1.334	0.193
			Spatial Working Memory	-0.530	0.600
			Cybercruiser	0.375	0.710
			Colour-Word Interference	-1.427	0.165
			Digits Backwards	1.440	0.161
			Age	2.131*	0.042

**\* $p < 0.05$ .**

Finally, to ensure that observed correlations between the multitasking and executive function measures was not merely due to increased processing speed seen with greater age, the effects of processing speed on the relationships between the multitasking and executive function measures were assessed in separate regressions for each multitasking measure. This was done by entering reaction time from the first block of the go/no go task as a measure of processing speed together with each executive function as

the independent variables in separate regression analysis, while each multitasking measure was the dependent variable. The results of these analyses are presented in Table 6. The inclusion of reaction time in these analyses did not alter any of the significant relationships between any of the measures.

TABLE 6

*Summary of Multiple Regression analyses predicting multitasking performance from executive function measures while controlling for processing speed.*

Multitasking Measure	$R^2$	F	Predictor	t-statistic	p-value	
CMAG	0.061	1.040	Go/No Go Commissions	-1.197	0.240	
			Go/No Go Reaction Time	-0.915	0.367	
	0.102	1.814	Go/No Go Omissions	-1.718	0.096	
			Go/No Go Reaction Time	-0.120	0.905	
	0.170*	3.283	Spatial Working Memory	-2.415*	0.022	
			Go/No Go Reaction Time	-0.304	0.763	
	0.349*	8.585	Cybercruiser	-4.029***	0.000	
			Go/No Go Reaction Time	-0.378	0.708	
	0.126	2.312	Colour-Word Interference	1.982	0.056	
			Go/No Go Reaction Time	-0.032	0.974	
	0.020	0.333	Digits Backwards	0.214	0.832	
			Go/No Go Reaction Time	-0.795	0.432	
	SPT	0.050	0.842	Go/No Go Commissions	0.731	0.470
				Go/No Go Reaction Time	-0.997	0.326
0.048		0.798	Go/No Go Omissions	-0.671	0.507	
			Go/No Go Reaction Time	-0.742	0.463	
0.052		0.872	Spatial Working Memory	-0.769	0.447	
			Go/No Go Reaction Time	-0.878	0.387	
0.037		0.611	Cybercruiser	-0.297	0.768	
			Go/No Go Reaction Time	-1.011	0.320	
0.034		0.566	Colour-Word Interference	-0.043	0.966	
			Go/No Go Reaction Time	-1.003	0.324	
0.088		1.536	Digits Backwards	1.369	0.180	
			Go/No Go Reaction Time	-1.144	0.261	

\* $p < 0.05$ . \*\* $p < 0.01$ . \*\*\* $p < 0.001$

## DISCUSSION

This study investigated the development of children's ability to multitask. The results of the present study revealed a significant developmental trend in the ability to multitask in children ages 7 to 11 years, and thus were consistent with the hypothesis that older children are better able to multitask than younger children. These results imply that older children have developed an increased capacity for planning and organizing multiple goal-directed behaviours in situations that are relatively open-ended. The second major goal of the study was to examine the cognitive processes hypothesized to underlie the ability to multitask. The CMAG multitasking score was significantly related to spatial working memory and prospective memory and inhibition (colour-word interference task), exhibited a trend toward significance. Interestingly, when controlling for all other executive function measures (including age), prospective memory was the only unique predictor of CMAG multitasking ability accounting for a significant proportion of variance above and beyond the other measures. Conversely, the SPT was not significantly related to any of the executive function measures.

Contrary to the hypothesis that both measures of multitasking would be related to the various measures of executive function, results of this study revealed that the CMAG was better predicted by the measures of executive functions than was the SPT. The interactions between age, executive functions tasks, and the multitasking measures were also examined to determine whether age significantly moderated any of the relationships between these abilities. No interaction effects were found, suggesting that the

relationships between the various multitasking measures and each executive function do not vary across the age range studied.

The results of this study provide further evidence of children's increasing capacity to coordinate multiple concurrent events. Furthermore, these results provide evidence that this ability improves as children age in concordance with the maturing prefrontal cortex (Goldman-Rakic, 1987; Diamond, 1988; Dempster, 1992). While this is a novel finding, it is not surprising given that the component processes on which this ability has been thought to rely have consistently been shown to improve over the age range studied.

### **The Relationships between Multitasking and the Cognitive Control Processes**

Inhibition has been shown to develop in this age range as evidenced by significant improvements in inhibiting a prepotent response on Stroop, flanker, go/no go and stop signal paradigm tasks, not reaching full maturity until roughly 12 years or later (Williams, Ponsse, Schachar, Logan & Tannock, 1999; Diamond, 1990; Durston, Thomas, Yang, Ulug, Zimmerman & Casey, 2002). Overall, the developmental literature indicates refined development of cognitive control in terms of overriding both behavioural and attentional responses during mid to late childhood.

Given that overcoming a strong habitual response is a function of the SAS and is thought to be necessary in complex goal-directed behaviours (Shallice & Burgess, 1991), it was anticipated that its development coincides with that of the ability to multitask. The results of the present study revealed a significant relationship between age and inhibition as measured by a colour-word interference task, where older children were better at inhibiting the interfering effects of the stimuli than younger children. However, this same

developmental trend was not found on the go/no go task used in the study. Out of the 75 trials (46 percent no-go trials), 7 year olds did have the highest number of commissions (mean of 4.67 commissions), while the oldest children made just slightly fewer errors (mean of 4.18) perhaps suggestive of a ceiling effect on this task. As further evidence for this point, all age groups responded correctly to a very high percentage of trials with 7 year olds having a mean percentage correct of 92%, while for 8, 9, 10 and 11 year olds the percentages correct were 95.3%, 93.3%, 94.1% and 93.8% respectively. These results suggest that the task failed to capture a significant developmental trend perhaps because it was too easy to produce enough variability with most children performing very well. As similar go/no-go tasks have been related to age in other studies (Archibald, Kerns & Saltzmann, 1998), it is likely that this task was not demanding enough. As noted, the low level of difficulty of the task may be secondary to it being designed for use with young children and subsequently having a high number of no-go trials decreasing the inhibitory requirements (Logan, 1980).

Another reason for the different results found for the go/no go and colour-word interference tasks could be due to inhibition being a more general construct which defines multiple functions rather than a single unitary ability as several theorists have proposed (Dempster, 1993; Harnishfeger, 1995; Nigg, 2000). More general inhibition, of which interference control and intentional motor inhibition should be considered most relevant to this study, may develop at different rates throughout childhood (Dempster, 1993; Rothbart & Bates, 1998). Interference control includes the suppression of distracters that might slow the primary response by interfering with the current operations of working

memory (Nigg, 2000). This is most relevant when performing the CMAG, as all the games are visually salient and therefore while performing one it is necessary to inhibit the distracting stimuli from the other games from interfering with performance. The Stroop task is one of the most widely used measures of interference control as it is presumed that the automatic processing of the printed word needs to be suppressed in order to rapidly name the ink colours. Alternatively, intentional motor inhibition involves the purposeful control of a primary motor response during changing contextual cues (Nigg, 2000). The go/no go task is considered an intentional motor inhibition task, as it requires inhibiting a dominant or prepotent response to the infrequent no-go stimuli. Likely, the CMAG does not have the same involvement of inhibition of a prepotent response but instead may rely more heavily on interference control requirements.

Working memory, another component process of the SAS, is known to be involved in the performance of simultaneous activities and has consistently been shown to develop over this age range (Shallice & Burgess, 1991; Conlin, Gathercole and Adams, 2005). Generally, working memory performance is thought to increase sharply up until eight years of age, and thereon shows gradual improvement to asymptotic levels at 11 or 12 years (Gathercole, 1999). Fry and Hale (1996), using a combination of simple and complex span tasks, found the working memory performance increased significantly in individuals aged between 7 and 19 years of age. The results of the present study support this finding, with a significant relationship found between age and working memory as measured by the spatial working memory task. However, a developmental trend was not found on the auditory working memory task, the Digit Span Backwards task.

Differences between spatial and auditory working memory tasks are well known, as working memory is postulated to be composed of a central executive control system monitoring two independent subsystems, a visuospatial sketchpad (which the spatial working memory task would rely on) and a phonological loop for non-spatial, mainly verbal information processing (which the digit span backwards task can be thought to rely on) (Baddeley, 1992). Furthermore, differences in the development of these abilities have been found in children. For example, Vuontela, Steenari, Carlson, Koivisto, Fjallberg, and Aronen (2003) identified differences on visual and auditory n-back tasks for children aged 6-13 years, providing evidence of a more protracted maturation of auditory working memory relative to visual working memory. The lack of developmental improvements on the current digit span backward tasks could be the result of too narrow an age range in this sample to adequately capture the protracted growth of this system. The mean scores of children in the current study on this task are similar to previous findings (Passolunghi and Siegel, 2004; Lehmann and Hasselhorn, 2007) and therefore appear reasonable despite the lack of a developmental trend. Small sample size may have also had an impact on failing to find a developmental improvement on this task.

Prospective memory is another ability that appears to mature along with the prefrontal lobe and the executive functions that are associated with this area and indeed prospective memory tasks have been shown to be utilized this area in studies using fMRI and PET in the normal population (Burgess, Scott, & Frith, 2003; Simons, Scholvinck, Gilbert, Frith, & Burgess, 2006). The development of the prefrontal lobe and of the resultant executive functions, therefore likely explain the improvements of prospective

memory as children grow older. It would also follow that these same abilities would support the capacity to multitask. Indeed ‘intentionality’ (a term that has been substituted for prospective memory ability (Ellis, 1996) has been found to be closely related to multitasking ability, even after controlling for measures of intelligence, memory, language and perception (Knight, Alderman & Burgess, 2002).

The results of the current study provide evidence of a significant relationship between age and prospective memory and highlight the development of prospective memory ability in this age range. Specifically, older children demonstrated significantly fewer prospective memory failures (ran out of gas less) than younger children. These findings are in line with previous research documenting age-related gains in prospective memory between the ages of 8 and 11 years old on tasks using three different encoding strategies (visual, verbal, & motoric) (Passolunghi, Brandimonte, & Cornoldi, 1995). Kerns (2000), using the original version of the Cybercruiser, also found reliable developmental gains in the ability to execute responses based on prospective memory within the required time interval for children aged 7 to 12 years.

It would seem logical that the development of the executive abilities examined would parallel the finding that the ability to multitask develops over the same age range. This reasoning follows from the results of previous studies that have found working memory, inhibition and prospective memory to be highly correlated (Ward, Shum, McKinlay, Baker, Tweney & Wallace, 2005). Executive functions are required to plan intended actions, maintain them in an active state, or to inhibit the ongoing activity when a prospective cue is encountered (McDaniel, Glisky, Rubin, Guynn & Routhieaux, 1999;

Okuda, Fujii, Yamadori, Kawashima, Tsukiura, Fukatsu et al, 1998). Furthermore, these studies also found prospective memory ability to be superior in patients with frontal lobe damage having higher abilities compared to frontal lobe patients with lower abilities based on a composite measure of a variety of tasks, (McDaniel, Glisky, Rubin, Guynn & Routhieaux, 1999), as well as evidence of activation in the prefrontal cortex on prospective memory tasks using PET (Okuda, Fujii, Yamadori, Kawashima, Tsukiura, Fukatsu et al, 1998). These findings provide further evidence supporting the involvement of prefrontal cortex in prospective memory, inhibition and working memory, as well as providing a coherent rationale for their association with the development of the ability to multitask. Interestingly, differences were found in the relationship of different tasks of multitasking (between the CMAG and the SPT) especially in terms of their correlations with the other measures of executive function.

### **Differences between the CMAG and the SPT – The SAS**

Since multitasking is expected to engage SAS function and the executive functions studied are critical components of this system, it was hypothesized that there would be significant relationships between the underlying cognitive processes measured by the executive function tasks and the multitasking tests. Results provided support for the CMAG being significantly related to some of these measures (both spatial working memory and prospective memory), and a trend toward a significant relationship with inhibition (interference control). However, when controlling for age and the other executive function measures in a multiple regression analyses, only prospective memory uniquely predicted performance on the CMAG.

Shallice and Burgess (1991) propose that the process of intention generation and realization (an aspect of prospective memory) are the critical components giving rise to impaired performance of patients with frontal head injuries while carrying out multitasking tests, such as the Six Elements test. Interestingly, in this study with children the SPT (child modified version of the SET) was not found to be related to any of the executive function measures included in this study. While surprising, it is important to consider aspects of the actual task (SPT) that may have impacted the findings. The SPT was created as a close variant to the SET, a task intended to provide a lab-based “model of the world” – able to capture a presumed critical component (voluntary multiple delayed task-switching) of the “real world” (Burgess et al, 2006). Results from previous studies using variants of the SET, such as the MET, have shown closer concordance with observed symptoms in everyday life than with performance on traditional experimentally-derived executive function tasks (Burgess et al, 1998). It is possible that the lack of relationships between the SPT and the traditional measures of executive function in this study support the equivalence of the SET and the SPT and the use of the SPT as an ecologically valid measure of everyday life problems. Indeed, Burgess (2000) stated that if the SET measures processes that are crucial to everyday multitasking, only low correlations should be found between it and traditional executive function tests.

However, Shallice and Burgess (1996) stated that a variety of subsystems, each of which is responsible for carrying out a separate process and is differently localized within the prefrontal cortex, could be characterized as different parts of a single system if certain conditions are met. These conditions include the subsystems having a common function

within the overall processing system while typically being utilized in a related fashion. Given the accounts detailed above regarding the relationships among prospective memory, inhibition and working memory, it would seem likely that they are subservient to a common goal in the context of multitasking (i.e. a common function as per Shallice and Burgess (1996)). This interpretation should be apparent given that the SAS was developed to model the cognitive processes that are hypothesized to be responsible for the executive control of goal-directed behaviour in novel situations, and as such should include the abilities described above (Norman & Shallice 1986, Shallice, 1982, 1988). In confronting these non-routine situations, most of the subsystems of the SAS should be involved, and prospective memory, inhibition and working memory should be considered essential components in functioning effectively in these situations. The foundation of the SAS is that coping with a novel situation requires a variety of different types of processes operating across a number of stages. The key element in coping with these situations is the construction or temporary implementation of new schema, which can replace the typical schema to produce effective goal-oriented behaviour. These processes will include working memory for the specific purpose of holding the currently active schema in mind (as this schema is not triggered automatically in a non-routine situation). Furthermore, the formation and realization of intentions, (prospective memory), will be required in order to develop a strategy and plan of action. Inhibitory mechanisms are also necessary to prevent inappropriate schemas from being selected, which become activated via well-learned triggers identified by the perceptual system. The SAS uses inhibition, as it is responsible for resolving the conflict between multiple active schemas by

modulating activation levels, thereby biasing the probability of a particular schema being selected (Shallice & Burgess, 1991). Thus, prospective memory, inhibition and working memory should all be considered subsystems (or processes) of the SAS and should be related to multitasking performance.

### **Differences between the CMAG and the SPT – The Characteristics of Multitasking**

The multitasking paradigms used in the study were developed with characteristics of most real life multitasking situations, including the need for several discreet and different tasks to be completed, while performance on these tasks must be dovetailed in order to be time-effective. There were also constraints imposed, such that only one task could be performed at one time. Unforeseen interruptions or distractions can occasionally occur that may be of high priority and therefore require a change in plan, and the time for a return to a task is not always signaled directly by the task. Furthermore, tasks did differ in difficulty, priority, and length of time they occupy, with the assumption that people should be able to decide for themselves what represents adequate performance with no immediate feedback about performance available (Burgess, 2000).

Task analysis of the multitasking measures used in this study, suggests that the CMAG may have encompassed more of the characteristics of multitasking (Burgess, 2000) than did the SPT. For instance, the CMAG certainly included discreet and different games (tasks) to be completed including counting, an auditory monitoring, a visual monitoring and a visual search (McInerney & Kerns, 2003). Secondly, successful performance required the tasks to be interleaved as there were penalties imposed for not returning to a task in a timely manner, while the tasks clearly have the constraint, both

physically and cognitively, that only one may be performed at a time. Thirdly, unforeseen interruptions occasionally did occur that required the participant to change their plan in order to effectively perform the task. For example when the cuckoo sounded, the participant had a limited amount of time to return to the auditory monitoring game before they were penalized; this required them to rapidly reformulate their current plan. In addition, while the return to the auditory monitoring game was directly signalled, the return to the other games was not. Further, while there is not an objective measure of game difficulty, the requirements of each were quite varied, and differences in priority were firmly established by the point values assigned to each. Moreover, the time that each task required also varied in that the auditory monitoring game required continuous monitoring but short and infrequent responses, whereas the counting and visual search games did not require monitoring but were continuously available for increasing points. Participants decided for themselves what constituted adequate performance and how to utilize their attention resources.

In comparison, the SPT had fewer of the characteristics listed by Burgess (2000). Specifically, the tasks of the SPT are: different and discreet; need to be dovetailed; can only be performed one at a time; the time to return to a task is not signaled; and, immediate feedback about performance is not given. However, there were no unexpected interruptions requiring a reformulation of a plan, nor were the tasks given different importance that would require assigning priority. Given a key requirement of multitasking is the creation and realization of delayed intentions (Burgess, 2000), it seems highly important that the multitasking measures would include the necessary

characteristics of unforeseen interruptions and varying task priorities. As such, while the CMAG appears to require rapid reformulation of the plan in the face of interruptions, the SPT can be performed entirely using a plan that was developed before the task actually even begins. Given the finding that prospective memory uniquely predicted multitasking performance as measured by the CMAG, this study clearly requires the creation and realization of intentions in multitasking situations.

It is also important to note that working memory and inhibition were found to be related to CMAG performance as evidenced by simple correlations, not unexpected given the significant differences in attention-control, as conceptualized in the SAS, in contexts that present strong competition between task goals and habitual responses (Kane & Engle, 2003). Successful performance of the CMAG requires all tasks to have at least a certain level of goal activation in addition to the creation intentional markers for returning to the tasks. In order to achieve efficient performance, both the goal activations and the intentional markers need to be rapidly reorganized in response to interruptions from other tasks. The rules and intentional makers can be held within the limited-capacity resource of working memory (Kerns, 1999; Einstein et al, 1997). The significant relationship between spatial working memory and multitasking as measured by the CMAG is not surprising. The relationship between CMAG and inhibitory control is also anticipated given all games are within the visual field at one time, making it necessary to inhibit interfering stimuli of the other games.

Conversely, because the tasks of the SPT do not have to be constantly monitored, the rules of the tasks not being performed do not need to be actively held in working

memory. Instead, the rules of the other tasks need only be activated when you return to those tasks. Furthermore, plans do not need to be updated or reformulated as a result of interruptions from other tasks, thereby decreasing the load on prospective memory and the working memory store. This would likely decrease the reliance on these abilities resulting in the lack of relationships found between these abilities and the ability to multitask as measured by the SPT. In addition, the tasks not being performed are not as visually salient as in the CMAG and can be ignored with little inhibitory control and the demands on interference control to inhibit oneself from returning to the other tasks are minimal. These arguments may explain the finding that none of the executive function tasks were related to performance on the SPT. However, it should not go unnoticed that performance on the SPT and the CMAG were closely, though not significantly, related. This may be the result of the tasks having similar requirement in terms of initial plan formulation, strategy generation and the execution of plans and strategy. Yet, as has just been described, the CMAG requires these plans and strategies to be constantly monitored and updated while confronted with a number of distracting stimuli, providing increased challenges for prospective memory and the associated capacity of working memory as well as inhibitory control.

It is also important to note that performance on the CMAG may be much more dependent on processing speed. Rapidly switching between and activating the rules for tasks is much more a requirement of this measure and therefore variability in individuals' processing speed could be driving the differences between the multitasking measures. Arguments have been made that much of cognitive development may represent the

results of age-related increases in processing speed mediating much of developmental increases in working memory capacity and subsequently fluid intelligence (Fry & Hale, 2000). However, an attempt to assess this by using reaction time from the baseline condition of the go/no go task as a covariate (proxy for processing speed) in the regression analyses, did not diminish significant relationships between any of the measures. Indeed, the bivariate relationship between processing speed and CMAG performance was found to be quite small ( $ES= 0.02$ ).

### **Strengths and Potential Limitations**

A clear strength of this study lies in its novelty, specifically taking a developmental approach to study the ability to multitask on two multitasking paradigms in relation to a number of executive functions that serve as subsystems of the SAS. Since many children with childhood disorders such as ADHD, FASD and autism have difficulties with aspects of executive function (Siklos & Kerns, 2004; Clark, Prior & Kinsella, 2000) determining the developmental pathway of these skills in conjunction with the ability to multitask is important. It has also been found that, using a paradigm based on the principles outlined by Burgess et al (2000), children with Asperger's syndrome have significant difficulties in the ability to multitask compared to typically developing children (Mackinlay, Charman & Karmiloff-Smith, 2006). Therefore, studying the development and interaction of the executive function abilities, with which these children are known to have difficulty (Geurts, Verte, Oosterlaan, Roeyers, & Sergeant, 2004), with their multitasking abilities seems all the more relevant. Investigating multitasking using a novel paradigm (CMAG) with several characteristics

that differ from the SET (in comparison to previous tasks studied that also used similar paradigms, including the SPT, the MET, and the Battersea Multitasking Paradigm, which are quite similar; Shallice & Burgess, 1991; Mackinlay, Charman & Karmiloff-Smith, 2006) is another strength of this study. It allowed for an examination of relationships between this new measure of multitasking, argued here to be more closely related to the SAS, and the executive functions. A more thorough understanding of the relationships between multitasking performance and the executive functions studied through the inclusion of a variety of tasks within the working memory and inhibition domains.

There are also several limitations to the current study. First, the reliability of the results is reduced without replication due to the test-retest reliability and internal consistency of the other measures, in addition to the use of a new paradigm. Second, the small number of participants included in this study has the effect of limiting the generalizability of the findings as well as reducing the chances of finding significant relationships between the measures due to insufficient power. Third, the age range used in this study was limited. While this age span was considered useful for capturing a stage in development where the abilities are under development are rapidly maturing, including a wider age range would be more informative. Moreover, similar to having a small number of participants, having a restricted age range and studying typically developing children likely limited the scope of variability in the measures leading to a reduced likelihood of finding significant relationships between the measures, and also providing only a limited look at the impact of development. Given that age was significantly related to a number of measures used with known developmental trends, the age effects

reported are most likely reliable. Concerns about the reliability and validity of specific tasks within this study include the low level of difficulty of the Go/No Go task which likely significantly limited the variability of the results and the subjective scoring nature of the strategic component for the SPT total score, which also limited both the reliability and variability of the findings for this task.

Finally, it would have also been beneficial and interesting to include a measure of intelligence in this study in order to control for its impact on the development of the abilities studied though previous studies in adults have multitasking effects remained after taking into account differences in IQ (Alderman, Burgess, Knight & Henman, 2003; Burgess et al, 2006) and in previous studies prospective memory was not related to intelligence in children (Kerns, 2000).

### **The Future of Multitasking Research**

Future studies in this area may find it useful to include other populations, such as those mentioned above, in addition to a wider age range in order to capture a broader range of functioning.

The ability to perform cognitive set switching is anatomically and functionally related to other frontal executive skills, including working memory and inhibition (Wecker, Kramer, Wisniewski, Delis & Kaplan, 2000). Miyake, Friedman, Emerson, Witzki, Howerter and Wager (2000) identified shifting as one of three key executive functions in addition to updating, which is a function of working memory, and inhibition. Thus, including a measure of this ability and relating it to the development of the ability

to multitask in order to determine whether cognitive set switching predicted multitasking performance could have also proven interesting.

Finally, and perhaps most importantly, the inclusion of a questionnaire designed to assess executive function behaviours in everyday environments, such as the Behaviour Rating Inventory of Executive Function (BRIEF), would have been useful. This measure could have further established the ecological validity of the multitasking measures used in this study as well as identified which behaviours were related to problems in the ability to multitask. Of note, a recent study investigated the relationships between BRIEF sub-scores and multitask variables for children with Asperger's (Mackinlay, Charman & Karmiloff-Smith, 2006). This study found that many of the relationships they had anticipated were not observed. For example, multitask switching was not found to correlate with the BRIEF shift. Taking those results, along with the different relationships between the executive function tasks and the CMAG and SPT found in this study, it would seem that a study relating performance on the CMAG and SPT to parent's ratings on the BRIEF would be a logical extension of this work.

In conclusion, the results of the current study support the hypothesis that the ability to perform multiple concurrent activities, known as the ability to multitask, shows significant development between the ages of 7 and 11 years old. Furthermore, it was found that the executive functions developing at this time are more closely related to the CMAG measure of multitasking than the SPT. Specifically, CMAG was related to spatial working memory and prospective memory, while a trend toward a significant relationship with inhibition (specifically interference control) was also found. Conversely, the SPT

was not related to any of the executive function measures. It was argued that the differences in relationships are the product of inherent task differences, where the CMAG is considered here to be more heavily reliant on SAS function and seems to typify more of the characteristics hypothesized as crucial for multitasking. The knowledge of developmental change in this ability and how it relates to executive functioning is an important step toward a better understanding of the development of effective goal-directed behaviour in children.

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