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**THE DEVELOPMENT OF EXECUTIVE FUNCTION:
STABILITY AND CONTINUITY**

by
MARTHA McDOUGALL, B.S.c., B.Ed.

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfilment of the requirements for the degree of

Master of Arts

Department of Psychology

Carleton University
Ottawa, Ontario
May 14, 1998
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The undersigned recommend to
the Faculty of Graduate Studies
acceptance of the thesis

**“The Development of Executive Function:
Stability and Continuity”**
submitted by **Martha McDougall, B.Sc., B.Ed.**
in partial fulfillment of the requirements for
the degree of Master of Arts

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May 14, 1998

ABSTRACT

Executive function (EF) is a multifaceted construct that is used to represent the higher order functioning attributed to the most evolved, and elaborately interconnected region of the brain, the prefrontal cortex. Executive function is described as a top-down, integrative process encompassing three interactive components; working memory, mental flexibility, and interference control. Tasks purported to assess EF are grouped into three categories according to their emphasis on the components of executive function. Most of the research that has been conducted in the area of EF has been carried out with adults. However, there is developmental evidence indicating that, structurally and functionally, the prefrontal lobes, thus executive functions, begin to develop early in life. The focus of the present study is to examine the growth patterns of early EF behaviour.

The development of EF has been examined by most researchers cross-sectionally. The Ottawa Prenatal Prospective Study (OPPS) is an ongoing longitudinal study that is designed to assess the effects of life-style habits during pregnancy on the developing child. Given the numerous measures that were administered repeatedly throughout the OPPS, the data available from this work offers a unique opportunity to examine the development of EF longitudinally, on the same subjects over time. Patterns of stability (i.e., consistency of individual differences) and continuity (i.e., patterns of change in developmental functions) in EF abilities were examined in a sample of 53 subjects from childhood through to early adolescence (i.e., 3 to 12 years of age).

Cross-age correlational analyses revealed that different aspects of EF behaviour demonstrate varying patterns of longitudinal stability. In one such pattern, similar to non-EF behaviour such as verbal ability and short-term memory, individual differences in certain executive functions such as mental flexibility and sustained attention (an aspect of interference control) are consistent across age. In another instance, stability with two other aspects of EF abilities, working memory and response inhibition (a component of interference control), did not yield such consistency in individual differences across age.

To explore continuity in EF behaviour, EF and non-EF tasks were examined for developmental patterns of change across age. The present study revealed that EF processes appear to include a combination of both continuous and discontinuous development. Progression across age on all non-EF tasks was found to be continuous. On the other hand, development on some EF tasks was found to be continuous (e.g., Spelling subtest of the Wide Range Achievement Test-Revised, Category test) whereas, development on others appeared to be discontinuous (e.g., verbal fluency, Delay task of the Gordon Diagnostic System). Continuity and discontinuity within EF tasks were not differentiated solely on the three components of EF, i.e., working memory, mental flexibility and interference control. Findings of continuity or discontinuity were likely somewhat related to differences in the demands of the tasks from which the indices of EF were drawn.

Executive function skills consistently appear to develop later than underlying non-EF abilities reflecting the top-down, integrative requirements of executive function. This

study also provides preliminary evidence suggesting that non-EF and EF abilities may follow differential developmental courses.

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The prefrontal cortex

Phylogenetically and ontogenetically, the frontal lobes are the largest, most unique, and most highly evolved parts of the human brain (Fuster, 1989). The prefrontal cortex, the most anterior portion of the frontal lobes, comprises 29% of the human cortex (Fuster, 1989; Goldman-Rakic, 1987). Based on studies with humans, it has been established that the prefrontal lobes have a bidirectional interconnectivity with many other brain areas (Stuss & Benson, 1984). Their rapid evolutionary expansion, large size, and rich interconnectivity has led to the belief that the prefrontal cortex of the human brain subserves our highest cognitive functions (Diamond, 1991; Fuster, 1989; Lezak, 1995).

In the past there has been inconsistency in the literature with respect to the neuroanatomical subdivisions of the prefrontal cortex and many authors discussed the prefrontal cortex as a whole without addressing the issue of subdivisions. Now, based on anatomic evidence (distinct regions and connectivity with other brain regions) and, clinical evidence (behavioural dysfunction associated with specific lesions) there seems to be a general consensus that the prefrontal cortex can be partitioned into three subregions, which Lezak (1995) refers to as the dorsolateral (top, outer sides), orbitomedial (inner sides, between the hemispheres), and orbital or basal (lower, lateral sides) prefrontal cortices. Anatomically, although these three regions can be described as distinct, they are elaborately interconnected (Grattan and Eslinger, 1991).

Despite its apparent complexity and thus, potential importance, the functional significance of the prefrontal cortex has previously been grossly underestimated. In fact, the prefrontal lobes have been referred to as functionally "silent" for a number of reasons.

Damage sustained to the prefrontal lobes in adulthood produces minor, if any, effects on intellectual functioning as measured by standardized tests (Fuster, 1989; Milner, 1964; Pennington, 1994), which have, traditionally, been the basis of assessment procedures. In addition, prior to adulthood, it was previously thought that prefrontal lobe function was not observable until puberty, and therefore prefrontal lobe functioning was not examined in children.

More recently, the exploration of the functional role(s) of the prefrontal lobes has escalated. Research indicates that the three subdivisions of the prefrontal cortex, mentioned above (dorsolateral, orbitomedial, and orbital), appear somewhat functionally distinct, although when considering cognitive outcomes, there is evidence of some overlap in function (Grattan & Eslinger, 1991; Passler et al., 1986). The dorsolateral prefrontal cortex is the region that is most closely associated with self-regulation of behaviour (including control of inhibition) and the temporal integration of activities (Diamond, 1991a; Lezak, 1995). The orbitomedial prefrontal cortex is thought, primarily, to be involved in emotional and social behaviour concerning drive and motivation. The functions of the orbital (or basal) portion of the prefrontal cortex include maintenance of set and set shifting, interference control (specifically impulse control), and thus self-regulation of behaviour. However, with respect to this functional distinction, there is lack of clarity in the literature (Grattan & Eslinger, 1991). The association between particular functions and specific brain region(s) is often based on the loss of function that is observed following brain injury. In most studies determining the exact site of lesion poses great difficulty, thus complicating the association between structure and function.

Despite the intensive research that has been conducted, the intricacy of the human prefrontal lobe system obscures our complete understanding of its functioning. More detailed analysis of both anatomy and cognition are required to define with greater certainty the relationship between the subdivisions of the prefrontal cortex and specific cognitive functions. Given the current state of knowledge regarding the association between anatomy and function within the prefrontal cortex, the ability to discuss the subdivisions is limited. Wherever possible, specific regions will be addressed in the context of particular functions that have been repeatedly associated with particular subregion(s) of the prefrontal cortex.

The construct of executive function

Analysis of numerous adult clinical cases has led to the following outline of behavioural difficulties that are characteristic of patients with prefrontal lobe pathology: dissociation between thought and action, difficulty shifting concepts and changing behaviour, difficulty integrating isolated details (spatially and temporally), difficulty handling multiple sources of information simultaneously, and the inability to regulate one's own behaviour (Stuss & Benson, 1987). These deficits manifest themselves in impulsive behaviour, poor planning ability, perseveratory behaviour, and failure to inhibit extraneous and irrelevant information (Lezak, 1983; Passler, Isaac, & Hynd, 1985). As an ensemble these behaviours, that are associated with damage to the prefrontal cortex, have come to be known as the "frontal lobe syndrome" (Stuss & Benson, 1984). Therefore, from this point on, the term "frontal" will be used in reference to the prefrontal cortex.

Executive function (EF) is a descriptive term that is used to combine the diverse functions that are attributed to the prefrontal cortex (Welsh & Pennington, 1988; Welsh et al., 1991; Stuss, 1992), and that are described above as representing the "frontal lobe syndrome". The psychological concept of EF, derived from the behavioural description of prefrontal function (Stuss, 1992), is employed to represent the functioning of a highly developed brain area that performs complex functions. "The human prefrontal cortex attends, integrates, formulates, executes, monitors, modifies, and judges all nervous system activities" (Stuss & Benson, 1987). Since the construct of EF is intended to encompass all of these functions, then it should be conceived as a goal-directed, adaptive, and integrative process that is inherent in higher cognitive function (Williams & Mateer, 1992).

Executive function appears to be a broad, multi-faceted domain. Factor analytic studies performed on batteries of EF tasks have not yielded one common "prefrontal" factor (Levin et al., 1991; Shute & Huertas, 1990; Welsh et al., 1991), providing support for the conviction that EF involves several components. This raises the possibility that the application of one semantic label, "executive function", to unify a series of complex behaviours may not be justified. Different aspects of what is included in the concept of EF may actually be more distinct than this unifying approach permits. Whether there is exact correspondence between the different components of EF and the subdivisions of the prefrontal cortex described above, is unknown at this time (Denckla, 1993).

Components of executive function

While certain components of EF are controversial, there are some aspects of EF that are considered fundamental, and for the most part are undisputed (Denckla, 1993). However, different theorists tend to emphasize different aspects as the core function upon which the rest is based. Perhaps this is consequential to the fact that, although deficits in EF tend to manifest themselves in a "cluster of deficiencies", a particular deficit may predominate (Lezak, 1995).

There are three components argued here to be central to EF processes: working memory, mental flexibility, and interference control.

1) Working memory

Working memory serves to transiently store information that is used to guide behaviour in the absence of direct stimulation (Fuster, 1995). Consequently, the behaviour that ensues is based on ideas or thoughts, that is, internalized information (Goldman-Rakic & Friedman, 1991). Therefore, working memory, defined as such, presupposes the ability to form and maintain internal representations of external stimuli (Denckla, 1993) and involves the ability use this represented information in preparation for action (Denckla, 1996).

The working memory system operates by means of the interaction of two subfunctions, one retrospective and the other prospective. The retrospective aspect of working memory draws on past experience and holds information on line for future use. The prospective component involves anticipation and planning for future action, thus

subsumes the ability to conceptualize change (Lezak, 1995). Their combination, therefore, necessitates the integration of temporally separate pieces of information (Fuster, 1989, 1991, 1995; Pennington, 1994). To use Fuster's (1991) terminology, the integration of these two subcomponents involves the "mediation of cross-temporal contingencies" to carry out a specific goal. Working memory entails the extrapolation of knowledge from previous experience and the application of that knowledge to future behaviour, thus involving abstraction, concept formation.

Neuroanatomically, working memory depends on intact frontal lobe structures (Goldman-Rakic, 1993). More specifically, the dorsolateral prefrontal cortex is thought to play a role in temporal integration (Diamond, 1991a). Damage to the prefrontal cortex can cause an impairment of one's ability to regulate behaviour by representation, resulting in poor planning ability (Fuster, 1989), perseveratory behaviour, heightened susceptibility to distraction (Goldman-Rakic, 1987) and impulsive behaviour (Pennington, 1994).

2) Mental flexibility

Mental flexibility refers to the flexibility of thought and action that allows the maintenance of a response set when appropriate and a shift in responding in accordance with the demands of a novel situation. Grattan & Eslinger (1991) propose two forms of mental flexibility, reactive and spontaneous. The former entails set shifting in response to demands posed by the environment. Spontaneous flexibility involves the generation of alternative response sets in the absence of external cues. Both types of mental flexibility described above provide the individual with the ability to generate hypotheses and

contemplate alternatives in order for selection of the most appropriate response.

Failure to demonstrate mental flexibility results in "perseverative, stereotyped, nonadaptive behaviour" (Lezak, 1995) which is most commonly associated with damage to the dorsolateral frontal lobes (Milner, 1964; Stuss & Benson, 1984). However, perseveration, defined as "the continuation of a response after it is no longer appropriate" (Lezak, 1995), is not present in all frontally damaged patients. It has been suggested that perseveration may result from frontal-subcortical damage (Stuss & Benson, 1984). That is, the perseveratory behaviour that is characteristic of frontally damaged patients may result from the disconnection of the prefrontal cortex from the subcortical regions of the brain. If this is the case, patients with these connections intact would not display perseveratory behaviour, thus accounting for the inconsistency alluded to above. As well, perseveration has been observed in patients with damage to other cortical regions. One main difference, however, is that following prefrontal damage perseveration can occur in multiple cognitive/behavioural domains and perseveration resulting from damage to other cortical regions is usually limited to a particular domain, which is determined by the site of the lesion (Goldberg & Bilder, 1987; Lezak, 1995).

3) Interference control

Although there is some variability, many theorists contend that executive functioning involves aspects of attentional processes (Denckla, 1993). The prefrontal lobes appear to play a complex role in attention. This region of the brain "explores, monitors, fixates, and shifts the direction of attention" (Stuss & Benson, 1987). With

respect to EF, attention can be considered within the context of the control of interference in the performance of cognitive tasks rather than as a singular function, ie- "pure" attention (Shute & Huertas, 1990).

Interference control (Fuster, 1985) is the term used here to represent the "twin attentional functions of activation and inhibition" which have been considered as central to the notion of executive function (Case, 1992). That is to say, interference control provides the individual with the capacity to deal with multiple pieces of information simultaneously and to organize logical sequencing of behaviour. This involves the ability to activate a particular response set when necessary (selective attention, i.e., sustained attention over time; Denckla, 1996) and to inhibit competing incoming information (response inhibition) (Case, 1992).

Attentional problems, such as failure to inhibit irrelevant information resulting in impulsive behaviour, are commonly observed after frontal lobe damage (Stuss & Benson, 1987). In particular, the dorsolateral prefrontal cortex, in monkeys and in humans, has been associated with interference control (Diamond, 1991a; Fuster, 1989; Milner, 1964; Milner et al., 1985).

The three components of EF are highly interrelated. Selection of the most appropriate response involves the coordination of anticipation and planning ability (the prospective component in the working memory system) and knowledge from past experience (the retrospective component in the working memory system) to generate and evaluate potential responses (the ability to conceptualize change). In addition, mental

flexibility requires decision making in order to select the most appropriate response from a set of alternatives. In this sense, working memory and mental flexibility are associated. The operational mechanism of the working memory system (temporal integration) depends on internal representations, and good inhibitory control is necessary to be able to maintain information, deemed useful, on line via internal representations, and in the face of competing information. Therefore, the functions of working memory and interference control are related. In addition, the processes involved in mental flexibility, such as response selection and the ability to shift responding when necessary, undoubtedly require efficient control of interference. Thus, working memory, mental flexibility, and interference control are three interactive subfunctions that, together, make the process of EF, as described above, possible.

There are aspects of functioning, other than EF, that can be associated with the prefrontal lobes (eg. social discourse; Dennis, 1991). However, for purposes of this paper, the terms "prefrontal function", and "executive function" will be used to represent the interactive components described above as being involved in the purposeful, goal-directed behaviour that have been attributed to the prefrontal cortex.

Assessment of executive function

Prior to listing and describing the measures that are traditionally used to assess EF, there are a few general issues in the assessment of executive function that must be addressed.

It is important to note that the validity underlying the construct of EF is grounded

primarily in the association between the functioning of the prefrontal lobes and performance on the assessment procedures used to measure executive function (Shallice, 1982). The body of knowledge that has accumulated on prefrontal function is derived mainly from the neuropsychological examination of human adults who have sustained damage to the prefrontal cortex (Stuss & Benson, 1984) and experimental lesion studies that have been conducted on nonhuman primates (eg. Diamond & Goldman-Rakic, 1985). While use of these research methods most often results in the association of the behavioural problems observed with the area of the brain that is suspected to be damaged or lesioned, both of these research methods have limitations. Firstly, although experimental lesion studies with nonhuman primates may provide precise localization of lesion, drawing inferences with respect to human functioning based on behaviour that is unaffected by language can be imprecise. Secondly, the study of the neuropsychological sequelae of brain damage in humans is complicated by the fact that cases with damage to one specific area (the prefrontal cortex, in this case) are extremely rare. Further, as mentioned above, in the past it has been difficult to determine precisely which brain areas had suffered damage, in humans. Today, additional information with respect to the localization of specific behaviours to the prefrontal cortex is provided by more advanced technology such as single-cell recording and functional brain imaging, including positron emission tomography (PET) and regional cerebral blood flow (rcbf). These techniques supplement the behavioural evidence by establishing which brain areas demonstrate increased activation during performance of a particular cognitive function (Lou, Henrikson, & Bruhn, 1984; Welsh, Pennington, & Groisser, 1991; Passingham, 1993).

Use of these techniques is necessary to further validate the use of so-called EF measures to reflect prefrontal lobe functioning.

Secondly, the assessment of EF is a paradoxical concept. Assessing EF should involve measuring the subject's ability to take control and to impose structure on the situation themselves. However, inherent in the concept of a neuropsychological examination is the imposition of some sort of structure by the examiner. "Almost all tests are well structured and administered by an examiner who plans, initiates, and conducts the examination" (Lezak, 1995). Therefore, the tests available that allow sufficient goal directed behaviour by the subject within a setting structured by the examiner are limited in number (Lezak, 1995). One such example is the Tinker Toy Test (TTT), designed by Lezak (1995), which allows the subject to initiate, plan, and structure a complex activity independently. However, as this test was only developed in 1981, few comprehensive validity and reliability studies have been conducted with this test, and norms for the TTT are lacking.

The construct of EF can be operationalized within numerous cognitive/behavioural domains. For example, two test instruments, one verbal and the other spatial, that appear very different on the surface could pose similar demands on the EF system. "Executive function assessment therefore always is potentially confounded by the content domains overlapping with the 'execution'" (Denckla, 1993). In order to ensure that the process of EF is measured independently from the content of the task, the EF demands of the task must be isolated. The isolation of the core of EF can be accomplished by specifying the discriminant domains of the tasks being studied, and including discriminant measures in a

similar analysis for purposes of comparison. For example, verbal fluency behaviour requires verbal skills, working memory, and mental flexibility, and is often included in studies as an EF task. In the event that a verbal fluency task is examined, another verbal task with minimal, if any, demands on the EF system should be included for analysis. The inclusion of a vocabulary task, for example, allows for the examination of underlying verbal ability independently from EF abilities, providing for the isolation of the EF component(s) of the task.

Successful performance on the tests used to assess EF abilities, generally speaking, depends on intact prefrontal lobe functioning. However, since these tests assess a wide variety of cognitive functions, not all patients with frontal lobe injury show impairments on these tests and none are so specific that the only population showing any deficit in performance are those with frontal damage (Weinberger et al., 1994).

The assortment of procedures that are traditionally used to assess EF have been compiled from measures with specific use in developmental psychology and/or in neuropsychology and are based on proposed association with brain area(s) (Denckla, 1993). Given that there are not many tests that are designed specifically for the assessment of EF, it is not suggested that all of the tasks used to measure this construct will involve all of the core aspects of the construct itself (working memory, mental flexibility, and interference control) to the same degree. Executive function appears to be multifactorial, however, the components described above are interrelated. Thus, it is not surprising that most of the measures will involve all three of the core components of EF to some degree. However, depending on the demands of the task, emphasis on one of the

aspects of EF will likely predominate in each task.

The Ottawa Prenatal Prospective Study (OPPS)

The OPPS, which began in 1978, is an ongoing longitudinal study that was originally designed to assess the effects of life-style habits during pregnancy on the developing child. The children in this study represent a low risk sample and have been assessed longitudinally, from birth up to the present using specific, yet comprehensive test batteries at various stages of development. The data that is currently available for examination spans development up to 12 years of age. Although none of the test batteries administered to this sample up to 12 years of age have been specially designed to assess EF, there are a number of tests that have been administered that appear to assess aspects of executive function.

The rationale for the identification of tasks from the OPPS as involving EF will be primarily theoretical. The underlying processes and demands of the selected measures will be argued to be consistent with the construct of EF as outlined and to be similar to the underpinnings of traditional measures of executive function (also discussed below). Additional evidence for the executive skills required in the performance of these tasks may be provided if the particular task has been administered to adults with frontal lobe damage. Once again, not all of the tasks discussed will operationalize every feature of EF to the same degree.

Tasks of executive function

The assessment tools that will be described below as measures of EF will be presented under three subheadings: working memory, mental flexibility, and interference control. Each section will discuss a series of tasks that are argued to assess EF with emphasis on a particular component of executive function. Within each section a discussion of some traditional tasks will precede a discussion of the measures selected from the OPPS (i.e., non-traditional tasks of executive function). A summary of this information is presented in Table 1.

Table 1 about here

1) Working Memory

Working memory involves the temporary storage of information which is used to guide future behaviour.

1A. Traditional measures of EF that emphasize the working memory component are: object search tasks, the Tower of Hanoi, and the Porteus Maze Test.

1A1. Object search tasks

The delayed response task, an object search task first described by Jacobsen (1931), is the test of cognitive function that is most commonly linked to dorsolateral prefrontal function in nonhuman primates (Diamond & Goldman-Rakic, 1989; Oscar-

Table 1:
Involvement of the Components of Executive Function in Tasks of Executive Function

# in text	Components of Executive function			Traditional Measures of Executive Function	Measures selected from the Ottawa Prenatal Prospective Study (OPPS)
	Working Memory	Mental Flexibility	Interference Control		
1	◆◆◆	◆	◆	Object search tasks (1A1) Tower of Hanoi (1A2) Porteus Maze Test (1A3)	Wide Range Achievement Test-Revised (1B1) - Spelling subtest McCarthy Scales for Children's Abilities (1B2) - Numerical Memory II - Block Building - Puzzle Solving Wechsler Intelligence Scales for Children (1B3) - Digits Backward - Block Design - Object Assembly - Picture Arrangement - Mazes - Similarities Auditory Working Memory Test (1B4)
2	◆◆	◆◆◆	◆	Fluency Tasks (2A1) Wisconsin Card Sorting Test (2A2)	McCarthy Verbal Fluency (2B1) Phonologic Verbal Fluency (2B1) Category Test (2B2) Trail Making Test - Part B (2B3)
3	◆	◆	◆	Stroop Test (3A1) Object Retrieval (3A2)	Gordon Diagnostic System (3B1)

() indicates corresponding section in text
 Number of "◆" indicates the degree of involvement of the three components of executive function in the tasks discussed
 (greater # of "◆" indicates greater emphasis on that component)

Berman, McNamara & Freedman, 1991). In this task, the subject is shown a reward which the examiner subsequently places under one of two identical wells. Following a delay, usually between 0 to 10 seconds, the subject is permitted to recover the hidden reward. In the original version of the delayed response task, the location of the reward is varied randomly over trials and a schedule of its location is determined prior to the beginning of the test.

Performance on this goal-directed task is contingent upon the subject's ability to internally represent an environmental event over the time delay. The subject must remember "where the reward has been hidden in the absence of visible cues" and use that memory to guide future behaviour (Diamond, 1991a; Diamond & Goldman-Rakic, 1989; Fuster, 1991), and thus, it can be considered a working memory task (Passingham, 1993). Inhibitory control and flexibility in responding are also required to some degree in that the task involves the selection of the appropriate response, the inhibition of the inappropriate response (which in some cases is the last rewarded response) and the ability to switch response sets when necessary.

Both infant and adult monkeys demonstrate impaired performance on these tasks following dorsolateral prefrontal lesions (Diamond & Goldman-Rakic, 1989; Weinberger et al., 1994). As well, some human subjects with prefrontal dysfunction show impaired performance on this task (Oscar-Berman, McNamara, & Freedman, 1991).

Another object search task is the classic Piagetian object permanence paradigm (Piaget, 1954), the AB (A not B) task, which is a variation of the delayed response task. Like the delayed response task, the examiner hides a toy in one of two wells in the

subject's presence. After a delay (0 to 10 seconds), the child uncovers one of the wells, and if correct, retrieves the toy. What distinguishes this task from the delayed response task is that the examiner hides the reward under a given well until the subject correctly uncovers that well a certain number of times which is in accordance with a prespecified criterion. A classic error made by children before 12 months of age is to choose the well that has previously been reinforced, as opposed to the new location. This task, proposed to require set maintenance over a delay, flexibility in responding, and inhibitory control (Goldman-Rakic, 1987; Welsh & Pennington, 1988), is argued to assess a rudimentary form of executive function (Dennis, 1991).

Due to the similarity between the two object search tasks (the delayed response task and the AB task) it has been suggested that both of these tasks require the same abilities and are subserved by the same area of the brain (Welsh & Pennington, 1988). To confirm this hypothesis, Diamond & Goldman-Rakic (1989) examined the performance of normal human infants, and intact and brain damaged infant and adult monkeys, on the AB task. By comparing object search behaviour in these samples, Diamond and Goldman-Rakic (1989) were able to localize performance on the AB task to the dorsolateral prefrontal cortex in infant and adult monkeys, and by inference to this same area in humans. The dorsolateral prefrontal cortex appears to be necessary for the spatial and temporal integration of information, flexibility in responding, and the inhibition of inappropriate responses, as is required in the AB, and delayed response tasks (Diamond, 1991b).

1A2. Tower of Hanoi (TOH; Shallice & Burgess, 1991)

In this ring transfer task three (or four) rings of differing sizes are placed in a specific configuration on a set of three posts. The subject is required to transfer the rings between posts to achieve a goal configuration in the least number of moves, while respecting the restrictions as to which rings can be piled on top of each other. The TOH is nonverbal in nature, and has been used to study strategic problem solving behaviour by a number of researchers (Byrnes & Spitz, 1979). The TOH task demands anticipation and planning (Lezak, 1995; Shallice, 1982; Weinberger et al., 1994; Welsh et al., 1991; Weyandt & Willis, 1994) and thus requires working memory (Pennington, 1994). Mental flexibility is also involved to a degree since the subject must be able to contemplate alternative responses to get to the goal configuration in the least number of moves. In a factor analytic study, when used with children as part of a battery of EF tasks, the TOH loaded on a planning factor (Welsh et al., 1991).

The TOH appears to be a measure that is sensitive to prefrontal dysfunction in adults (Denckla, 1993; Shallice, 1982) and in children (Levin, et al., 1991). In addition, the TOH is a discriminating measure of EF ability in a number of developmental disorders (PKU, ADHD, autism) (Pennington, 1994).

1A3. Porteus Maze Test (Porteus, 1959, 1965)

In this planning task (Dennis, 1991; Lezak, 1995), the subject must make their way through increasingly complex mazes without lifting the pencil from the page, and without entering any blocked passages. Successful completion of the Porteus Maze task involves

hypothesis testing, that is, "the process of choosing, trying, and rejecting or adopting alternative courses of conduct or thought" (Porteus, 1959, p. 7).

This maze task has been implicated in sensitivity to executive disorders (Segalowitz, Unsal & Dywan, 1992). Providing additional support, the Porteus Mazes have loaded on a planning factor in factor analytic studies conducted with an elderly population, and they are claimed to be sensitive to prefrontal lobe damage (Daigneault, et al., 1988, 1992). In children, the Porteus Mazes have been observed to correlate with the Tower of London (a variation of the TOH involving the rearrangement of three same-size, coloured rings on a set of three upright posts; Lezak, 1995) and the authors suggest that these two tests share a planning component (Krikorian et al., 1994).

1B. There are four sets of measures, selected from the OPPS, argued to assess EF with highest demands on the working memory system and relatively minimal demands on the other two components of EF (mental flexibility, and interference control). The Spelling subtest of the Wide Range Achievement Test-Revised (WRAT-R), three subtests from the McCarthy Scales of Children's Abilities (McCarthy), 5 subtests from the Wechsler Intelligence Scales for Children-III (WISC-III;), and the Auditory Working Memory Task are presented below.

1B1. WRAT-R Spelling subtest (Jastak & Wilkinson, 1984)

The WRAT-R is a test of educational achievement assessing reading, spelling and arithmetic abilities in people ranging from 5 to 75 years of age. The Spelling subtest

requires subjects to write words of increasing difficulty given by dictation. The process of spelling relies on phonology (the sound structure of language), orthography (the system of written symbols used to represent a spoken language) and psychological processes such as working memory (Stage & Wagner, 1992). In order to correctly spell a word the subject must hold the spoken word in mind, most likely by visually based representation, and retrieve the appropriate sound-letter correspondences (Stage & Wagner, 1992; Kreiner, 1992). This requires simultaneous storage and processing of information, thus taxing the working memory system of the brain.

Some researchers would argue that as children get older working memory is no longer involved in spelling performance (Stage & Wagner, 1992). Case's (1985) information-processing perspective posits that growth in working memory capacity (active processing space), which is mediated by increases in operational automaticity, plays a large role in the development of executive functioning abilities. In accordance with this theory, it would be possible for an ability that is thought to be executively mediated in infancy to become habitual or automatic, and thus no longer necessitate executive functioning skills. Regarding spelling across age, the spelling of more basic words that was once effortful and deliberate may become less novel, and more automatic and routine as children get older, thus no longer requiring EF abilities. However, with the use of increasingly long and difficult words for older children, which require more effort, the working memory system is most likely still being impacted during spelling performance. Given the range of difficulty of items on the WRAT-R Spelling subtest, it is suitable for longitudinal research examining performance of children throughout development.

1B2. McCarthy Scales of Children's Abilities (McCarthy, 1972)

The McCarthy Scales are designed to assess a number of intellectual and motor abilities in children 2.5 to 8.5 years of age. The McCarthy General Cognitive Index, a score derived from 15 of the 18 subtests, has a .71 correlation with the Wechsler IQ. Of the 18 subtests, the following 4 will be argued to assess aspects of EF: Verbal Fluency (presented below, in section 2B2 as involving mostly mental flexibility), Block Building, Puzzle Solving, and Numerical Memory II. The latter two subtests are each analogous to subtests on the Wechsler Intelligence Scale for Children-III, which are discussed directly below as involving aspects of executive function. Therefore, Puzzle Solving and Numerical Memory II will be presented very briefly here.

McCarthy Block Building

In this task, the subject is presented with twelve 1-inch cubes and is required to copy four models constructed by the examiner. This visual-spatial copy task may serve as a very rudimentary assessment of non-verbal concept formation. Based on Case's (1985) theory, discussed briefly above, although this task may be considered less sophisticated than other working memory tasks, in young children performance of the Block Building task may require EF abilities, since it is likely still novel and non-automatic.

McCarthy Puzzle Solving

This subtest, similar to Object Assembly on the WISC-III, involves the assembly of

each of 6 sets of puzzle pieces into a whole, without the aid of visual models. The puzzles represent an animal or a food and range in difficulty from 2 to 6 pieces.

McCarthy Numerical Memory II

This subtest involves the repetition of increasingly long sequences of numbers, in reverse order, thus it is analogous to the Digits Backward portion of the Digit Span subtest on the WISC-III.

1B3. Wechsler Intelligence Scale for Children-III (WISC-III; Wechsler, 1991)

The WISC-III is a comprehensive battery designed to test the intellectual ability of children between the ages of 6 and 16 years. This battery comprises 13 subtests that are divided into two scales: the Verbal Scale and the Performance Scale. Six subtests, four from the Performance Scale (Mazes, Block Design, Object Assembly, and Picture Arrangement) and two from the Verbal Scale (Similarities, and Digit Span) will be argued to assess aspects of executive function.

WISC-III Mazes

This subtest of the WISC-III, much like the Porteus Mazes, is a measure of planning ability in which the subject must work their way through increasingly complex mazes. With a pencil, the subject begins in the centre of the maze and works toward the exit, without entering any blocked passages or crossing through walls. Despite a few minor differences between the WISC-III Mazes and the Porteus Maze Test (the WISC-III

Mazes take less time to complete, have a time limit and have an error scoring system), the level of difficulty of the two tests is considered comparable. Lezak (1995) claims that the WISC-III Mazes are an adequate substitute for the Porteus Maze Test. In addition, the WISC-III Maze Test has been found to correlate highly with the WCST and Trail Making, which are both considered traditional measures of executive function (Segalowitz, Unsal, & Dywan, 1992).

This Maze Test may be sensitive to the integrity of the frontal system (Segalowitz, Unsal, & Dywan, 1992) and has previously been used as a measure of executive function in children (Weyandt & Willis, 1994).

WISC-III Block Design

This is a visuoconstructional task that measures nonverbal concept formation ability and problem solving ability (Sattler, 1992). The subject is required to reproduce models and pictures of geometric patterns with a set of 9, two-coloured blocks and within specified time limits. Although this test is inherently highly structured, its use is thought to provide a crude assessment of the nature of a persons planning ability (Lezak, 1995).

In the absence of any impairment in the primary function of visual processing, patients with damage to the frontal lobes demonstrate difficulty on this subtest (McFie & Thompson, 1972; Shimamura, Janowsky, Squire, 1991; Sohlberg & Mateer, 1989). In patients with frontal lobe damage, performance on Block Design of the WIS (Wechsler Intelligence Scales) correlated highly with other measures of frontal lobe function, the number of categories achieved and the perseverative errors on the Wisconsin Card Sorting

Test, measures of utilization of the working memory system and mental flexibility, respectively (Horner et al., 1989). Patients with frontal damage may fail items due to impulsivity and carelessness, to difficulty abstracting resulting in random approaches to problem solving (Johanson, Gustafson, & Risberg, 1986) or to a discontinuity between intent and action (Lezak, 1995). Stuss and Benson (1984) suggested that since performance of frontal lobe patients on the Block Design test has been observed to improve when structure and partial programming were provided, deficits must be due to difficulties devising an organizational strategy (i.e., planning).

WISC-III Object Assembly

This is another visuoconstructional task requiring visual concept formation (Lezak, 1995), in which the subject must assemble 6 sets of puzzle pieces to form common objects, without the aid of visual models. This task involves abstraction, integration of isolated details into a whole and a planning/strategy component, thus requiring working memory. For example, the subject may assemble the pieces by locating boarders, grouping similar colours, or arranging colour patterns according to the picture. Object Assembly and Block Design are the two tests from the WIS that correlate most highly (Wechsler, 1991).

Frontal pathology is often involved when patients' responding is concrete and/or depends on structure. If a patient is structure dependent they may perform well on Block Design and not Object Assembly. Some patients have difficulty dealing with the abstract

designs in the Block Design and consequently do poorly (especially on the more complex items) yet are able to perform well on Object Assembly due to the concreteness of the objects in this subtest. Both of these patterns of responding can be characteristic of frontal lobe pathology (Lezak, 1995).

WISC-III Picture arrangement

In this subtest, the subject must rearrange 14 sets of cards (each set consisting of 3 to 6 panels) into an order that tells a logical story. This is a measure of nonverbal reasoning ability (Sattler, 1992) reflecting socially appropriate thinking and involving organization, sequential ordering of activities, and the ability to see relationships between events (Lezak, 1995).

McFie and Thompson (1972) suggest that Picture Arrangement is a useful additional measure of degree of impairment of the “capacity for anticipation and planning” in frontal lobe patients. They also note that although many different patient groups may perform poorly on this subtest, patients with frontal lobe damage have a tendency to leave many of the pictures in the order in which they are presented. Walsh (1987) describes this behaviour as impulsive responding based on details that first catch the eye. Alternatively, this decreased productivity could be due to dissociation between thought and action or to a planning defect (Lezak, 1995).

WISC-III Similarities

The Similarities task is a test of verbal reasoning and concept formation that

measures the subject's capacity to make abstractions and to generalize, thus involving working memory. Each item consists of the presentation a pair of words. Subjects are required to state the commonality between the words in each pair, which become increasingly difficult as the task progresses. Differences between abstract and concrete generalizations are reflected in the score recorded for each item.

In support of this measure as a tool for the assessment of EF abilities, depressed scores on the Similarities task have been associated with damage to the frontal lobes (Denckla, 1994; Lezak, 1995). In addition, during performance on the Similarities subtest of the Wechsler Adult Intelligence Scale, glucose metabolism in the frontal lobes of normal subjects is increased, indicating increased activation in the areas associated with this task (Chase et al., 1984).

WISC-III Digit Span

The Digit Span subtest involves the repetition of orally presented numerical sequences, some in the order of presentation (Digits Forward) and some in reverse order (Digits Backward). As a whole, this test requires attention, and the brief storage of information (Sattler, 1992). Digits Backward, however, requires the repetition of increasingly long sequences of orally presented digits, in reverse order. This involves brief storage and mental reorganization of the number sequences for output (Lezak, 1995; Segalowitz, Unsal, & Dywan, 1992). Thus, this portion of the Digit Span subtest can be viewed as a working memory task. Frontal lobe lesions may lower scores on reversed Digit Span (Canavan et al., 1989; McFie & Thompson, 1972; Shimamura, Janowsky, &

Squire, 1991; Stuss, Kaplan et al., 1981).

1B4. The Auditory Working Memory Task (Daneman & Carpenter, 1980)

This task involves the oral presentation of groups of 2, 3, 4, or 5 incomplete sentences. The subject is required to fill in the missing words at the end of each sentence. At the end of each series, the subject must recall the words used to complete the sentences in that series. The words used must therefore be maintained on line in the performance of the task, thus calling upon working memory (Dennis 1991).

2) Mental Flexibility

Mental flexibility involves the ability to maintain and shift responding when appropriate.

2A. Traditional EF assessment techniques with the most emphasis on the mental flexibility component of EF are fluency tasks (verbal and nonverbal) and the Wisconsin Card Sorting Test (WCST). The function of working memory also plays a significant role in the performance of these tasks and interference control is involved to a lesser degree.

2A1. Fluency tasks

Fluency tasks, verbal or non-verbal, involve mental search, the organization of information to devise a searching strategy, and the retrieval of words from semantic memory (in the absence of a visual stimuli) (Berninger & Fuller, 1992). Just as problem

solving tasks do, fluency tasks also require initiation and generation of responses and flexible thinking (Shimamura, Janowski & Squire, 1991). Verbal and non-verbal fluency tasks will be discussed.

Verbal fluency is usually measured by quantity of words generated spontaneously, within a specified category and within a time limit. This involves spontaneous flexibility, organization of thought and thus output, strategy for word search, and memory for words already listed (Estes, 1974).

One type of verbal fluency task involves generation of words beginning with a designated letter. An alternative to this format involves producing words that belong to the same semantic category. Of these two variations, the former is more abstract and provides less structure, allowing for a broader scope of strategies employed in the word search.

Findings with respect to verbal fluency performance and laterality of brain damage are controversial. Lezak (1995) claims that decreased productivity on verbal fluency tasks is associated with frontal lobe damage regardless of laterality. However, impaired performance on verbal fluency tasks involving the production of words beginning with specific letters has been observed to be most pronounced when damage is in the left frontal lobe as compared with right frontal lesions, bilateral frontal lesions (Benton, 1968), and non-frontal lesions (Fuster, 1989; Milner, 1964; Parks, Loewenstein, Dodrill, et al., 1988; Perret, 1974). Benton (1968) found that bilateral frontal damage does not lead to a more severe impairment of verbal fluency than damage to the left frontal lobe alone.

Verbal fluency performance has been localized to the dorsolateral prefrontal cortex

but not solely to this region. Warkentin, et al. (1991) found that regional cerebral blood flow increased in the left dorsolateral prefrontal cortex of healthy subjects during verbal fluency performance. However, PET scans have shown that while performing verbal fluency tasks, metabolic activation is most pronounced in the temporal and frontal lobes, bilaterally (Parks, et al., 1988). In addition, frontal patients are not selectively impaired on verbal fluency tasks involving categories (Diamond, 1991a). In spite of the conflicting information on the sole affiliation of verbal fluency tasks with the frontal lobes, the fact remains that tests of verbal fluency are associated with the dorsolateral prefrontal cortex and are commonly used to assess executive function.

Verbal fluency is hypothesized to be sensitive to frontal lobe function in children (Milner, 1964) and has previously been used as an EF task with children (Welsh et al., 1991; Weyandt & Willis, 1994). In children, adult levels of verbal fluency skills are thought not to be achieved prior to age 12 (Welsh & Pennington, 1988; Welsh et al., 1991).

Design fluency (Jones-Gotman & Milner, 1977), a nonverbal counterpart to verbal fluency, is increasing in popularity as a measure of executive functioning. Subjects are instructed to "invent drawings" that are not permitted to be recognizable objects. There are two trials: the free trial, on which the subject can use any number of lines per drawing and the fixed condition which provides a restriction of four lines per drawing. Aspects of EF that contribute to design fluency tasks are productivity, rapid variation in responses, self-monitoring, memory, use of strategy, and the scoring includes a record of the subject's perseverative responses (a measure of mental flexibility) (Lezak, 1995). The free trial of

the design fluency task has been included on frontal batteries for use with a normal and an aging population (Daigneault et al., 1988, 1992; Levin et al., 1991).

2A2. The Wisconsin Card Sorting Test (WCST; Heaton, 1981)

The WCST is a measure that is sensitive to prefrontal damage (Milner, 1963, 1964; Segalowitz, Unsal & Dywan, 1992) and, relative to other neuropsychological tests, is considered fairly specific to prefrontal damage (Milner, 1964; Weinberger et al., 1994). Therefore, it is no surprise that the WCST is the test that is most commonly associated with the functioning of the prefrontal cortex in humans (Weinberger et al., 1994). Two lines of evidence provide support for this association. Firstly, poor performance on the WCST is commonly associated with dorsolateral prefrontal lobe damage (Grattan & Eslinger, 1991). In addition, functional brain imaging studies have shown that during performance on the WCST, regional cerebral blood flow is increased bilaterally in the dorsolateral prefrontal cortex (Weinberger et al., 1994). Therefore, it appears that performance on this task involves dorsolateral prefrontal function, bilaterally.

The WCST requires the subject to sort each of 64 cards according to one of the four distinct key cards, the first displaying a red triangle, the second with two green stars, the third with three yellow crosses, and the fourth with four blue circles. The array on the cards to be sorted varies along the following three dimensions: colour, geometric form, and number of forms presented. After the placement of each card, response-contingent feedback is provided. Once the subject achieves 10 correct responses in a particular set, the examiner shifts the sorting principle without notifying the subject (Lezak, 1995;

Spreeen & Strauss, 1991).

The scoring system for the WCST provides information on several aspects of executive functioning. The most widely used scores for these purposes are the number of categories achieved, the number of perseverative errors, and the percentage of errors made after a number of correct responses (Lezak, 1995).

The number of categories achieved is the number of sets of 10 consecutively correct sorts and is considered a measure of concept formation (Chelune & Baer, 1986; Levin et al., 1991). This measure is indicative of the subject's ability to utilize the working memory system. In order to succeed on this task, the subject must remember which sorting criteria have been tried and found incorrect in order to know which criteria is, or will be, correct (Diamond, 1991a). In a factor analytic study, Daigneault, Braun et al. (1988) found that the number of categories loaded on a "planning-organization" factor.

Perseveration is the repetitive sorting according to a previously correct principle that is no longer correct or continual sorting according to an initial incorrect guess. This is an indication of mental flexibility, and use of feedback (Chelune & Baer, 1986).

Perseverative errors have been found to load on a "planning-flexibility" factor (Daigneault, Braun, et al., 1988). Heaton (1981) claims that the number of perseverative responses is the score that best predicts prefrontal dysfunction. In fact, patients with excisions to the dorsolateral prefrontal cortex, irrespective of laterality, have been observed to make more perseverative errors on the WCST than patients with excisions to other portions of the prefrontal cortex and patients with non-frontal excisions (Milner, 1963).

The percentage of errors made after a number of correct responses provides

insight into the subject's ability to maintain set. The failure to maintain a particular response set after the correct sorting principle has been achieved is a measure of susceptibility to interference and is disruptive to the working memory system. This is a common problem that is experienced by frontal lobe patients (Lezak, 1995).

Given that the WCST requires the use of representational memory (Goldman-Rakic, 1987), anticipation and planning (Weinberger et al., 1994), and flexibility of thought and action (Lezak, 1983), this task is considered to have similar demands to the delayed response tasks, with greater emphasis on the mental flexibility component of executive function. Providing supporting evidence for this association, in human adults with bilateral frontal lesions, perseveration on the WCST correlates highly with the number of errors committed on the delayed response task (Diamond & Goldman-Rakic, 1989; Freedman & Oscar-Berman, 1986).

The WCST has been used with children as well as adults (Chelune & Baer, 1986; Chelune & Thompson, 1987; Levin et al., 1991) and is hypothesized to be sensitive to frontal lobe function in children (Chelune & Thompson, 1986; Milner, 1963, 1964).

2B. The measures administered throughout the OPPS proposed to involve EF processes with maximal emphasis on mental flexibility, fairly high working memory demands and also involving interference control are: the Verbal Fluency tasks, the Category Test, and the Trail Making Test Part B.

2B1. Verbal Fluency

Two versions of verbal fluency tasks were used in the OPPS. The verbal fluency subtest on the McCarthy Scales of Children's Abilities was administered to the OPPS sample from three to seven years of age (McCarthy, 1972). This version involves the generation of as many words as possible in 20 seconds within each of the following semantic categories: things to eat, animals, things to wear, and things to ride. For the older children a phonologic version was used, in which the subject was required, over two 60 second trials, to generate words that begin with specific consonant sounds (Strong, 1963). Verbal fluency tasks are considered among the traditional measures used to assess EF and thus the involvement of EF processes in these tasks has been presented previously (in section 2A1).

2B2. The Category Test (Halstead, 1947; Reitan, 1959)

The general principle of the Category Test is the same as for the WCST, that is, to measure the subject's mental flexibility, and abstraction or concept formation ability (Spreeen & Strauss, 1991). The subject's goal in the Category Test is to ascertain the underlying principle in each of several sets of items, based on variables of size, shape, number and position. Each set of items has a predetermined sorting strategy with the exception of the last subtest, which consists of a selection of the items presented in previous subtests. On each trial, a series of four stimuli are presented on a slide projector. The subject is required to choose one of the stimuli by pressing the key that corresponds to the item chosen, with the intention of satisfying a particular sorting principle.

Following each trial, feedback is provided, indicating whether the response was correct or incorrect with the sound of a bell or a buzzer, respectively. The examiner notifies the subject of the beginning of each subtest. The total number of errors is recorded.

There are a few procedural differences between the Category Test and the WCST that warrant mentioning. Since the scoring on the Category Test only yields one composite score, the WCST, which produces a number of different measures, might be able to provide more detail with respect to the nature of a subject's difficulties (Lezak, 1995). This does not undermine the relevance of the score yielded by the Category Test. In fact, the Category Test is thought to be an equally good, if not better measure of abstraction and concept formation (Pendleton & Heaton, 1982).

While the procedure in the Category Test allows the examiner to notify the subject at the beginning of each new set, in the WCST the subject is required to determine when the principle shifts according to feedback provided by the examiner (Bond & Buchtel, 1984; Lezak, 1995). Despite this difference and the lack of a measure of perseverative tendencies, the process of the Category Test does require the ability to execute shifts in responding. Therefore, like the WCST, the Category Test can be considered a measure of mental flexibility.

Both the Category Test and WCST are similarly sensitive to the general screening of brain damage, discriminating with 69-88% accuracy (Pendleton and Heaton, 1982). In terms of more specific brain regions, the WCST is thought to be a measure that is more sensitive to frontal lobe damage than the Category Test (Heaton, 1981; Milner, 1963) and the WCST is better documented as a measure of frontal lobe function (Grattan & Eslinger,

1991). Although Halstead (1947) describes this task as being especially sensitive to frontal lobe disorders, it has been reported since that impaired performance on the Category Test is not related to location or laterality of brain damage (Bornstein, 1986; Lansdell & Donnelly, 1977; Pendleton & Heaton, 1982). In contradiction, frontal lobe patients have been reported to show impairment on the Category Test (Russell et al., 1970) as compared with patients with lesions in other brain areas (Stuss & Benson, 1984).

Despite the differences between the Category Test and the WCST, there is a strong relationship between these two measures (Shute & Huertas, 1990). In a factor analysis study, Shute & Huertas (1990) have shown that the WCST, and the Category test load on a the same unlabelled factor. The variance shared by the Category Test and the WCST are reported to fall between 12% (Donders and Kirsch, 1991) and 1/3 (Pendleton & Heaton, 1982; Perrine, 1993).

Finally, the demands of the Category Test are consistent with EF as outlined previously (Shute & Huertas, 1990), and are consistent with those of the WCST. Both tests involve selective responding, hypothesis testing, use of feedback, abstraction, ability to maintain and shift response sets which are all are all part of executive function.

In addition, the Category Test correlates strongly with the following WISC-III subtests: Block Design, Picture Arrangement, Object Assembly, and Similarities (Lansdell & Donnelly, 1977). Factor analyses have shown that the Category Test loads highly with Block Design, and Object Assembly from the WISC-III (Klonoff, 1971; Lansdell & Donnelly, 1977).

2B3. The Trail Making Test (Reitan, 1971)

This is a two part, visual conceptual and visuomotor task developed by Reitan. In Part A, the subject must connect numbers, that are randomly arranged on a page, in the proper sequential order. Part B is comprised of a random display of numbers and letters that must be connected in a sequential, yet alternating fashion (i.e., 1 to A to 2 to B, etc...). Throughout the test, the examiner points out any errors made by the subject to stimulate self-correction.

For purposes of the assessment of EF, the second part of this test is of interest. In Part B, a subject's ability to mentally sequence (which involves the ability to hold an internal representation on line in the performance of a task), to handle information simultaneously, and to flexibly alternate between conceptual realms is examined (Lezak, 1995). The alternation required may provide interference and could result in perseverative responding due to a difficulty shifting response sets (Lezak, 1995; Stuss, 1991), resulting in more errors.

Performance on the Trail Making Test is associated with frontal lobe activation. Segalowitz, Unsal, & Dywan (1992) have shown that, electrophysiologically, frontothalamic functioning, as measured by the early stages of the Contingent Negative Variation (CNV), correlates with the Trail Making Test. In addition, the Trail Making Test has strong relationships with other tests of executive function. In a factor analytic study, Shute & Huertas (1990) found that Trails, parts A and B, loaded on a distinct factor with the Category Test and the WCST. This test has also been observed to correlate highly with the WCST and the WISC-III Mazes (Segalowitz, Unsal, &

Dywan, 1992).

3) Interference Control

Interference control involves the ability to selectively attend to a situation and to inhibit impulsive responding to competing information.

3A. Tasks primarily requiring adequate control of interference that are traditionally considered among the procedures used to assess EF are the Stroop Color-Word Interference Test and Object Retrieval.

3A1. Stroop Color-Word Interference Test

This test, involving selective attention and response inhibition (Denckla, 1993; Lezak, 1995; Stuss, 1991) is a direct assessment of interference control. The original version of the Stroop test is comprised of three subtests: color naming, reading of colour names printed in black ink, and naming of ink colour when the stimuli are conflicting colour words. Word naming is more practiced relative to color naming, and therefore when the task demands require the colors to be named, more time is taken to complete the trial. Furthermore, when colour words are printed in ink of different colours, in the event that the subject is unable to inhibit the dominant response in favour of the less dominant response, word naming will interfere with the task at hand, slowing responding even more. This slowed responding is referred to as the Stroop Effect and can be attributed to poor interference control.

Evidence associating this task with frontal lobe function is conflicting. Stroop tasks are reported by some investigators as sensitive to the effects of frontal lobe damage in adults (Denckla, 1993; Pennington, 1994; Perret, 1974) and hypothesized to be sensitive to frontal function in children (Perret, 1974). However, Stuss (1991) found that patients with frontal leukotomy did not differ from controls on any of the Stroop trials.

3A2. Object Retrieval

Object retrieval is another task that is associated with the prefrontal cortex in monkeys (Diamond and Goldman-Rakic, 1985). In this task, the experimenter places an object within a clear plexiglass box that is open on only one side. The subject must detour around the box, to the open side, in order to achieve the goal of obtaining the object (Diamond, 1991a). Success on object retrieval requires mainly inhibitory control to prevent reaching directly for the object. Flexibility to generate and try a new response if necessary, planning and self-control are also involved (Diamond, 1991a; Welsh & Pennington, 1988).

3B. There are two measures from the OPPS that are considered assessors of inhibitory control with minimal, if any, demand for working memory and mental flexibility: the Delay and Vigilance subtests on the Gordon Diagnostic System.

3B1. Gordon Diagnostic System (GDS; Gordon, McClure & Post, 1983)

The GDS is a technique comprised of two subtests, the Delay task and the

Vigilance task, administered using a portable electronic unit.

The Delay subtest involves the inhibition of responding according to a Differential Reinforcement of Low Rates (DRL) behaviour schedule. The subject is required to press a button, wait six or more seconds, then press a button again for attainment of a reward. If the subject does not allow the appropriate time to elapse between button presses, no reward is given and the timer resets. The paradigm requires delayed responding to obtain rewards, thus this task involves anticipation, the use of feedback to guide responding, and most of all, impulse control (an aspect of interference control) (Dennis, 1991).

The Vigilance subtest involves the presentation of a series of digits at a rate of one per second. Two versions of this task were administered to the OPPS sample. The younger version requires the subject to press a button in response to a specified target stimulus. In the version that was used with older children, the subject responds when the target digit is immediately preceded by a particular number (when "1" is preceded by "9"). This assesses the capacity for sustained attention in the absence of reinforcement, and inhibition of responding to the irrelevant stimuli, thus providing a measure of interference control, similar to Stroop tests.

In conclusion, all of the tests selected from the OPPS, varying in content and demand, contribute to aspects of the underlying processes of EF (working memory, mental flexibility, interference control) although some to different degrees. Although some of these tasks are not yet validated measures of EF in children, given their underpinnings they are hoped to be able to provide some information in this understudied area.

Development

Adult prefrontal lobe function is far from being completely understood. Even less is known about prefrontal lobe function in the developing child (Becker, Isaac, & Hynd, 1987). In the past the assumption has been that the prefrontal lobes do not play a role in the dynamics of brain function prior to adolescence (Golden, 1981). It was believed that lesions in the frontal lobes of preadolescent children were "silent". If damage was sustained early in life, the deficits characteristic of prefrontal lobe injury were not apparent until adolescence or early adulthood (Golden, 1981). It is possible for deficits to show up fairly late in development, perhaps due to the failure of certain competencies to reach adequate levels of functioning by the expected age (Williams & Mateer, 1992).

However, two lines of evidence now point to the possibility that the prefrontal lobes of children are operational early in life: (a) neurobiological studies, and (b) the study of the development of executive functioning abilities, the behaviour that is thought to reflect prefrontal lobe functioning.

Neurobiological evidence generally indicates that the frontal lobes, including the prefrontal cortex, appear to have a protracted developmental course. In terms of structure, it appears that the frontal lobes are undergoing neuroanatomical changes from very early on in the course of development (Dennis, 1991). In fact, there is evidence that the elaborate circuitry of the frontal lobes begins to develop in the second trimester of pregnancy (Goldman-Rakic, 1987a). Axons in the frontal lobes are undergoing the process of myelination from the sixth month of life, extending into the third decade of life (Yakovlev & Lecours, 1967). Other markers of structural development, such as cortical

thickening, cortical fissuration, morphological differentiation (i.e., cell differentiation, and division of the cortex into layers), neuronal density, and axonal connectivity indicate that development in the frontal region of the brain is slow relative to other brain areas, and continues to develop beyond childhood (Smith, Kates & Vriezen, 1992). Two markers of functional activity, synaptogenesis, and regional cerebral blood flow, are evident early in the development of the prefrontal lobes (Welsh & Pennington, 1988). As well, positron emission tomography images have evidenced increased glucose utilization in the frontal cortex, reflecting increased activation, by 8 or 9 months of age in human infants (Chugani & Phelps, 1986).

Based on the above neurobiological factors, the development of the prefrontal lobes begins early in life and extends into adulthood. It seems reasonable to assume that the development of this brain region would correspond with the emergence and maturation of the cognitive abilities that are purported to be mediated by the prefrontal lobes. Therefore, in addition to the examination of the structural and functional maturation of the frontal lobes, it is important to consider the developmental course of the behaviour that is suspected to be reflective of prefrontal lobe function, that is, executive function. There is evidence to suggest that executive functioning abilities may emerge prior to adolescence and that some may even be present in infant behaviour.

Traditionally, adult neuropsychology and the use of neurobehavioural tests that are purported to be sensitive to prefrontal lobe functioning in adults have been the guiding force in the study of the developmental course of prefrontal lobe function in children (Dennis, 1991; Smith, Kates & Vriezen, 1992; Welsh & Pennington, 1988). The

following two reasons for why this is the case will be discussed: (a) children with focal frontal lesions that are available for comprehensive cognitive examination are limited in number (Smith, Kates & Vriezen, 1992), and (b) the availability of age-appropriate measures designed specifically for assessing prefrontal functions in children is also limited (Grattan & Eslinger, 1991).

Firstly, although the consequences of frontal lobe injury in children remain largely ambiguous, it appears that damage of this type puts children at risk for developing EF difficulties (Dennis, 1991). Children with frontal damage after closed head injury have been observed to perform poorly on tests of concept formation, flexibility, and planning as compared with the performance of those who sustained closed head injury without damage to the frontal lobes (Evankovich, Levin, Mattson, Fletcher, & Ewing-Cobbs, 1990). Grattan & Eslinger (1991) suggest the possibility that the behavioural sequelae resulting from prefrontal lobe damage may be observable as early as 8 years of age.

With respect to psychometric tools, the developmental measures that are available are not traditionally considered measures of EF, and the traditional measures of EF are designed for use with adults. Essentially, adult measures have been used to index prefrontal function in children (Chelune & Baer, 1986). However, tests designed for adults may make different demands on children, measuring different functions, and are therefore, not always adequate for use with children (Spreeen & Strauss, 1991).

Nevertheless, modifications of tests designed to assess adult prefrontal lobe function have been used with children (e.g., WCST; Diamond and Boyer, 1989) and norms for children have been established for some tests that are used to assess prefrontal functioning in adults

(Chelune & Baer, 1986). Although use of tests specifically designed for children is preferable, few such tests are available in the realm of executive function. Despite the difficulties posed by this issue, use of measures designed for adults has contributed to the understanding of EF behaviour in children.

Limited study of childhood cases with focal damage to the prefrontal lobes, and an interest in understanding the development of normal brain function have prompted the administration of measures of purported prefrontal lobe functioning to normal infants and children. The following is a review of the empirical studies that have been conducted regarding the development of EF in normal children.

Diamond & Goldman-Rakic (1989) noted that human infants, at 7.5 to 9 months of age were still committing the AB error on Piaget's AB task at delays of 2 to 5 seconds (i.e., in search for the reward they were still uncovering the previously reinforced food well). It was not until 12 months of age that errorless performance on the AB task was achieved. Similarly, on the object retrieval task, human infants at 6.5 to 7 months only reached for the concealed object along the direct path of vision. By 11 to 12 months of age, children were able to inhibit or flexibly modify reaching behaviour that is guided by visual information, in favour of the path which led to the object (Diamond, 1991a, 1991b). Therefore, evidenced by the performance of human infants on these two tasks, there appears to be some form of executive behaviour observable by 12 months of age. Although these skills in EF may be less complex than at later stages, some form of working memory function, flexible responding, and inhibition of inappropriate responding appear to be present in infancy.

Passler, Isaac, and Hynd (1985) examined mental flexibility and interference control in normal children between the ages of 6 and 12 years. A number of tasks, ranging in difficulty, and assessing perseveratory responding, and the ability to inhibit irrelevant stimuli were employed. The greatest period of development was observed to occur between 6 and 8 years of age, and by 12 years of age mastery of these skills was evident. The results obtained from this study are suggestive of multistage development of these behaviours. In general, selective attention, inhibition of attention to irrelevant stimuli, and perseverative responding appear to improve with increasing age.

Becker, Isaac, and Hynd (1987) examined temporal ordering and interference control in the face of simultaneously presented information in a group of 6 to 12 year old children with average intelligence. Performance on all of the tasks, ranging in stimulus modality and in difficulty, is attributed to prefrontal lobe functioning. The most significant period of development in the performance of this type of behaviour occurred between 6 and 8 years of age although, by age 12 some of the more complex tests were still not mastered. Consistent with the study by Passler et al. (1985), these results suggest a stepwise developmental emergence of EF processes which extends into adolescence. In addition, Becker et al. (1987) observed that children under 8 years of age were able to verbalize the correct responses yet often still had difficulty correctly responding. This type of dissociation between intent and action is characteristic of adults with prefrontal lobe damage, (Lezak, 1995; Stuss & Benson, 1987), and in this sample was most likely due to a young child's inability to inhibit inappropriate behaviour.

Chelune and Baer (1986) found that the performance of normal children on the

WCST, the most traditional measure of EF, advanced most significantly between the ages of 6 and 10 years. Improvement in the number of categories achieved (reflective of the ability to use feedback in the development of problem solving strategies) and the ability to maintain set (reflective of the ability to control interference), and decreases in the number of perseverative errors (reflective of the ability to maintain and shift responding) occurred with increasing age. By 10 or 12 years of age, these children displayed adult levels of competence in the performance of this task. These results are consistent with those obtained by Passler et al. (1985) and Becker et al. (1987).

Levin et al. (1991) assessed developmental changes in performance on a series of eight tasks that are associated with prefrontal lobe function, including some traditional measures of executive function. Developmental changes were observed on all of the tasks that were administered to a small sample of normal children between 7 and 15 years of age. Consistent with the findings of other researchers, gains in concept formation, the capacity to shift set, and inhibitory control were demonstrated by 12 years of age. However, changes in planning and strategizing behaviour, and increases in spontaneous flexibility were found to be more significant during adolescence than at younger ages. Although the other studies reviewed only investigated EF behaviour in children up to age 12, most of the results obtained are suggestive of further development of some executive function skills, beyond 12 years of age.

Finally, upon examination of the performance of normal children between the ages of 3 and 12 years of age on a battery of EF tasks (including Verbal Fluency, the WCST, the TOH, and other tasks), Welsh, Pennington, and Groisser (1991) observed a particular

developmental pattern in the emergence of EF skills. Adult levels of performance were attained in three different stages, depending on the specific demands of the task. At 6 years of age, children exhibited visual search and simple planning behaviour comparable to adults. By age 10, maturation of the ability to maintain set was complete. By adolescence, complex planning, motor sequencing and verbal fluency were performed with adult levels of competency.

All of the above evidence is converging in support of the notion that prefrontal skills begin to emerge earlier in development than was previously thought (i.e., prior to puberty). The development of EF processes appears to occur as a multistage process, with adult-levels of function emerging throughout childhood until adolescence and depending on the demands and the complexity of the task (Becker et al., 1988; Passler et al., 1985; Welsh et al., 1991; Weyandt & Willis, 1994). Between 8 and 12 months of age, it has been noted that inhibitory control and relational abilities (such as dealing with information simultaneously, and relating information spatially or temporally) which are dependent on the prefrontal cortex are beginning to emerge in infant behaviour (Diamond, 1991b). A couple of studies suggest that the demonstration of executive functioning abilities in more complex tasks occurs in three stages (Passler et al., 1985; Welsh et al., 1991). From 6 to 8 years of age, the greatest period of development of executive skills, children begin to demonstrate organization and simple planning behaviour. The next stage occurs at age 10, when set maintenance, hypothesis testing, and impulse control become part of the child's repertoire of functions. Finally, by adolescence children are capable of adult levels of executive functioning, including competencies such as complex planning,

motor sequencing, and verbal fluency.

As mentioned previously, the prefrontal cortex can be partitioned into three structural regions, the dorsolateral, orbitomedial and orbital (or basal) prefrontal cortices. In terms of development, evidence in the literature suggests that the orbital region of the prefrontal cortex matures earlier than the dorsolateral region (Goldman, 1971; Yakovlev, 1962). It has been suggested that the differential timing for the maturation of the subdivisions of the prefrontal cortex (i.e., orbital before dorsolateral) may be related to the developmental timing of the behavioural correlates of the prefrontal cortex (Stuss, 1992). If this is the case, then it would be possible for the component processes of EF to demonstrate a similar pattern of emergence. However, the descriptions in the previous paragraph of the developmental emergence of cognitive competencies attributed to the prefrontal lobes are not in correspondence with the documented functional significance of the subregions of the prefrontal cortex (outlined on page 2). In addition, there is a lack of clarity in the literature, thus some uncertainty, with respect to the functional significance of the subdivisions of the prefrontal cortex.

Gender

Based on performance on behavioural tasks, there are sex differences in certain neuropsychological abilities that arise in development. Given that EF can be operationalized within a variety of domains of function, gender differences within these underlying domains is an issue of importance. Although some differences in function do appear to be sex-related, the distribution of scores in the performance of most tasks

between the sexes overlaps a great deal (Spree, Risser & Edgell, 1995), and that individual differences within the sexes are often more pronounced (Burstein, Bank, & Jarvik, 1980; Lezak, 1995). In addition, the literature available on the subject of gender differences in function is replete with inconsistencies. However, in terms of cognitive ability, the sex differences that are most frequently observed are in the domains of verbal and spatial functioning.

Gender differences indicating female superiority in verbal ability are generally regarded as fairly well-established (Hyde & Linn, 1988). However, the magnitude of many of these differences is extremely small (Hyde & Linn, 1988; Maccoby and Jacklin, 1974), very little is known about the types of verbal abilities that show gender differences and the timing of the emergence of these differences (Hyde & Linn, 1988). In addition, the documentation on sex differences with respect to verbal ability is not consistent. Many studies have found that girls tend to achieve higher scores than boys on tests of verbal ability prior to age 8 and again throughout adolescence (Burstein et al., 1980; Townes, Martin, Trupin & Goldstein, 1980). In their review of gender differences, Maccoby and Jacklin (1974) concluded that female superiority in verbal ability does not arise before 11 years of age. A meta-analysis combining 165 studies on many different test of verbal skills, on subjects from 2 to 64 years of age, indicated that 27% show female superiority, 6% suggest male superiority, and 66% of studies resulted in no significant differences between the sexes on verbal ability (Hyde & Linn, 1988).

With respect to spatial abilities, generally boys tend to outperform girls on a wide range of visuospatial tasks (Lezak, 1995). This difference is thought by some not to arise

until 5 or 6 years of age and to continue through to adolescence (Kirk, 1992; McGee, 1979; Townes, Martin, Trupin, & Goldstein, 1980). However, other researchers claim that a difference between the sexes on achievement level on spatial tasks does not occur until adolescence (Maccoby & Jacklin, 1974; Karnovsky, 1974).

The present study

Most of the work that has been conducted in the area of EF has been carried out with adults. Thus, there is little information available at present on executive functioning in children (Weyandt & Willis, 1994). As discussed earlier, the research available suggests that the biological and psychological development of the prefrontal cortex has a developmentally protracted course, extending beyond childhood. As is evident from the research presented in the previous section, EF, which is reflective of prefrontal functioning, can be detected early on in development when developmentally appropriate tasks are used.

Two shortcomings of the studies that are available on the development of EF are as follows. Firstly, investigators who have studied EF in children have mainly been concerned with when in development prefrontal functioning, as measured by performance on tasks designed for adults, reaches adult levels (Dennis, 1991). In addition, the existing developmental studies on EF, limited in number as they are, have been carried out cross-sectionally rather than longitudinally. Although this method of research may be more practical, due to time constraints and the difficulty of follow-up procedures, longitudinal analyses permit more detailed developmental analysis than cross-sectional methods. The

advantages of a longitudinal design include the requirement of fewer subjects given that the same subjects are assessed repeatedly. In addition, each subject acts as his/her own control, eliminating the problem of the influence of between subject differences on the outcomes which is of concern in a cross-sectional design.

The Ottawa Prenatal Prospective Study offers a unique opportunity to explore the development of aspects of EF in a sample of children, who have been followed longitudinally from birth to 12 years of age. This will allow an examination of the development of executive functioning abilities throughout childhood that, simply, would not be possible in a cross-sectional study. In addition, the measures selected from the OPPS, although not all considered traditional measures of EF, are developmentally appropriate for use with children at the age(s) at which they were administered throughout the OPPS.

Generally, the focus in this study will be on individual differences and change in EF behaviour over time in a sub-sample of the subjects from the OPPS. Stability in the performance across age on the tasks selected from the OPPS for their involvement in EF will be investigated. Stability refers to the maintenance of individual differences among a group of individuals over time. When individuals maintain their relative position with respect to others on a particular dimension over time, there is stability on that dimension (Als, Duffy, McAnulty, & Badian, 1989; Bornstein, 1989; Kagan, 1980; Uzgis, 1989). This means, for example, that those who perform well on a particular dimension at time 1 will be expected to perform well on the same dimension at time 2 (Bornstein, 1989). The present study proposes to inquire whether performance on each of the three types of EF

tasks (tasks emphasizing working memory, mental flexibility, or interference control) administered to the OPPS sample is consistent throughout childhood, from 3 to 12 years of age. Is there stability of individual differences in early executive function?

Typically, stability of individual differences is assessed by computing cross-age correlations. However, application of this statistical technique does not reveal whether there is developmental change on the relevant dimension. That is, even with high cross-age correlations, there can be marked changes in the level of performance on the dimension. Therefore, achieving high correlational stability does not imply any particular shape to the developmental function. The exploration of developmental profiles of performance on the different types of EF tasks is a separate and equally important matter.

The concept of continuity/discontinuity refers to the rate of change on a dimension that occurs with development (Kagan, 1980; Uzgis, 1989). Growth on a dimension can be considered either continuous or discontinuous. If change with age is incremental, gradual, and linear, the growth function can be described as continuous and if there are plateaus and changes occur in spurts (i.e., deviations from linearity), growth is assumed to be discontinuous (Uzgis, 1989). The examination of continuity, thus involves the examination of the shape of developmental profiles and encourages the exploration of the nature of developmental changes that occur on the dimension at hand (Uzgis, 1989).

This study proposes to explore the continuity of EF by examining the patterns of change in the developmental functions for the three types of EF tasks throughout childhood. The fact that EF is described by most researchers as a non-unitary domain raises the question of whether the development of EF function behaviour throughout

childhood is a unitary process. Do different aspects of this construct develop at different rates or demonstrate different patterns of development? To assess this issue, the developmental profiles revealed for each of the three types of EF measures will be examined and compared to determine whether the developmental shifts in performance are the same for tasks that appear to be predicated upon working memory, mental flexibility, or interference control.

Using adult measures, there is evidence of change in EF behaviour occurring mostly between 6 and 10 years of age. It has been proposed that, although the maturation of the cognitive systems of the prefrontal cortex appears gradual, the emergence of behaviour attributed to the prefrontal cortex may not represent a constant and uniform progression, but a process that is characterized by identifiable phases of functional development (Grattan and Eslinger, 1991). It is expected that this study will reveal nonuniform changes throughout development in aspects of executive function behaviour. In addition, given that EF is described by researchers as a non-unitary domain it is hypothesized that scores on tasks emphasizing different components of EF may reflect different patterns of change throughout development.

In summary, the principal objectives of this investigation are twofold. The observations in this study will attempt to determine whether there is stability of individual differences in each of the three types of EF tasks. Even if stability is obtained, the possibility that there is change in EF behaviour throughout development is likely. To assess this possibility developmental function(s) for each of the three types of EF tasks must be examined. The growth functions obtained for the three types of EF tasks will be

compared to determine whether developmental change in EF behaviour throughout childhood should be considered unitary or non-unitary.

II. METHODS

Subjects

The subjects included in the present study were selected from the large sample of participants in the Ottawa Prenatal Prospective Study (OPPS) and represent a predominantly middle-class, low risk population. Ongoing since 1978, the OPPS began with 698 pregnant volunteers who learned of the study from their physicians or from notices in waiting rooms. At this time, subjects were notified of the main objective of the study: to examine the effects of life-style habits during pregnancy on the developing child. Upon entry into the study, interviews conducted once during each trimester of pregnancy allowed for the reliable collection of extensive information regarding demographics and life-style habits.

The prenatal interviews provided information on the following variables: socioeconomic status (SES; i.e., income and education), health status and health history of both the mother and father, obstetrical history of previous pregnancies, a dietary recall for the 24 hours preceding the interview, and patterns of drug use (focusing primarily on marijuana use, cigarette smoking, and alcohol consumption) prior to, and during pregnancy. Further detail regarding the interviews conducted during pregnancy have been described previously (Fried et al., 1980).

Approximately 165 offspring of the original participants in the OPPS have been included in follow-up procedures. The remainder were excluded for a number of practical reasons. For example, budget constraints led to limiting the number of follow-up subjects and some subjects have moved out of the Ottawa area.

After birth, the children in the follow-up cohort were assessed at least annually until seven years of age, and once thereafter between 10 and 12 years of age, on a variety of age appropriate measures. Testing throughout the OPPS has included standardized global measures, and more specific neuropsychological assessment techniques designed to measure aspects of functioning within the domains of language, memory, visual/perceptual function, and sustained attention. All testing sessions throughout the OPPS were conducted at Carleton University, by the same trained examiner who was unaware of the children's maternal drug history.

The present study is a longitudinal analysis requiring as many data points per subject between the ages of three and 12 years as possible. The criteria for inclusion of subjects from the OPPS in the analyses of this study are as follows: subjects must have been tested on the McCarthy Scales at 3 and 4 years of age, on the neuropsychological battery administered at the next three testing times, 5, 6, and 7 years of age, and once between 10 and 12 years of age. Due to the nature of the analyses (i.e., the examination of the issue of longitudinal stability and continuity) subjects missing data on any of the executive function variables in these test batteries were excluded from the sample.

Fifty three subjects, 33 boys and 20 girls, satisfied the criteria for inclusion and contributed data to this study. The mean chronological age (and SD) and age range of the subjects at each of the times of test administration are presented in Table 2. The sample characteristics for the 53 children included in this study are presented in Table 3. One subject is identified as taking medication for Attention Deficit Disorder.

Tables 2 and 3 about here

As previously mentioned, this sample was drawn from the larger sample of the OPPS. One of the original objectives of the OPPS was to assess the effects of the life-style habits of mothers during pregnancy on the postnatal development of their children. Included in the life-style habits that were assessed was the use of drugs such as marijuana, nicotine and alcohol. As displayed in Table 3, of the current sample 30%, 49% and 92% of children were prenatally exposed to marijuana, nicotine and alcohol, respectively. There are no data available to report the prevalence of drug use by pregnant women in the general population at the time when the OPPS data was collected (i.e., the late 1970s and early 1980s). However, according to the data available, in 1993 the annual prevalence of drug use in women of child bearing age (19 to 32 years) was 20.6%, 35.8% and 85.1% for marijuana, nicotine and alcohol, respectively (NIDA, 1994). It is important to note that these figures from 1993 represent women who were, and those who were not pregnant at the time surveyed. On the other hand, since the 1980s, use of these drugs by women has decreased and therefore, it is possible that the 1993 figures provide a conservative estimate, compared to the early 1980s.

It is evident that the percentages of babies exposed to drugs before birth in the present sample are elevated in comparison with the general population. Given that the effect of prenatal drug exposure is not a focus of the present paper, certain means were taken to ensure that any results obtained were not unduly influenced by this over sampling.

Table 2: Age Levels at Each Test Administration

	Age levels in months								
		36 (N=53)	48 (N=53)	60 (N=53)	72 (N=53)	84 (N=53)	120-144 (N=53)		
							120 (N=25)	132 (N=16)	144 (N=12)
Actual Age (in months)	M SD	36.05 .22	48.45 .89	60.35 .99	72.35 1.27	83.85 .49	122.20 1.73	131.31 3.00	141.58 2.91
Age Range (in months)		34-38	47-53	59-63	71-76	83-87	120-125	127-138	139-149

N=Number of subjects

M=Mean

SD=Standard deviation

Table 3: Sample Characteristics

Mother's age at child's birth (in years), M (SD), range		28.53 (4.63), 19-37
Father's age at child's birth (in years), M (SD), range		30.74 (6.06), 20-57
Mother's Educational Rating*, M (mode)		2.60 (3)
Father's Educational Rating*, M (mode)		2.89 (3)
Family Income (\$CDN), M (SD), range		\$29 567.83 (\$16 767.01), \$5472-\$80000
Parity, M (mode)		2.03 (2)
Gender	Males, N	33
	Females, N	20
Language of home	English, N	53
	French, N	0
Language of school program	English, N	32
	French, N	2
	Bilingual, N	19
Prenatal exposure to nicotine (≥ 0.1 mg. Nicotine/day)**, percentage		49%
Prenatal exposure to alcohol (≥ 0.1 oz. AA/day)**, percentage		92%
Prenatal exposure to marijuana (≥ 1 joint/week)**, percentage		30%

* Educational Ratings: 0=No Education, 1=Some Highschool, 2=Highschool Graduate, 3=University/College Graduate, 4=Postgraduate Degree

** Maternal use during pregnancy - any trimester with data

The specific measures taken to deal with the over representation of women who exposed their babies to marijuana, nicotine and alcohol during pregnancy are outlined below, in the statistical analysis section.

Test Instruments

For the most part the assessment procedures included in the present study were selected from the numerous measures administered at various stages throughout the OPPS on the basis of their proposed involvement in executive function (EF) processes. All tasks of EF contain underlying abilities in other domains (e.g., language, spatial). Therefore, a few discriminant measures, i.e., non-executive function (non-EF) tasks, were included for purposes of comparison with the EF tasks in order to isolate the EF components of the tasks. A summary of all the selected measures, and the ages at which they were administered is presented in Table 4. For a number of the tests chosen, several scores were recorded. However, only the outcome variables deemed useful for the purposes of this paper will be discussed. Norm references and the relevant scores yielded for each of the measures are presented in Table 5.

Tables 4 and 5 about here

A description of the discriminant measures will follow. Each of the EF measures included in this study is discussed thoroughly in the introductory section of this paper,

Table 4: Summary of Test Administration

Age in months	Age in years	Tests Administered
36	3	McCarthy
48	4	McCarthy, PPVT
60	5	McCarthy, PPVT, WRAT-R, Category Test*, GDS
72	6	McCarthy, PPVT, WRAT-R, Category Test*, GDS
84	7	McCarthy, PPVT, WRAT-R, Category Test*, GDS
120-144	10-12	WISC-III, PPVT, WRAT-R, the Category Test**, GDS, the Trail Making Test, Phonological Verbal Fluency, the Auditory Working Memory Test

* 5 category version of the Category Test

** 6 category version of the Category Test

McCarthy=McCarthy Scales of Children's Abilities (McCarthy, 1972)

PPVT=Peabody Picture Vocabulary Test (Dunn & Dunn, 1981)

WRAT-R=Wide Range Achievement Test-Revised (Jastak & Wilkinson, 1984)

GDS=Gordon Diagnostic System (Gordon, McClure, & Post, 1983)

WISC-III= Wechsler Intelligence Scales for Children-III (Wechsler, 1991)

Table 5: Test Instruments: Scores recorded and norm references

Test		Score(s) recorded	Norm reference
McCarthy Scales of Children's Abilities		detailed scoring system provided in the manual (McCarthy, 1972)	McCarthy (1972)
Peabody Picture Vocabulary Test		# of correct responses*	Dunn & Dunn (1981)
Wide Range Achievement Test-Revised, Spelling Subtest		# of words correctly spelled	Jastak & Wilkinson (1984)
Category Test		# of errors	Knights & Norwood (1980)
Gordon Diagnostic System	Delay Task**	# of rewards efficiency ratio (# of rewards/ # of responses)	Gordon & Mettelman (1986)
	Vigilance Task***	# of errors of omission # of errors of commission	
Wechsler Intelligence Scale for Children-III		detailed scoring system is provided in the manual (Wechsler, 1991)	Wechsler (1991)
Trail Making Test		time to completion # of errors	Reitan (1971)
Phonologic Verbal Fluency Task		mean # of correct words****	Knights & Norwood (1980)
Auditory Working Memory Task		# of words recalled correctly	Siegel & Ryan (1989)

* The # of errors is subtracted from the ceiling item to obtain the # of correct responses. The ceiling item is identified as the lowest 8 consecutive responses containing 6 errors.

** each score is obtained by summing over 4, 2-minute blocks

*** each score is obtained by summing three 3, 3-minute trials

**** averaged over 2, 60-second trials

therefore, only information pertaining to the administration of the EF tasks not previously mentioned will be discussed in this section.

The Peabody Picture Vocabulary Test-Revised (PPVT-R), Numerical Memory I of the McCarthy Scales (forward digits), the Digits Forward portion of the WISC-III Digit Span task and the Trail Making Test Part A have been included in the present study as discriminant measures, i.e., assessment tools unrelated to the construct of executive function. None of these tasks meet the criteria of EF abilities outlined previously and in the literature they are not reported as being related to prefrontal lobe function or executive function.

The PPVT-R is an achievement test that measures receptive vocabulary (Dunn & Dunn, 1981). This task, designed for children from 2 to 18 years of age, is comprised of 175 plates, each containing 4 pictures. The subject is presented with a stimulus word, either orally or printed, and is required to identify the corresponding picture on the plate that is showing. The score that is recorded is the sum of the items passed (Table 5).

The PPVT-R has previously been used as a discriminant measure in the study of the development executive function (Chelune & Baer, 1986; Weyandt & Willis, 1994). The likelihood of floor and ceiling effects in the performance of this task are minimal due to the wide range of difficulty covered, rendering this task well suited for use in longitudinal research. In the present study the PPVT-R was administered to the sample yearly between 4 and 7 years of age, and then once between the age of 10 and 12 years.

Both the Numerical Memory I (forward digits) subtest of the McCarthy Scales (McCarthy, 1972) and the Digits Forward portion of the WISC-III Digit Span task

(Wechsler, 1991) involve the repetition of increasingly long series' of digits in the order of presentation. The McCarthy Scales for Children's Abilities (pg. 21) was administered to the children in the OPPS yearly from the age of three to seven years. The Wechsler Intelligence Scales for Children-III (pg. 22) was administered to the children in the OPPS once between ten and 12 years of age. Scoring details for each of the subtests is outlined in the test manual (Wechsler, 1991).

Part A of the Trail Making Test (pg. 36) is visual motor tracking task, involving the connection of circles in numerical sequence (Reitan, 1971). The scores recorded are the number of errors and the time to completion, the same as for the EF portion of this task, Part B. The Trail Making Test was administered once between the ages of ten and 12 years.

Two versions of the Category Test (pg. 33) were used throughout the OPPS study. At 5, 6, and 7 years of age the children were administered a version of this task in which there were a total of five categories. Between the ages of 10 and 12 years, these children were tested once on an intermediate version of the Category Test. Six categories were used in this version.

The Gordon Diagnostic System (pg. 38) and the WRAT-R Spelling test (pg. 19) were administered to the OPPS sample yearly from the ages of five to seven years inclusive, and once between ten and 12 years of age. At five years of age the children received a simpler version of the Vigilance Task of the GDS than at older ages. Both versions are described under the subheading 3B2 in the introductory section of this paper. The measure that was analysed on the GDS Delay task was the efficiency ratio (# rewards

/ # responses) which is a reflection of impulsivity on responding. However, it is possible to obtain a reasonable efficiency ratio with receipt of only a few rewards. Therefore, the means for the number of rewards were consulted and included in Tables 7 and 8 to confirm the magnitude of the number of rewards that contributed to the calculation of the efficiency ratio at each age tested.

The phonologic Verbal Fluency Task (Strong, 1963) (pg. 33), and the Auditory Working Memory Task (pg. 27) were administered once between the ages of ten and 12 years.

Statistical Analyses

All of the measures collected from the tests administered to the OPPS sample, described previously, constitute the outcome variables. Preliminary univariate descriptive statistics were conducted on each of the outcome variables to identify outliers, to verify that there was no missing data, and to examine the distribution of scores.

One of the main purposes of this study was to examine the issue of cross-age stability of individual differences between three and 12 years of age in the performance of tasks that involve executive function. To specify whether there is stability in EF behaviour over time, a cross-age correlational approach was adopted. Pearson product moment correlations were computed between all of the ages of test administration for EF and non-EF measures administered repeatedly throughout the OPPS to examine the relationship between scores achieved on the same task across time. Therefore, only certain measures within specific age ranges were able to contribute data for the analysis of longitudinal

stability: the PPVT (4 to 10-12 years), the McCarthy subtests (3 to 7 years of age), the WRAT-R spelling subtest (5 to 10-12 years), the Category Test (5 to 7 years), and the GDS (5 to 10-12 years).

The correlation coefficients reflect the consistency or inconsistency of individual differences in development on the measures of interest over time. However, the correlation coefficient is independent of the means of the distributions involved in its calculation. Therefore, even when high cross-age stability is achieved, indicating consistency of individual differences in behaviour throughout childhood, this does not imply that behaviour is unchanging.

In order to explore developmental change in EF behaviour, the developmental functions for the different outcome measures must be examined. A developmental function is a growth curve that indicates a pattern of change on a measure of group performance (e.g., mean) on a task, across time. To obtain a developmental pattern, the variability of scores across age must be retained. Therefore, analyses were computed using raw scores. The variety of EF tasks administered in the OPPS have for the most part disparate scales of measurement. Since the raw scores on different tests are not necessarily comparable, looking at change in performance over time involved comparing scores collected on the same task administered at different times. Therefore, to examine the developmental change in EF behaviour, the focus was on those measures that were administered repeatedly throughout the OPPS.

The continuity/discontinuity in the development of executive functioning abilities was examined over time for boys and girls. Mixed design repeated measures ANOVAs

were computed separately for performance on each of the tasks that were administered repeatedly in this study (the PPVT-R, WRAT-R Spelling subtest, the subtests of the McCarthy Scales, the Category Test and the GDS Delay and Vigilance tasks). The scores recorded for each of the tasks were the dependent variables. The independent variables were age (the within groups factor) and gender (the between groups factor).

A number of the tasks included in this study were administered to the sample once between the ages of 10 and 12 years (the PPVT-R, the WRAT-R Spelling subtest, the GDS, the WISC-III subtests, the Auditory Working Memory Task, the phonological Verbal Fluency task, and the Trail Making Test). In order to maximize the contribution of the data collected between 10 and 12 years of age to the analysis of longitudinal continuity, a cross-sectional approach was adopted with these variables within this age range. In this part of the analysis the whole sample was divided according to when these tests were administered: at 10, 11 or 12 years of age. Between groups ANOVAs were computed for each of these variables with age and gender as the two between groups independent variables.

Additional ANOVAs were conducted with some of the data, linking EF and non-EF tasks with similar demands and commensurate scales of measurement for purposes of comparison between these two types of tasks. A two-factor within-subjects design was employed when analysing the performance over time on forward digits (a non-EF task) and reverse digits (an EF task) from Numerical Memory of the McCarthy Scales. Age and digit span (2 levels; forward and reverse) were the two within groups variables. In a three-factor mixed design, the Digits Forward and Digits Backward portions of the Digit

Span subtest of the WISC-III were treated as the two levels of a repeated measures factor. Age and gender were the two between groups factors. Finally, a two-factor mixed design was adopted to combine Parts A and B of the Trail Making Test. The number of errors and the time recorded were considered separately, each as a repeated measures factor with 2 levels (Part A and Part B). Age (3 levels; 10, 11 and 12 years of age) served as the between groups independent variable in both of these analyses.

Post hoc analysis for all ANOVAs consisted of trend analysis to explore patterns of development over time. Additional follow-up procedures to further explain any findings included the analysis of the simple main effects in the case of a significant interaction or specific contrasts between levels of a factor in the case of a significant main effect.

Violations of the assumptions of homogeneity of variance and sphericity were addressed in any analysis containing a repeated measures factor. All analyses were two-tailed with alpha set at .05.

With respect to the characteristics of the sample, the preponderance of subjects who were prenatally exposed to drugs could potentially confound the results of the present study. In order to maximize the generalizability of the results obtained to the general population it was necessary to assess whether the increased percentage of subjects in this sample who were exposed prenatally to drugs influenced the results of the analyses.

In consideration of this issue, correlations were computed to examine the relationship between prenatal exposure to marijuana, nicotine and/or alcohol and the

outcome variables (i.e., scores collected on the tasks). A subgroup of eight subjects who were exposed to marijuana, nicotine and/or alcohol were then removed from the sample. Although this resulted in slightly fewer subjects, the reduced sample (N=45) was more representative of the general population than the original sample. With this reduced sample, all of the stability and continuity analyses described above were recomputed for the outcome variables that were significantly correlated with any of the drug variables. The results obtained with the two samples were examined and compared to ascertain whether the over sampling of drug exposed children had an effect on the findings. A more detailed discussion of this procedure is covered in the Results section of this paper.

III. RESULTS

Descriptive Data

The means and standard deviations for the standardized IQ scores, assessed at each test administration, are listed for the entire sample and separately for males and females in Tables 6a, 6b and 6c. Means and standard deviations for the raw scores on executive function (EF) and non-executive function (non-EF) measures, collected at all ages of testing are presented in Tables 7 and 8. Higher raw scores are indicative of better performance on all measures except for those in which the number of errors or the time taken to complete the task is recorded. A decrease in the number of errors of omission or errors of commission on the Vigilance subtest of the Gordon Diagnostic System, in the total number of errors on the Category Test or in the time to completion of the Trail Making Test demonstrate improved performance on their respective tasks.

Tables 6a, 6b, 6c, 7 and 8 about here

Outliers were identified as cases with a standardized score on a variable exceeding ± 3.00 (Tabachnick & Fidell, 1989). To reduce the influence of outlying scores on the results, the raw score for an outlier was adjusted to one unit larger or smaller than the next most extreme value in the distribution for that variable (Tabachnick & Fidell, 1989). A detailed record of the outlying scores and the adjustments that were made is presented in Appendix A.

Due to the specific criteria for inclusion of subjects into the analyses (outlined in

Intelligence Measures		Age in years																	
		3			4			5			6			7			10-12		
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD		
McCarthy Scales of Children's Abilities	Verbal Scale	60.47	10.07	63.23	10.37	61.89	10.53	61.91	8.96	63.83	7.28	--	--						
	Perceptual Performance Scale	58.51	9.01	62.57	8.14	60.70	6.81	65.00	7.70	64.91	8.16	--	--						
	Quantitative Scale	56.87	8.98	59.40	8.64	60.04	7.88	57.49	8.61	59.45	8.30	--	--						
	General Cognitive Scale	116.25	13.50	122.66	15.61	120.40	13.19	123.60	14.08	126.21	12.92	--	--						
	Memory Scale	60.02	7.90	59.06	9.55	60.72	8.85	58.74	7.84	59.81	7.02	--	--						
	Motor Scale	54.43	9.31	52.00	9.44	54.51	7.34	58.72	7.91	61.81	9.32	--	--						
Wechsler Intelligence Scales for Children-III	Verbal IQ	--	--	--	--	--	--	--	--	--	--	110.74	12.96						
	Performance IQ	--	--	--	--	--	--	--	--	--	--	111.72	12.99						
	Full Scale IQ	--	--	--	--	--	--	--	--	--	--	112.13	12.18						

—

Means and Standard Deviations for Assessments of IQ (Females - N=20)

[illegible]

Table 7
Means and Standard Deviations for Executive Function (EF) and Non-executive Function (non-EF) Measures (raw scores)

EF and non-EF Tasks		Age in years																	
		3			4			5			6			7			10-12		
		M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD		
PPVT (non-EF)	m	--	--	56.82	11.72	72.45	13.10	85.45	11.37	94.67	10.19	124.76	16.41						
	f	--	--	60.00	12.26	71.90	9.99	84.75	11.04	93.90	10.82	117.50	12.38						
WRAT-R Spelling (EF)	m	--	--	--	--	12.74	3.91	19.11	3.95	26.79	5.31	46.74	7.89						
	f	--	--	--	--	--	--	--	--	--	--	--	--						
McCarthy Scales of Children's Abilities	Block Building (EF)	7.00	2.21	9.43	1.10	9.89	.42	9.98	.14	10.00	.00	--	--						
	Puzzle Solving (EF)	2.60	2.48	6.91	2.81	9.92	2.37	11.72	1.90	12.53	1.14	--	--						
	Numerical Memory 1 (non-EF)	4.68	1.75	6.02	2.21	7.68	1.85	7.98	2.06	8.79	1.75	--	--						
	Numerical Memory 2 (EF)	.02	.14	.08	.33	4.19	3.33	6.15	3.06	8.53	2.58	--	--						
	Verbal Fluency (EF)	m	9.45	5.17	14.79	5.39	17.33	5.43	20.76	4.68	24.94	4.80	--	--					
	f	8.30	4.90	16.90	5.52	20.40	6.29	19.80	3.98	24.75	4.69	--	--						
Category Test	Total # of errors (EF)	--	--	--	--	26.19	11.05	15.83	9.61	9.26	6.31	--	--						
Gordon Diagnostic System	Delay Task (EF)	efficiency ratio		--	--	--	.67	.20	.69	.19	.76	.16	.75	.13					
		total # of rewards		m	--	--	--	31.30	8.93	38.30	6.69	40.24	8.02	49.33	9.34				
	Vigilance Task (EF)	total # of errors of omission		f	--	--	--	36.50	6.30	35.15	7.31	42.15	8.25	48.05	8.13				
		total # of errors of commission		m	--	--	--	--	--	14.30	10.32	7.76	5.91	3.24	3.46				
		f	--	--	--	--	--	--	18.95	12.34	7.60	4.95	1.40	1.76					
			--	--	--	--	--	19.91	18.84	16.08	16.07	7.08	7.82						

M=mean; SD=standard deviation; m=males (N=33); f=females (N=20). The whole sample (N=53) is used to calculate the means where m or f is not specified.

Table 8
Means and Standard Deviations for measures collected between 10 and 12 years of age
(raw means)

Executive (EF) and Non-Executive Function (non-EF) Tasks			Age in years					
			10		11		12	
			M	SD	M	SD	M	SD
Peabody Picture Vocabulary Test (non-EF)			118.36	16.17	122.25	14.79	129.33	12.24
WRAT-R Spelling (EF)			44.84	7.89	47.44	6.72	49.75	8.85
Wechsler Intelligence Scale for Children-III	Digits Forward (non-EF)		9.04	1.62	9.94	1.95	10.83	1.94
	Digits Backward (EF)	m	4.88	1.75	6.78	2.05	5.13	2.36
		f	5.67	1.80	5.57	1.27	7.75	2.63
	Mazes (EF)		20.36	4.07	20.19	2.59	23.67	2.99
	Block Design (EF)	m	46.81	11.74	49.00	8.28	50.00	11.21
		f	42.00	8.28	36.71	8.42	46.25	6.08
	Object Assembly (EF)		31.08	4.60	31.19	4.40	32.42	5.20
	Picture Arrangement (EF)		32.20	8.51	36.94	8.92	37.33	8.90
Similarities (EF)		18.96	4.40	20.81	3.31	23.08	4.62	
Phonological Verbal Fluency (EF)			10.14	2.49	10.34	3.12	11.04	2.67
Auditory Working Memory Task (EF)			6.68	2.44	7.13	1.54	7.58	1.31
Category Test	Total # of errors (EF)	m	31.28	13.16	24.31	11.73	29.50	16.01
		f	37.33	16.16	29.14	15.49	35.75	20.30
Trail Making Test	Part A (non-EF)	time	19.88	7.78	19.27	5.53	18.24	6.60
		errors	.12	.33	.13	.34	.08	.29
	Part B (EF)	time	44.71	13.61	36.17	11.86	31.90	8.90
		errors	.60	1.12	.19	.40	.33	.49
Gordon Diagnostic System	Delay Task (EF)	efficiency ratio	.74	.13	.75	.13	.80	.15
		total # rewards	49.16	8.16	47.31	10.68	50.25	7.96
	Vigilance Task (EF)	total # m	3.56	3.65	3.56	4.10	2.25	2.31
		omissions f	2.00	2.18	.57	.79	1.50	1.73
		total # m	11.19	9.61	9.33	8.00	4.63	3.20
		commissions f	6.44	7.73	1.86	1.77	1.00	1.15

M=mean; SD=standard deviation; m=males (N=33); f=females (N=20). The whole sample (N=53) is used to calculate the means

the Methods section) there were no missing values for any of the dependent measures.

To address the issue of the over selection of subjects who were prenatally exposed to drugs, Pearson product moment correlations were computed to determine which outcome variables were significantly related to prenatal exposure to marijuana, nicotine and alcohol. The correlation coefficients obtained are presented in Appendix B.

Attempts were made to randomly sample from those who were exposed to marijuana, nicotine and alcohol with the intention of creating a sample with a lower prevalence of exposure to each of these drugs. With this approach it was not possible to reduce both the prevalence of exposure to marijuana and nicotine and still retain a reasonably sized sample. However, there were eight subjects that were prenatally exposed to both marijuana and nicotine. By eliminating these eight cases, the sample became more representative of the general population, than the original sample, without drastically reducing sample size (from N=53 to N=45). Of this reduced sample 17.8%, 40%, and 95.6% were prenatally exposed to marijuana, nicotine and alcohol, respectively.

All analyses involving the outcome variables that demonstrated a significant relation to drug exposure were recomputed using the reduced sample of 45 subjects. A summary of the variables that were correlated significantly with each drug and the analyses conducted with these variables is presented in Table 9. The results obtained with the reduced sample were compared to those obtained with the original sample of 53 subjects to determine whether the preponderance of prenatal drug exposure in the original sample overly influenced the results. Any disparate findings were noted.

Table 9 about here

Stability Analyses

Due to the large number of bivariate correlations that were computed in this portion of the analysis, the alpha level was set at .01 to reduce the likelihood of type 1 error. All significance tests were two-tailed. The following guidelines regarding the magnitude of the correlations were adopted: 0.3 was considered a correlation of low magnitude, 0.4–0.6 was a moderate correlation and a magnitude of ≥ 0.7 indicated a strong correlation.

Initially, all analyses were computed separately by gender. Fisher's Z_r transformations were used to determine whether or not there were any gender differences in the cross-age stability on the variables in this study¹. No gender differences were found in cross-age stability on EF or non-EF variables. Therefore, cross-age correlations were computed using the combined sample ($N=53$).

¹*Footnote*

$$z = \frac{z_{r1} - z_{r2}}{1/(N_1-3) + 1/(N_2-3)}$$

Fisher's z_r transformation is used to detect significant differences between correlations for two independent samples. Correlations, r_1 and r_2 are converted to z_{r1} and z_{r2} , respectively, using Table E (Ferguson, 1959, p. 314). N_1 and N_2 represent the sizes of the two independent samples. The z value obtained is compared with a critical value of z to detect significance.

Table 9
Correlations between outcome variables and prenatal exposure to drugs*

Task	Age (in years)	Drug			Analyses to compute with N=45
		Marijuana ^a	Nicotine ^b	Alcohol ^c	
Peabody Picture Vocabulary Test	6	--	-.31 (p= .02)	--	Stability, 2-factor mixed ANOVA
	10-12	--	-.27 (p= .05)	--	
Numerical Memory 1 (McCarthy Scales)	6	--	-.36 (p= .01)	--	Stability, 2-factor mixed ANOVA, 2-factor repeated measures ANOVA
	7	--	--	-.28 (p= .04)	
	6	--	-.28 (p= .04)	--	
Block Building (McCarthy)	6	--	-.28 (p= .04)	--	Stability, 2-factor mixed ANOVA
Mazes (WISC-III)	10-12	--	-.31 (p= .02)	--	2-factor between groups ANOVA
Verbal Fluency (McCarthy)	3	--	-.38 (p= .01)	--	Stability, 2-factor mixed ANOVA
TMT Part A- Time	10-12	-.29 (p= .04)	--	--	2-factor between groups ANOVA, 2-factor mixed ANOVA
TMT Part B- Time	10-12	-.36 (p= .01)	--	--	2-factor between groups ANOVA, 2-factor mixed ANOVA
TMT Part B- Errors	10-12	-.29 (p= .03)	--	--	2-factor between groups ANOVA, 2-factor mixed ANOVA
GDS Delay Task, Rewards	10-12	.30 (p= .03)	--	--	2-factor between groups ANOVA

* alpha level= .05

^a Maternal use of marijuana during pregnancy (categories: no use, 1-5 joints/week, > 5 joints/week)

^b Maternal use of nicotine during pregnancy (categories: no use, 0.1-15.9 mg. Nicotine/day, >16.0 mg. Nicotine/day)

^c Maternal use of alcohol during pregnancy (categories: no use, .1-.13 oz. AA/day, .14-.85 oz. AA/day, > .86 oz. AA/day)

All stability analyses were conducted with and without the one case that was identified as having Attention Deficit Disorder. Removal of this case did not affect any of the findings. Therefore, this subject was included with the rest of the sample in the calculation and reporting of results in this section.

Stability correlations for the PPVT-R and the Numerical Memory I, Block Building and Verbal Fluency subtests of the McCarthy Scales were also computed with the reduced sample (N=45) to ensure that overrepresentation of children prenatally exposed to marijuana, nicotine and alcohol did not overly influence the results. With the exception of Verbal Fluency, in comparison of the results between the original and reduced samples none of the correlations differed significantly and no change in cross-age patterns was observed. Therefore, to maximize the power of the analyses, the results obtained with the original sample are reported. Regarding Verbal Fluency, the results obtained with both samples are reported. The results of the correlational analyses are presented in Tables 10-20.

Non-executive Function Measures (Tables 10 and 11)

Cross-age correlational stability is achieved for performance on the two non-EF measures included in this portion of the analysis, the PPVT-R ($r=.49$ to $.73$; Table 10) between 4 and 10-12 years of age and Numerical Memory I (forward digits) of the McCarthy Scales ($r=.48$ to $.65$; Table 11) between 3 and 7 years of age.

Tables 10 and 11 about here

Table 10
Cross-Age Correlations:
Peabody Picture Vocabulary Test (N=53)

Age in years	Age in years				
	4	5	6	7	10-12
4	1.0				
5	.66 (p<.001)	1.0			
6	.66 (p<.001)	.68 (p<.001)	1.0		
7	.67 (p<.001)	.73 (p<.001)	.72 (p<.001)	1.0	
10-12	.49 (p<.001)	.55 (p<.001)	.59 (p<.001)	.67 (p<.001)	1.0

Table 11
Cross-Age Correlations:
Numerical Memory I subtest of the McCarthy Scales of Children's Abilities (N=53)

Age in years	Age in years				
	3	4	5	6	7
3	1.0				
4	.65 (p<.001)	1.0			
5	.50 (p<.001)	.49 (p<.001)	1.0		
6	.61 (p<.001)	.60 (p<.001)	.61 (p<.001)	1.0	
7	.48 (p<.001)	.57 (p<.001)	.54 (p<.001)	.60 (p<.001)	1.0

Executive Function Measures (Tables 12-20)

Working Memory (Tables 12-15)

Working memory skills appear stable across age from 3 to 10-12 years of age except for between 5 and 7 years of age on one task. Performance on the Spelling subtest of the WRAT-R was stable across age from 5 through to 10-12 years of age ($r=.33$ to $r=.52$) except for between 5 and 7 years of age ($r=.18$; Table 12). The correlations that covered a larger age span were more moderate in magnitude.

Table 12 about here

On Numerical Memory II of the McCarthy Scales, performance at each age correlated moderately with performance at the immediately succeeding test age (Table 13). In addition, performance at each age except 3 years, correlated significantly with scores at 7 years of age. The lack of significant cross-age correlations obtained with scores at 3 and 4 years of age may have been due to a floor effect that was observed at these earlier test ages. In a correlational analysis, if one or both of the variables show little variability or a restricted range of scores, a lower correlation will result (Deikhoff, 1992). Almost all subjects scored 0 at both 3 and 4 years in the performance Numerical Memory II. Disregarding the two earliest test ages, performance on Numerical Memory II showed stability from 5 to 7 years of age (range $r=.42$ to $.55$).

Table 13 about here

Table 12
Cross-Age Correlations:
Wide Range Achievement Test - Revised, Spelling (N=53)

Age in years	Age in year			
	5	6	7	10-12
5	1.0			
6	.52 (p<.001)	1.0		
7	.18 (p=.20)	.44 (p<.01)	1.0	
10-12	.33 (p=.01)	.34 (p=.01)	.46 (p<.01)	1.0

Table 13
Cross-Age Correlations:
Numerical Memory II subtest of the McCarthy Scales of Children's Abilities (N=53)

Age in years	Age in years				
	3	4	5	6	7
3	1.0				
4	.39 (p<.01)	1.0			
5	.16 (p=.25)	.34 (p=.01)	1.0		
6	-.01 (p=.96)	.18 (p=.20)	.55 (p<.001)	1.0	
7	.30 (p=.03)	.45 (p<.01)	.50 (p<.001)	.42 (p<.01)	1.0

Most subjects approached a ceiling level of performance on the Block Building subtest of the McCarthy by 4 years of age. Consequently, there was very little variability in the scores on this subtest within and between ages (Table 7). Therefore, individual differences were slight and the issue of cross-age correlational stability after 4 years of age could not be adequately addressed. The largest change in mean performance on the Block Building task was observed from 3 to 4 years of age at which times there was also variability in the scores. Mean scores at these two test times were moderately correlated ($r=.35$; Table 14).

Table 14 about here

High cross-age correlational stability was achieved on the Puzzle Solving subtest of the McCarthy between all test ages (i.e., from 3 through 7 years of age). Correlations ranged from $r=.34$ to $.58$ (Table 15). The magnitude of the correlations obtained decreased progressively with increased distance off of the diagonal indicating that the larger the age span covered, the more moderate the relationship.

Table 15 about here

Mental Flexibility (Tables 16a, 16b, and 17)

Mental flexibility is stable from 3 to 7 years of age based on verbal fluency behaviour. However, similar to what was found with one of the working memory tasks

Table 14
Cross-Age Correlations:
Block Building subtest of the McCarthy Scales of Children's Abilities (N=53)

Age in years	Age in years				
	3	4	5	6	7
3	1.0				
4	.35 (p=.01)	1.0			
5	.29 (p=.04)	.15 (p=.29)	1.0		
6	.13 (p=.37)	.31 (p=.02)	-.04 (p=.79)	1.0	
7	--	--	--	--	1.0

"--" Indicates that the correlation coefficient cannot be computed due to all of the subjects obtaining the same value on this task at 7 years of age.

Table 15
Cross-Age Correlations:
Puzzle Solving subtest of the McCarthy Scales of Children's Abilities (N=53)

Age in years	Age in years				
	3	4	5	6	7
3	1.0				
4	.45 (p<.01)	1.0			
5	.46 (p<.001)	.58 (p<.001)	1.0		
6	.43 (p=.001)	.46 (p<.001)	.56 (p<.001)	1.0	
7	.34 (p=.01)	.43 (p<.01)	.42 (p<.01)	.46 (p<.001)	1.0

(i.e., WRAT-R Spelling), between 5 and 7 years of age on the Category Test stability was not achieved.

Performance on the Verbal Fluency subtest of the McCarthy was stable from 4 through 7 years of age (Table 16a). The strongest cross-age correlation was between 4 and 5 years ($r=.63$). With respect to all of the correlations with performance at 3 years of age, the results for the original sample were not congruent with those for the reduced sample. The results obtained with the original sample did not indicate stability in performance between age 3 and each of ages 4, 5 and 6 years. With the sample that is more representative of the general population ($N=45$), however, stability was achieved between 3 years and each of the other test ages up to 7 years of age ($r=.37$ to $r=.51$; Table 16b). This may be indicative of an effect of the overrepresentation of subjects prenatally exposed to drugs on cross-age stability in performance of this verbal fluency task.

Tables 16a and 16b about here

On the Category Test (total errors) there was cross-age stability from one year to the next from 5 to 7 years of age (Table 17). However, there was no stability in the performance of this task over the two year interval, between 5 and 7 years of age.

Tables 17 about here

Table 16a
Cross-Age Correlations:
Verbal Fluency subtest of the McCarthy Scales of Children's Abilities (N=53)

Age in years	Age in years				
	3	4	5	6	7
3	1.0				
4	.27 (p=.05)	1.0			
5	.33 (p=.02)	.63 (p<.001)	1.0		
6	.22 (p=.12)	.46 (p<.01)	.50 (p<.001)	1.0	
7	.36 (p<.01)	.29 (p=.03)	.37 (p<.01)	.48 (p<.001)	1.0

Table 16b
Cross-Age Correlations:
Verbal Fluency subtest of the McCarthy Scales of Children's Abilities (N=45)

Age in years	Age in years				
	3	4	5	6	7
3	1.0				
4	.77 (p=.01)	1.0			
5	.51 (p<.001)	.61 (p<.001)	1.0		
6	.44 (p<.01)	.42 (p<.01)	.50 (p<.001)	1.0	
7	.49 (p<.01)	.25 (p=.09)	.37 (p<.01)	.49 (p<.001)	1.0

Table 17
Cross-Age Correlations:
Total number of errors on the Category Test (N=53)

Age in years	Age in years		
	5	6	7
5	1.0		
6	.43 (p<.01)	1.0 (p= .)	
7	.21 (p=.13)	.40 (p<.01)	1.0

Interference Control (Tables 18-20)

Response inhibition and sustained attention, the two components of interference control demonstrated differences in terms of cross-age stability, the former was unstable and the latter was stable across age.

On the Delay Task of the GDS, the correlational analyses suggested that there was no stability of individual differences from 5 to 10-12 years of age in the ability to inhibit impulsive responding, based on the efficiency ratio (Table 18). However, given the limited range of scores for a ratio (i.e., 0 to 1) variability of scores was slight. Therefore, the stability of response inhibition was difficult to assess with the efficiency ratio of the Delay Task.

Tables 18 about here

There was no cross-age stability in the performance of another measure of response inhibition, the number of errors of commission on the Vigilance Task of the GDS, although it did not cover as broad of an age range (6-12 years of age; Table 19). The errors of omission on the Vigilance task of the GDS, measuring sustained attention, showed moderate stability between ages 6 and 7 years only ($r = .53$; Table 20). The remainder of cross-age correlations on this task however, indicated a tendency toward stability in contrast to the pattern of correlations for response inhibition.

Tables 19 and 20 about here

Table 18
Cross-Age Correlations:
Delay Task on the Gordon Diagnostic System - Total Efficiency Ratio (N=53)

Age in years	Age in years			
	5	6	7	10-12
5	1.0			
6	.35 (p=.01)	1.0		
7	.11 (p=.43)	.24 (p=.08)	1.0	
10-12	.03 (p=.83)	-.01 (p=.94)	.04 (p=.76)	1.0

Table 19
Cross-Age Correlations:
Vigilance Task on the Gordon Diagnostic System -
Total Number of Commissions (N=53)

Age in years	Age in years		
	6	7	10-12
6	1.0		
7	.14 (p=.30)	1.0	
10-12	.12 (p=.38)	.11 (p=.42)	1.0

Table 20
Cross-Age Correlations:
Vigilance Task on the Gordon Diagnostic System -
Total Number of Omissions (N=53)

Age in years	Age in years		
	6	7	10-12
6	1.0		
7	.53 (p<.001)	1.0	
10-12	.27 (p=.05)	.29 (p=.04)	1.0

Developmental Continuity

The overall results for the mixed design ANOVAs and the between groups ANOVAs for the original sample are summarized in Tables 21 to 23. To address the violation of the assumption of sphericity within the analyses involving a repeated measures factor, the corrected univariate F tests were consulted.

Tables 21, 22, and 23 about here

Subsequent to the overall analyses, trend analysis was performed to examine the shape of the relationship between age and performance on the dependent variables for males and females. Significant linear, quadratic, and cubic trend components to the growth curves were noted for each of the dependent measures. In instances where a significant age by gender interaction was found, an analysis of simple main effects was performed to isolate sex differences at each age of testing. If no interaction was found orthogonal comparisons between ages were computed to further investigate any significant main effects. This helped to provide insight into when throughout development marked changes in performance on the dependent measures occurred. For a repeated measures factor, either Difference or Helmert contrasts were employed depending on which was hypothesized to extract the most useful information from the data. Difference and Helmert contrasts involve the comparison of each level of a factor to the average of the levels that precede it or succeed it, respectively (SPSS, 1994).

With the between groups variables, the exploration of significant main effects when

Table 21
ANOVA Table for Repeated Measures Analysis of Developmental Continuity

EF and Non-EF Tasks (age range analysed, in years)	Interactions and Main Effects		
	Age-by-Gender Interaction	Age Main Effect	Gender Main Effect
PPVT (4 to 10-12) (non-EF)	F(3,21,204)=3.20 p=.02*	F(3,21,204)=508.24 p<.001*	F(1,51)=.18 p=.68
WRAT-R Spelling (5 to 10-12) (EF)	F(2,20,153)=.25 p=.80	F(2,20,153)=535.50 p<.001*	F(1,51)=.15 p=.70
McCarthy Scales of Children's Abilities (3-7)	Numerical Memory 1 (non-EF)	F(4,204)=.41 p=.80	F(4,204)=82.49 p<.001*
	Numerical Memory 2 (EF)	F(2,73,204)=.69 p=.55	F(2,73,204)=169.90 p<.001*
	Verbal Fluency (EF)	F(4,204)=2.90 p=.02*	F(4,204)=112.30 p<.001*
	Block Building (EF)	F(1,52)=.04 p=.92	F(1,52,204)=71.60 p<.001*
	Puzzle Solving (EF)	F(4,204)=.19 p=.94	F(4,204)=290.97 p<.001*
Category Test (5-7)	Total # of errors (EF)	F(2,102)=.11 p=.90	F(2,102)=62.70 p<.001*
Gordon Diagnostic System	Delay Task (5 to 10-12) (EF)	F(3,153)=.70 p=.56	F(3,153)=3.76 p=.01*
	Vigilance Task (6 to 10-12) (EF)	F(1,44,102)=3.73 p=.04*	F(1,44,102)=68.80 p<.001*
	total # omissions		F(1,51)=.33 p=.57
	total # commissions	F(2,102)=1.10 p=.34	F(2,102)=11.53 p<.001*
			F(1,51)=3.57 p=.06

Table 22
ANOVA Table for Between Groups Analysis of Developmental Continuity (10-12 years of age)

Executive (EF) and Non-Executive Function (non-EF) Tasks			Interactions and Main Effects					
			Age-by-Gender Interaction		Age Main Effect		Gender Main Effect	
			F(2,47)	p	F(2,47)	p	F(1,47)	p
Peabody Picture Vocabulary Test (non-EF)			.27	.78	2.30	.11	2.01	.16
WRAT-R Spelling (EF)			.47	.63	2.04	.14	.42	.52
Wechsler Intelligence Scale for Children-III	Digits Forward (non-EF)		.74	.48	4.39	.02*	.65	.42
	Digits Backward (EF)		3.22	.05*	1.75	.18	1.64	.21
	Mazes (EF)		.21	.81	3.28	.05*	1.15	.29
	Block Design (EF)		.85	.43	.93	.40	5.56	.02*
	Object Assembly (EF)		.26	.77	.49	.62	.06	.82
	Picture Arrangement (EF)		2.05	.14	2.95	.06	.16	.69
	Similarities (EF)		.45	.64	3.25	.05*	1.17	.28
Phonological Verbal Fluency (EF)			.22	.80	.22	.80	.75	.39
Auditory Working Memory Task (EF)			1.48	.24	.32	.73	.61	.44
Category Test	Total # of errors (EF)		.01	.99	1.72	.19	5.50	.02*
Trail Making Test	Part A (non-EF)	time	.20	.82	.25	.78	1.49	.23
		errors	1.75	.19	.06	.94	.11	.75
	Part B (EF)	time	.48	.62	4.43	.02*	.16	.69
		errors	.43	.66	.87	.42	.06	.81
Gordon Diagnostic System	Delay Task (EF)	efficiency ratio	1.41	.25	1.32	.28	.25	.62
	Vigilance Task (EF)	total # omissions	.49	.62	.44	.64	3.89	.05*
		total # commissions	.26	.77	2.68	.08	5.95	.02*

Table 23
ANOVA Table for Analyses linking Developmental Continuity for
Executive Function and Non-Executive Function Measures

Task	Non- executive function portion	Executive function portion	Interactions and Main Effects		
			3-way Interaction	2-way Interactions	Main Effects
Numerical Memory	Part 1 (forward)	Part 2 (reverse)	-- --	<i>Age by Task</i> : $F(3, 25, 208)=47.93$ $p<.001^*$	<i>Age</i> : $F(2, 94, 208)=264.62$ $p<.001^*$ <i>Task</i> : $F(1, 52)=232.83$ $p<.001^*$
Digit Span	Forward	Backward	<i>Age by Task by Gender</i> : $F(2, 47)=2.02$ $p=.14$	<i>Age by Task</i> : $F(2, 47)=.53$ $p=.59$ <i>Age by Gender</i> : $F(2, 47)=2.25$ $p=.12$ <i>Gender by Task</i> : $F(2, 47)=4.44$ $p=.04^*$	<i>Age</i> : $F(2, 47)=3.63$ $p=.03^*$ <i>Task</i> : $F(1, 47)=217.99$ $p<.001^*$ <i>Gender</i> : $F(1, 47)=.14$ $p=.71$
	Errors	Part B	--	<i>Age by Task</i> : $F(2, 50)=1.10$ $p=.34$	<i>Age</i> : $F(2, 50)=1.10$ $p=.34$ <i>Task</i> : $F(1, 50)=4.29$ $p=.04^*$
Trail Making Test	Part A	Part B	--	<i>Age by Task</i> : $F(2, 50)=4.41$ $p=.02^*$	<i>Age</i> : $F(2, 50)=3.76$ $p=.03^*$ <i>Task</i> : $F(1, 50)=119.58$ $p<.001^*$
	Time	Part A	--		

there was no interaction involved the computation of repeated contrasts. Repeated contrasts involve the comparison of successive levels of the independent factor.

Since the case identified as Attention Deficit Disorder did not contribute any outlying scores to the data set, scores obtained by this subject were not likely to overly influence the results. Therefore, this case was included in the analysis of developmental continuity.

Using the reduced sample of 45 subjects, additional ANOVAs were conducted with those outcome variables that were significantly correlated with drug exposure (Table 9). Separate mixed design ANOVAs were computed for the PPVT-R, Numerical Memory I, Block Building and Verbal Fluency and separate between groups ANOVAs were computed for the PPVT-R, the Mazes subtest on the WISC-III, the time recorded for Part A of the Trail Making Test, time and errors for Part B of the Trail Making Test and the total number of rewards on the Delay Task of the GDS. In addition, analyses combining Numerical Memory part I and part II, Digits forward and Digits backward and the Trail Making Test Part A and Part B were conducted with the reduced sample. The two sets of results (i.e., those obtained with N=45 and N=53) were compared and any differences were noted.

Non-Executive Function Measures (Figures 1 to 3)

Analysis of the PPVT-R from 4 to 10-12 years of age revealed a significant age by gender interaction and a main effect of age in the performance of this verbal, non-EF task (Figure 1). Post hoc trend analysis yielded a significant linear interaction between age and

gender. These results suggest that performance on the PPVT improves linearly with age between 4 and 10-12 years of age however, at slightly different rates for boys and girls. The simple main effects suggested that no significant difference between girls and boys was present at any of the ages tested. However, the magnitude and direction for the results of the analysis of simple main effects support the linear interaction. It appears that boys' performance improves at a very slightly faster rate than girls' performance between 7 and 10-12 years of age. Between groups analysis of the PPVT-R from 10 to 12 years of age revealed no interaction between age and gender, no main effect of gender and no difference in performance of this task between these ages. The means (Table 8), however, indicated a tendency toward improvement in performance with age.

Figure 1 about here

A mixed model repeated measures ANOVA yielded no significant age by gender interaction or main effect of gender in the performance of the Numerical Memory I subtest of the McCarthy Scales (forward digits). A significant main effect of age was observed (Figure 2). Post hoc polynomial contrasts revealed a strong positive linear trend in performance across age (accounting for approximately 93.9% of the variability across age) and a much weaker, negative quadratic trend. Difference contrasts comparing performance between ages indicated that the most significant improvement on this task seemed to occur between 3 and 5 years of age after which time improvement was more slight.

Figure 1
PPVT-R - Performance across age

REPEATED MEASURES ANALYSIS:

Interaction - Age by Gender

Trend Analysis

linear $t=2.58$ $p=.01$ $R^2=.928$

Simple Main Effects

4 yrs $t=-.94$ $p=.35$

5 yrs $t=.16$ $p=.86$

6 yrs $t=.22$ $p=.83$

7 yrs $t=.26$ $p=.80$

10-12 yrs $t=1.70$ $p=.10$

BETWEEN GROUPS ANALYSIS:

No significant results were found.

The means suggest improvement with age.

* All 53 subjects were tested on the PPVT-R yearly between 4 and 7 years of age and once between the ages of 10 and 12 years (i.e., at 10, 11 or 12 years of age).

Figure 2 about here

Between groups analysis on a similar task between 10 and 12 years of age, the Digits Forward portion of the Digit Span subtest of the WISC-III, yielded a significant overall main effect of age on performance (Figure 3). Trend analysis demonstrated that improvement in performance at this time was linear in nature. None of the repeated contrasts were significant indicating that growth could not be statistically differentiated between successive ages (i.e., at one year intervals). An independent samples t-test performed between ages 10 and 12 years confirmed that significant development on this function did occur over the two year age span.

Figure 3 about here

No progression is apparent from age 10 to age 12 on the Trail Making Test Part A as evidenced by the analysis of both the number of errors committed and the time to completion of the task.

Executive Function Measures (Figures 2 to 15)

Working Memory (Figures 2 to 9)

Within groups analysis of the Spelling subtest from the WRAT-R from 5 to 10-12 years of age revealed no age by gender interaction or main effect of gender. The age main

Figure 2
Numerical Memory - Performance across age (N=53)

REPEATED MEASURES ANALYSIS:

Numerical Memory I

Main Effect of Age

Trend Analysis

linear $t=17.00$ $p<.001$ $R^2=.939$

quadratic $t=-4.26$ $p<.001$ $R^2=.044$

Difference Contrasts

3 yrs to 4 yrs $t=5.79$ $p<.001$

Sum(3 to 4 yrs)/2 to 5 yrs $t=9.46$ $p<.001$

Sum(3 to 5 yrs)/3 to 6 yrs $t=9.04$ $p<.001$

Sum (3 to 6 yrs)/4 to 7 yrs $t=10.95$ $p<.001$

Numerical Memory II

Main Effect of Age

Trend Analysis

linear $t=23.56$ $p<.001$ $R^2=.949$

quadratic $t=2.55$ $p=.01$ $R^2=.010$

cubic $t=-4.34$ $p<.001$ $R^2=.021$

quartic $t=3.59$ $p<.001$ $R^2=.021$

Difference Contrasts

Sum(3 to 4 yrs)/2 $t=8.73$ $p<.001$

Sum(3 to 5 yrs)/3 to 6 yrs $t=12.48$ $p<.001$

Sum (3 to 6 yrs)/4 to 7 yrs $t=19.21$ $p<.001$

Numerical Memory I & II

Interaction - Age by Task

Trend Analysis

linear $t=11.91$ $p<.001$ $R^2=.823$

quadratic $t=4.10$ $p<.001$ $R^2=.085$

cubic $t=-4.44$ $p<.001$ $R^2=.072$

Simple Main Effects

3 yrs $t=19.60$ $p<.001$

4 yrs $t=20.02$ $p<.001$

5 yrs $t=8.61$ $p<.001$

6 yrs $t=4.06$ $p<.001$

7 yrs $t=.72$ $p=.48$

Figure 3
Digit Span - Performance across age

BETWEEN GROUPS ANALYSIS:

DIGITS FORWARD:

Main Effect of Age

Trend Analysis

linear $t=2.92$ $p<.01$

T-test

10-12 yrs $t= -4.25$ $p<.001$

DIGITS BACKWARD:

Interaction - Age by Gender

Trend Analysis

quadratic $t=2.42$ $p=.02$

Simple Main Effects

10 yrs $t= -1.08$ $p=.29$

11 yrs $t= 1.36$ $p=.20$

12 yrs $t= -1.76$ $p=.11$

DIGIT SPAN - FORWARD & BACKWARD:

Interaction - Gender by Task

Simple Main Effects

boys $t= -13.26$ $p<.001$

girls $t= -8.91$ $p<.001$

*The 53 subjects were tested on the Digit Span task once between the ages of 10 and 12 years (i.e. at 10, 11, or 12 years of age).

effect achieved significance and displayed significant linear, quadratic and cubic trend components for this developmental function (Figure 4). Although the quadratic and cubic deviations from linearity were statistically significant, the linear component accounted for most of the variability in performance across age (99.2%). Difference contrasts indicated that the period of most marked development on this task was from 7 to 10 to 12 years of age. Given that this denoted the largest age interval covered this finding was not surprising. Additional between groups analysis provided no further statistical insight regarding developmental progression on this task between 10 and 12 years of age. However, examination of the means indicated some improvement in performance at this time.

Figure 4 about here

On Numerical Memory II of the McCarthy Scales, no age by gender interaction and no main effect of gender were found. There was a main effect of age on performance (Figure 2). Linear, quadratic, cubic and quartic trends achieved significance. However, the linear component was the trend that was the most pronounced in the development of this function, accounting for approximately 94.9% of the variability in performance across age on this task. The observed means and computation of difference contrasts confirmed that successful performance on this task did not occur until after 4 years of age, before which time a floor effect was observed (i.e., at 3 and 4 years of age).

The Digits Backward portion of the Digit Span subtest of the WISC-III showed an

Figure 4
WRAT-R Spelling - Performance across age

REPEATED MEASURES ANALYSIS:

Main Effect of Age

Trend Analysis

linear	t= 30.26	p<.001	R ² =.992
quadratic	t= -3.63	p<.001	R ² =.007
cubic	t= -2.02	p=.05	R ² =.001

Difference Contrasts

5 yrs to 6 yrs	t=11.78	p<.001
Sum(5 to 6 yrs)/2 to 7 yrs	t=14.89	p<.001
Sum(5 to 7 yrs)/3 to 10-12 yrs	t=27.90	p<.001

BETWEEN GROUPS ANALYSIS:

No significant results were found.

The means suggest improvement with age.

* All 53 subjects were tested on the WRAT-R yearly between 5 and 7 years of age and once between the ages of 10 and 12 years (i.e., at 10, 11, or 12 years of age).

interaction between age and gender from 10 to 12 years of age (Figure 3). Despite insignificant results in the analysis of simple main effects, trend analysis indicated a quadratic interaction. The pattern of sign changes of the simple main effects was consistent with this finding.

There was no interaction between gender and performance over time on the Block Building task of the McCarthy Scales and no main effect of gender. A significant main effect of age was found (Figure 5). Polynomial contrasts displayed significant linear, quadratic and cubic trends in the development of this function. Both the linear and quadratic components accounted for significant proportions of the variability in the dependent variable across age, 65.2% and 29.0%, respectively. Additional post hoc analysis using Helmert contrasts revealed that the most marked improvement on this task was observed between 3 and 4 years of age followed by a period of less discernable improvement between 4 and 5 years of age. After this time no significant change in performance ensued. This is consistent with the ceiling effect that is noted in the observed means as subjects approach 7 years of age.

Figure 5 about here

The Block Design subtest of the WISC-III revealed no age by gender interaction and no main effect of age. A significant main effect of gender was observed, indicating that boys demonstrated superior performance to girls on this task between 10 and 12 years of age (Figure 6).

Figure 5
Block Building - Performance across age (N=53)

REPEATED MEASURES ANALYSIS:

Main Effect of Age

Trend Analysis

linear $t = 9.40$ $p < .001$ $R^2 = .652$

quadratic $t = -9.03$ $p < .001$ $R^2 = .290$

cubic $t = 5.32$ $p < .001$ $R^2 = .054$

Helmert Contrasts

3 yrs to Sum(4 to 7 yrs)/4 $t = -9.42$ $p < .001$

4 yrs to Sum(5 to 7 yrs)/3 $t = -3.50$ $p < .001$

Figure 6 about here

The age by gender interaction and the gender main effect were insignificant in the analysis of the Puzzle Solving subtest of the McCarthy Scales from 3 to 7 years of age. Development on the puzzle solving appeared gradual over time (Figure 7). Trend analysis indicated that in addition to a strong positive linear progression across age, a less marked, negative quadratic trend was present (accounting for 92.4% and 7.5% of the variability in performance across age). Difference contrasts revealed that the most distinct period of change in performance on this task took place prior to 5 years of age and improvement began to level out after this time.

Figure 7 about here

Concerning the remainder of the WISC-III subtests that were included in the present study, there were no significant findings for the Object Assembly and Picture Arrangement subtests from 10 to 12 years of age. On the Picture Arrangement task, however, the observed means suggested improved performance between 10 and 11 years of age. This result may have been significant with an increase in the power of the analysis.

Both the Mazes (Figure 8) and Similarities (Figure 9) subtests exhibited a significant main effect of age only, demonstrating a linear trend with age. The most marked improvement on the Mazes task was noted between 11 and 12 years of age. Conducting the analysis of the Maze subtest with the sample of 45 subjects caused a loss

Figure 6
Block Design (WISC-III) - Performance across age

BETWEEN GROUPS ANALYSIS:

Main Effect of Gender

Repeated Contrast

Males to Females $t=2.36$ $p=.02$

* The 53 subjects were tested on the Block Design task once between the ages of 10 and 12 years (i.e., at 10, 11, or 12 years of age).

Figure 7
Puzzle Solving - Performance across age (N=53)

REPEATED MEASURES ANALYSIS:

Main Effect of Age

Trend Analysis

linear $t=30.90$ $p<.001$ $R^2=.924$

quadratic $t=-9.15$ $p<.001$ $R^2=.075$

Difference Contrasts

3 yrs to 4 yrs $t=10.89$ $p<.001$

Sum(3 to 4 yrs)/2 to 5 yrs $t=18.01$ $p<.001$

Sum(3 to 5 yrs)/3 to 6 yrs $t=20.49$ $p<.001$

Sum(3 to 6 yrs)/4 to 7 yrs $t=20.48$ $p<.001$

of the significant main effect. Since performance on the Mazes subtest for all subjects (N=53) between 10 and 12 years of age was moderately and negatively correlated to prenatal exposure to nicotine ($r=-.31$), this change in results could be attributed to the reduced sample embodying a more representative number of subjects prenatally exposed to smoke. Another possibility is that such an incongruity may have been due to a significant decrease in power noted in the analysis with the reduced sample (N=53, power= .60; N=45, power=.26).

Figures 8 and 9 about here

Regarding the Similarities task, although the overall main effect of age was significant, none of the specific post hoc repeated contrasts reached significance. An independent samples t-test performed between age 10 and age 12 indicated that development on this task was evident over the two year interval.

No significant results were found with the Auditory Working Memory task between 10 and 12 years of age, although the means were suggestive of slight amelioration in performance with increasing age.

Mental Flexibility (Figures 10 to 12)

In the analysis of the Verbal Fluency task of the McCarthy Scales there was an age by gender interaction, a main effect of age and no main effect of gender (Figure 10). An analysis of trend indicated that the interaction between age and gender in the performance

Figure 8
Mazes - Performance across age

BETWEEN GROUPS ANALYSIS:

Main Effect of Age

Trend Analysis

linear $t=2.37$ $p=.02$

Repeated Contrast

11-12 yrs $t=-2.26$ $p=.03$

* The 53 subjects were tested on the Mazes and Similarities tasks once between the ages of 10 and 12 years (i.e., at 10, 11 or 12 years of age).

Figure 9
Similarities - Performance across age

BETWEEN GROUPS ANALYSIS:

Main Effect of Age

Trend Analysis

linear $t=2.52$ $p=.02$

T-test

10-12 yrs $t=-2.63$ $p=.01$

* The 53 subjects were tested on the Mazes and Similarities tasks once between the ages of 10 and 12 years (i.e., at 10, 11 or 12 years of age).

of this task could be largely explained by quadratic and cubic components which accounted for approximately 49.0% and 34.8% of the variability in scores across age, respectively. Although the simple main effects did not display any significant findings, they were suggestive of a developmental pattern. Prior to 4 years of age it appeared that girls improved more rapidly on this task. Between 4 and 5, although girls' performance was superior, girls and boys appeared to improve at roughly the same rate. By six years of age girls and boys seemed to be at the same level and both genders continued to develop at the same rate to 7 years of age.

Figure 10 about here

From age 10 to 12 years on the Phonological Verbal Fluency task there did not appear to be any gender differences, any significant progression in the performance of this task or any interaction between age and gender.

The age by gender interaction and gender main effect were insignificant in the repeated measures analysis of the Category Test from 5 to 7 years of age. A significant main effect of age was found (Figure 11). Orthogonal polynomial contrasts revealed a significant negative linear trend for the total number of errors committed between 5 and 7 years of age, which accounted for 98.1% of the total variability in performance across age. Difference contrasts did not provide any additional insight into development on this task. From 10 to 12 years of age, between groups analysis denoted only a main effect of gender and no main effect of age or age by gender interaction. In this age range girls appeared to

Figure 10
Verbal Fluency - Performance across age (N=53)

REPEATED MEASURES ANALYSIS:

Interaction

Trend Analysis

quadratic $t = 2.01$ $p = .05$ $R^2 = .490$

cubic $t = -2.40$ $p = .02$ $R^2 = .348$

Simple Main Effects

3 yrs $t = .80$ $p = .43$

4 yrs $t = -1.36$ $p = .18$

5 yrs $t = -1.88$ $p = .07$

6 yrs $t = .76$ $p = .45$

7 yrs $t = .14$ $p = .89$

commit more errors than boys on the Category Test with 6 subtests ($t = -2.35$, $p = .02$).

Figure 11 about here

In the between groups analysis of the Trail Making Test Part B between 10 and 12 years, age and gender did not interact and there was no distinction in performance between girls and boys with respect to either the number of errors committed or the time recorded. In addition, no main effect of age for the number of errors was evident. The only significant result that appeared was a main effect of age for the time taken to complete this task which was evident between 10 and 11 years of age (Figure 12b). An analysis of trend showed that between 10 and 12 years, the amount of time to complete this portion of the Trail Making Test decreased linearly with increasing age. When the results were computed with the reduced sample the significance was lost. This may have been as a result of a loss of power in the analysis with fewer subjects ($N = 53$, $\text{power} = .73$; $N = 45$, $\text{power} = .55$). Another possibility is that the loss of significance may have been related to the reduction of children exposed to marijuana before birth in the sample of 45 subjects, since this measure is negatively correlated with prenatal exposure to marijuana ($r = -.36$) in the original sample.

Figures 12a and 12b about here

Figure 11
Category Test (5 subtests) - Performance across age (N=53)

REPEATED MEASURES ANALYSIS:

Main Effect of Age

Trend Analysis

linear $t = -10.23$ $p < .001$ $R^2 = .981$

Difference Contrasts

5 yrs to 6 yrs $t = -6.61$ $p < .001$

Sum(5 to 6 yrs)/2 to 7 yrs $t = -9.24$ $p < .001$

Figure 12a
Trail Making Test, Errors - Performance across age

BETWEEN GROUPS ANALYSIS:

Errors - Part A & Part B

Main Effect of Task

Part A to Part B $t=2.07$ $p=.04$

* The 53 subjects were tested on the Trail Making Test once between the ages of 10 and 12 years (i.e., at 10, 11, or 12 years of age).

Figure 12b
Trail Making Test, Time - Performance across age

BETWEEN GROUPS ANALYSIS:

TIME - PART B

Main Effect of Age

Trend Analysis

linear $t = -2.79$ $p < .01$

Repeated Contrasts

10-11 yrs $t = 1.97$ $p = .05$

TIME - PART A & PART B

Interaction - Age by Task

Trend Analysis

linear $t = -2.71$ $p = .01$

Simple Main Effects

10 yrs $t = -9.62$ $p < .001$

11 yrs $t = -5.88$ $p < .001$

12 yrs $t = -5.17$ $p < .001$

* The 53 subjects were tested on the Trail Making Test once between the ages of 10 and 12 years (i.e., at 10, 11, or 12 years of age).

Interference Control (Figures 13-15)

In the analysis of the efficiency ratio (i.e., the ratio of rewarded responses to the total number of responses) on the Delay Task of the GDS from 5 to 10-12 years of age, the age by gender interaction and main effect of gender proved to be insignificant. However, a significant main effect of age was observed for this measure (Figure 13). As the subjects increased in age their efficiency in the performance of this task increased linearly. An equally moderate, although negative, quadratic trend was also noted. The linear and quadratic components to this growth curve accounted for 44.1% and 38.9% of the variability in efficiency with age, respectively. Difference contrasts illustrated that the only recognisable amelioration in efficiency occurred between the ages of 6 and 7 years. Analysing this measure between groups from 10 to 12 years of age yielded no additional findings. However, from the graph it appeared that development in efficiency on this task did occur from 11 to 12 years of age.

Figure 13 about here

Repeated measures analysis from 6 to 10-12 years of age of another measure of response inhibition, the number of errors of commission on the Vigilance Task of the GDS, revealed a main effect of age only (Figure 14). Post hoc analyses indicated that commission errors decreased linearly with age and the most marked period of decline occurred between 7 years of age and early adolescence (10-12 years of age). Additional between groups analysis between 10 and 12 years of age suggested a main effect of gender

Figure 13
GDS Delay Tak, Efficiency - Performance across age

REPEATED MEASURES ANALYSIS:

Main Effect of Age (5 to 10-12 yrs)

Trend Analysis

linear $t = 2.16$ $p = .04$ $R^2 = .441$

quadratic $t = -2.06$ $p = .04$ $R^2 = .389$

Difference Contrasts

5 yrs to 6 yrs $t = .47$ $p = .64$

Sum(5 to 6 yrs)/2 to 7 yrs $t = 2.92$ $p = .01$

Sum(5 to 7 yrs)/3 to 10-12 yrs $t = 1.45$ $p = .15$

BETWEEN GROUPS ANALYSIS:

No significant results were found.

The means suggest improvement between 11 and 12 years of age.

* Efficiency Ratio = # rewards/#responses

** All 53 subjects were tested on the Delay Task yearly between 5 and 7 years of age and once between the ages of 10 and 12 years (i.e., at 10, 11, or 12 years of age).

with girls performing significantly better than boys.

Figure 14 about here

For a measure of sustained attention, the errors of omission on the Vigilance Task of the GDS, repeated measures analysis between 6 and 10-12 years of age yielded a significant age by gender interaction and a significant main effect of age (Figure 15). The presence of a linear interaction between age and gender indicated that the mean number of errors decreased significantly with increasing age, however at different rates for boys than for girls. The analysis of simple main effects revealed that the only significant difference in performance on this measure between males and females was at 10-12 years of age. This result suggested that subsequent to committing an equal number of omission errors, girls began to improve more rapidly than boys from age 7 to 10-12 years of age. In support of this finding, between groups analysis from 10 to 12 years of age yielded a significant main effect of gender indicating that females committed a smaller number of errors of omission in the performance of this task between 10 and 12 years of age.

Figure 15 about here

Executive function versus underlying domains (Table 23; Figures 2, 3, & 12)

In this section EF and non-EF tasks that were part of the same assessment tool were analysed together to explore developmental differences between EF skills and the

Figure 14
GDS Vigilance Task, Commissions - Performance across age

REPEATED MEASURES ANALYSIS:

Main Effect of Age

Trend Analysis

linear $t=-5.40$ $p<.001$ $R^2=.969$

Difference contrasts

6 yrs to 7 yrs $t=-1.51$ $p=.14$

Sum(6 to 7 yrs)/2 to 10-12 yrs $t=-5.38$ $p<.001$

BETWEEN GROUPS ANALYSIS:

Main Effect of Gender

males to females $t= 2.44$ $p=.02$

* All 53 subjects were tested on the Vigilance Task at 6 and 7 years of age and once between the ages of 10 and 12 years (i.e., at 10, 11, or 12 years of age).

Figure15
GDS Vigilance Task, Omissions - Performance across age

REPEATED MEASURES ANALYSIS:

Interaction - Age by Gender

Trend Analysis

linear $t=2.16$ $p=.04$ $R^2=.677$

Simple Main Effects

6 yrs $t=-1.47$ $p=.15$

7 yrs $t=.10$ $p=.92$

10-12 yrs $t=2.56$ $p=.01$

BETWEEN GROUPS ANALYSIS:

Main Effect of Gender

boys to girls $t=1.97$ $p=.05$

* All 53 subjects were tested on the Vigilance Task at 6 and 7 years of age and once between the ages of 10 and 12 years (i.e., at 10, 11, or 12 years of age).

underlying abilities of the task.

A two-factor completely within groups analysis was conducted with age and Numerical Memory as the repeated measures factors. Since gender did not play a role in the development of either Numerical Memory I or II when analysed separately, it was excluded as a factor to increase the power of the analysis of these two tasks together. A significant interaction between age and Numerical Memory was found (Figure 2). Trend analysis yielded significant linear, quadratic, and cubic components to the interaction. However, the linear trend was the most prominent accounting for 82.3% of the variability in performance between the two tasks across age. Analysis of simple main effects and examination of the observed means indicated that development on Numerical Memory I began earlier than Numerical Memory II. After 4 years of age performance on Numerical Memory II began to improve and by 7 years of age children were performing at the same level on the two Numerical Memory tasks.

In the three-way ANOVA comparing Digits Forward and Digits Backward from the Digit Span subtest of the WISC-III the significant results were a two way interaction between gender and task and two significant main effects, age and task (Figure 3). The simple main effects performed for the gender by task interaction indicated that for both boys and girls performance on the digits forward portion of the task exceeded that for the digits backward portion of the task. However, this difference was more pronounced for the boys. That is, as compared to girls, boys performed worse on the Digits forward portion and better on the Digits Backward portion of the task. The main effect of age suggested an improvement in performance over the two year age span from 10 to 12 years

of age, although the repeated contrasts were insignificant.

In the analysis of the Trail Making Test, Parts A and B, gender was discarded as a factor since it did not contribute any significant results to the analysis of each portion of the task when considered separately. A significant main effect of task for the number of errors committed on the Trail Making Test indicated that the children committed less errors on Part A of the test than on Part B (Figure 12a). In terms of the time taken to complete the Trail Making Test, there was a significant age by task interaction that displayed a negative linear trend (Figure 12b). The simple main effects suggested that although the time needed to complete Part A may not have decreased between 10 and 12 years of age, there was significant progression for the time recorded to completion of Part B in this age range. The most significant disparity between Parts A and B was noted at 10 years of age. The age by task interaction no longer achieved significance when the analysis was computed with the reduced sample. As mentioned, the TMT-B time recorded is negatively correlated with prenatal exposure to marijuana in the original sample ($r = -.36$). However, given that the means at each age were almost identical for the original and reduced samples the loss of significance is likely attributable to an observed reduction in power ($N=53$, power=.74; $N=45$, power=.43) and not to the reduction of the number of children prenatally exposed to marijuana.

IV. DISCUSSION

The principal objective of this longitudinal study extending from 3 to 12 years of age was to examine behaviour purported to reflect prefrontal lobe function from a developmental perspective. Data from the administration to one sample throughout childhood of numerous psychometric measures that assess executive function (EF) ability and others assessing non-executive function (non-EF) skills were examined to achieve a more thorough understanding of the development of EF behaviour in terms of: 1) the stability of individual differences across age, and 2) developmental continuity (i.e., patterns of maturation across age).

A few general issues relevant to the present study will precede a detailed discussion of the specific findings from the analyses of stability and continuity in the development of EF behaviour. The limitations of the current study will be outlined. Within the discussion of the limitations of the present study, the issue of the overrepresentation of children prenatally exposed to drugs and the results of stability and continuity which appear to be influenced by this issue will be addressed and discussed. Directions for future research will be suggested.

Consistent with recent developmental research in the area of prefrontal lobe function, executive functioning skills are observable in some rudimentary form early in childhood. Most of the developmental studies in this area have focused on the period between 6 years of age and early adolescence in their examination of the emergence and

developmental progression toward mastery of EF processes in children (Becker, Isaac, & Hynd, 1987; Chelune & Baer, 1986; Chelune & Thompson, 1987; Levin, et al., 1991; Passler, Isaac, & Hynd, 1985; Weyandt & Willis, 1994). Luria (1973) demonstrated, using a task that involves verbal regulatory control over motor behaviour, that functioning associated with the prefrontal lobes is beginning to develop significantly between 4 and 7 years of age. The current study has led to the confirmation of Luria's (1973) findings, that EF behaviour is observable and begins to progress earlier than was previously thought. The present findings indicate that even the years prior to age 6 appear to be meaningful in the development of executive processes. Although, the variety of tasks that were employed in the present longitudinal analysis may seem disparate in terms of their requirements in areas such as verbal and spatial domains of function, the common underlying element unifying these tasks is their demand(s) on the processes of EF (i.e., working memory, mental flexibility and interference control). Based on the examination of performance on most of the developmental tasks employed in the current study as indices of EF, working memory, mental flexibility and interference control were detectable at some level at 3 years of age, the earliest age tested.

Previous work in the area has maintained, as a focus, the attainment of adult levels of functioning based on children's performance on behavioural tasks designed for adults. In a developmental context, a shift away from reaching adult executive functioning on adult tasks is necessary in order to adequately explore the process of development, and not only the final stage of development (Welsh & Pennington, 1988). For these purposes, adult tasks are often inappropriate. The use of adult measures early in development may

mean that some frontal functions go undetected for reasons unrelated to frontal functioning. Children may find adult tasks difficult due to length of the task or due to the complexity of the underlying, non-frontal demands of the task (Smith, Kates, & Vriezen, 1992). In such instances children's functioning is not maximized, and the presence or development of EF abilities can go unrecognized. Therefore, to gain a more thorough understanding of the developmental process of executive functioning abilities, age-appropriate measures are needed. Due to the nature of the Ottawa Prenatal Prospective Study (OPPS), the longitudinal study from which the current sample and data are derived, numerous age-appropriate measures had been administered to the same group of children throughout development, from infancy to early adolescence. Although some of the developmental tasks employed in the current study are not considered traditional measures of EF, their involvement in the processes of EF were outlined in detail in the introductory section of this paper.

However, even with the use of developmentally appropriate tasks, the point in development at which EF behaviour can be detected, and the developmental progression of the actual process of EF are not easily demonstrable. Executive function is an overarching concept that can be operationalized within many different domains, permitting its measurement with a variety of assessment procedures. The developmental progression that is observed is somewhat dependent on the development of the non-EF abilities that are particular to the content of the tasks (Becker et al., 1988; Dennis, 1991; Gnys & Willis, 1991; Levin et al., 1991; Passler et al., 1985; Smith, Kates, & Vriezen, 1992; Welsh & Pennington, 1988; Welsh et al., 1991; Weyandt & Willis, 1994). Executive

functions and the frontal lobes do not develop in isolation from other brain areas and their respective cognitive systems. This can complicate the study of EF, making it difficult to isolate the behaviours associated with prefrontal lobe functioning and to assign the acquisition of these behaviours to specific points in development. Consider, for example, the analysis of reverse digits (Numerical Memory II) and the Puzzle Solving tasks of the McCarthy Scales in the present study. Both of these tasks are proposed to place demands on the working memory system of executive function. However, the former is a verbal task and subjects did not succeed on this task until after 4 years of age. The latter task, Puzzle Solving, is a visuoconstructional task and successful performance was already achieved and improving at 3 years of age. Therefore, in the study of EF, incorporating the examination of the maturation of other, non-frontal cognitive systems, such as verbal and spatial functioning, may be of importance. In the present study, converging evidence from diverse behavioural tasks was gathered to assess EF skills. In order to determine whether improvement in performance was due to the development of underlying task domains or to the development of the EF abilities involved, certain discriminant measures (i.e., similar yet non-EF tasks, such as the Peabody Picture Vocabulary Test-Revised (PPVT-R), forward digit span (from the McCarthy Scales and the WISC-III) and the Trail Making Test Part A (TMT-A)) were included for examination across age. These non-frontal tasks served as a developmental frame of reference in the investigation of the development of the cognitive systems of the prefrontal lobes. Although most researchers do include non-EF tasks in their study of EF, the statistical comparison between EF and non-EF tasks is not an issue that has been tackled previously. One of the advantages of

the present study was that certain EF and non-EF tasks were derived from the same measures, thus they shared the same scale of measurement. This permitted statistical comparison between some of the EF and non-EF tasks (e.g., forward and reverse digits, TMT parts A and B). As will be seen below, these comparisons illuminate differences between the patterns observed in the development of executive functioning abilities as compared to the development of the underlying domains of function involved in the tasks.

Stability

The objective of the examination of stability was to determine whether there is consistency of individual differences in EF behaviour across age. Correlations between repeated performance on EF and non-EF tasks were examined. Only those tasks that were administered to this sample repeatedly throughout development were used to examine longitudinal stability.

Most of the literature covering the issue of longitudinal stability tends to examine the consistency of individual differences across various tasks at certain points in development. For example, scores on infant tests are often used to predict functioning on a variety of different tests that are administered later in development (e.g., Kaplan, 1996; McCall, Eichorn, & Hogarty, 1977; Siegel, 1989). From this perspective, consistency in children's performance is highly dependent on similarities between the tasks administered at different developmental periods. A minimal amount of research assessing the issue of longitudinal stability in the performance of the same task over time in childhood, as has been investigated here, is available. Any evidence in the existing literature in support of

stability or instability of individual differences across age in the behaviours examined in this study, as measured by study of the same task across age, will be discussed in relation to the present findings.

In the present study, there were no gender differences in stability across age on any of the measures examined, non-EF and EF, indicating consistency of individual differences across the sexes in the development of behaviour.

The following EF measures included in the present study were not able to provide any conclusive evidence regarding the stability of individual differences: Block Building, and reverse digits from the McCarthy Scales, and the efficiency ratio from the Delay Task of the GDS. Scores on each of these three measures, displayed very little variability within the ages tested due to a ceiling effect on Block Building, a floor effect on reverse digits, and the limited range of possible scores on the efficiency ratio (i.e. scores range from 0 to 1). Under such circumstances, individual differences become relatively trivial and the issue of cross-age stability is difficult to address, thus limiting the conclusions that can be drawn from the examination of stability with these three tasks. Ideally, developmental stability should be assessed with scores that cover a broader range than a ratio, and in the absence of floor and ceiling effects, in order to ensure sufficient variability in scores within ages and to maximize the information that can be extracted from the cross-age stability within the age range studied.

Non-executive Function Measures

The cross-age correlational analyses of the non-EF measures, the PPVT-R and forward digits on the McCarthy Scales, indicate that in the development of non-EF skills, individual differences remain relatively stable between 3 and 10-12 years of age for both boys and girls. This constancy in the rate of development across age in this group of children is suggestive of a consistency in the quality of certain non-EF skills, such as verbal ability, and short-term memory (i.e., brief storage of information) throughout childhood.

Executive Function Measures

Working Memory

Children's working memory tends to display stability of individual differences across age in the domains of verbal and spatial functioning, with the exception of a transitional phase which is apparent on two tasks between 5 and 7 years of age.

On the Spelling subtest of the Wide Range Achievement Test-Revised (WRAT-R) and the Category Test, the only time at which stability was not achieved was when performance at age 5 was correlated with performance at 7 years of age. Given that stability was achieved over all of the ages studied on these measures with the exception of this one correlation, the overall pattern across age is considered one of stable individual differences for both tasks. However, the brief period of instability from 5 to 7 years of age reflects a temporary shift in the pattern of individual differences in the performance of each of these tasks.

Perhaps this period of instability arises for these two tasks due to a transition that occurs in a common element between the two tasks. The WRAT-R Spelling subtest is a working memory task. Although the Category test is classified for the present purposes under the heading “mental flexibility”, it is also described as placing demands on the working memory system. Each task requires the ability to hold isolated pieces of information on line for integration into a whole concept. The WRAT-R Spelling test requires the subject to make sound-letter correspondences, and combine the letters to form the word dictated (Stage & Wagner, 1992; Kreiner, 1992). The Category Test involves the extraction of a predetermined sorting principle from the presentation of a series of pictures varying on a number of dimensions (Spreen & Strauss, 1991). Therefore, the commonality between these two tasks may be that of abstraction and concept formation.

This raises the question of why the transitional phase of individual differences between 5 and 7 years of age was observed only with the WRAT-R Spelling and Category tests, and not with the other tasks that are claimed to involve abstraction and concept formation, such as the Puzzle Solving task of the McCarthy Scales. One could argue that although the Puzzle Solving task requires subjects to combine pieces into a whole object, the isolated pieces of each puzzle are concrete and readily available throughout the task. In the case of the WRAT-R Spelling and the Category tests, the component pieces that must be combined to form the concept are presented initially, but must be maintained as mental representations in working memory in order to successfully perform the task. As documented by White (1995, 1970) it has long been thought that an emergence in

symbolic and abstract thought are among the processes responsible for a behavioural transition between 5 and 7 years of age. It seems possible that this type of behavioural change (i.e., in abstract thought) may be manifest in the form of a brief instability of individual differences across the period between 5 and 7 years of age. Thus, in relation to the current findings, the period of transition that was observed for the WRAT-R Spelling and Category tests between 5 and 7 years of age may be thought of in terms of the temporary rearranging of individual differences in the acquisition of new abilities, such as abstraction and concept formation that are based on mentally represented information.

The stages of Piaget's theory of development (1929, 1952, 1954) provide some support for the emergence of executive functions in early life and their developmental progression from childhood through to early adolescence. For example, in the preoperational stage from 2 to 7 years of age, thinking tends to be guided by external stimuli. However, the acquisition and progression of language skills during the preoperational stage permits simple conceptualization and verbal control. Gradually throughout this stage rudimentary mental representations are within a child's capacity. The developmental timing of the transitional phase in stability, described above, that occurs as the working memory system develops appears to be in accordance with the emergence of the ability to mentally represent external information, described by Piaget during the preoperational stage of development.

Mental Flexibility

Verbal fluency is the spontaneous generation of words within a specified category, thus requiring mental flexibility. Based on verbal fluency behaviour, mental flexibility appears stable between 3 and 7 years of age. Providing an extension to the present findings, one study found that, verbal fluency shows temporal stability over a 2 to 5 month period in children between 6 and 16 years of age (Kindlon, Mezzacappa, & Earls, 1995). Therefore, individual differences in verbal fluency, thus mental flexibility behaviour, are stable across relatively short temporal intervals (i.e., 2 to 5 months), from childhood to adolescence.

The data available for the present study did not permit the assessment of stability of mental flexibility beyond 7 years of age. Two versions of both mental flexibility tasks, verbal fluency and the Category Test, were employed in the OPPS. Stability was analysed using the earlier versions of these tasks, both of which were administered up to 7 years of age. The later version of each task, the phonological verbal fluency test and the six subtest version of the Category test, were administered to the sample once between the ages of 10 and 12 years. Given that these later versions of the verbal fluency and Category tests were administered only once, and not repeatedly, they could not contribute to the analysis of longitudinal stability.

Interference Control

Across-time correlational analyses on the interference control variables suggest that the components of interference control are characterized by differential patterns of

stability in terms of individual differences. Scores reflecting response inhibition indicated instability across age and sustained attention across age were suggestive of stability over a period of 6 years.

The ability to inhibit prepotent responding, based on the commission errors from the GDS Vigilance task, was unstable across age from 6 to 10-12 years. This finding indicates that individual differences in impulse control were not preserved. That is, the relative position of individuals with respect to each other was changing regularly throughout this developmental period. Welsh and Pennington (1988) suggest that instability across age implies that skills are in poorly established form. The lack of developmental stability in response inhibition suggests that children's ability to control impulsive responding is developing at differential rates across individuals between 6 and 10-12 years of age resulting in inconsistent individual differences throughout this time period.

Parent ratings of impulsivity (i.e., ratings on the impulsivity-hyperactivity factor on the Revised Conners Parent Rating Scale (CPRS-R)) have been shown to display correlational stability across an 8-year follow-up period in a group of hyperactive children from 4 to 12 years of age (Fischer, et al, 1993). The discordance between the present findings and those from the study by Fischer and colleagues regarding the stability of response inhibition over age may be related to the differences between the samples (i.e., normal versus hyperactive children) or the use of different types of measures as indices of impulsivity (i.e., a child's performance on a cognitive task versus parental rating of behaviour).

Sustained attention, the other aspect of interference control, as measured by the number of errors of omission on the Vigilance task of the GDS was stable from 6 to 7 years of age. Although the other correlations obtained for this measure between 6 and 10-12 years of age did not achieve statistical significance, they are larger in magnitude than any of those obtained for the measures of response inhibition. This may be indicative of differential patterns of stability across age for the two different aspects of interference control, suggesting relative instability of response inhibition compared to relative stability of sustained attention across the ages studied.

In the assessment of inhibitory control over responding in children, using tasks described as involving suppressing/initiating activity to a signal, and effortful attention, performance was found to be stable longitudinally from toddler to early school age (3 to 5.5 years of age; Kochanska, Murray & Coy, 1997). Further research needs to be conducted to investigate the inconsistencies between the current findings and previous findings on the stability of individual differences in interference control across age.

In the present study, the longitudinal relationships of repeated performance on various executive function tasks across age from the perspective of the stability of individual differences, suggest that certain aspects of EF behaviour show distinct patterns of stability across age. Within the cohort of the present study, children's relative standings show constancy for many different types of behaviour, executive function and non-executive function. That is, those subjects who were experiencing difficulty relative to the rest of the sample at one age, continued to show greater difficulty at each follow-up age in

terms of verbal functioning (non-EF), short-term memory (non-EF), mental flexibility (EF) and sustained attention (EF). In terms of executive functioning, these findings suggest that even with the addition of an EF component, such as mental flexibility or sustained attention, to an otherwise non-EF task, children's behaviour is as enduring and predictive as the underlying non-EF skills. This provides evidence in support of the value of verbal fluency and vigilance measures in the assessment and prediction of EF behaviour, specifically mental flexibility and sustained attention from childhood through to early adolescence.

On the other hand, other aspects of EF, such as working memory and response inhibition, did not demonstrate the same level of stability that is observed with the other tasks. Working memory exhibited a similar, but not identical pattern of stability to the pattern described in the previous paragraph. Long range stability of working memory behaviour appears to be achieved from 5 to 10-12 years of age suggesting an equally enduring and predictive process compared with non-EF skills, mental flexibility, and sustained attention. However, between 5 and 7 years of age, there appears to be a transitional phase in an aspect of working memory in terms of instability of individual differences. That is, there appear to be differences across individuals in the rate of developmental change in abstraction and concept formation ability that is guided by mentally represented information from 5 to 7 years of age. In support of this finding Piaget documents an emergence of the ability to mentally represent external information in the preoperational stage of development (between 2 and 7 years of age).

Contrary to previous published findings, individual differences in the ability to inhibit responding in this sample showed no developmental stability from school age to early adolescence (i.e., 5 to 10-12 years of age). Individual differences in impulse control are not yet established in children at this stage, unlike non-EF behaviour and other aspects of executive function. The discovery that response inhibition has not yet stabilized during the period of development from 5 to 10-12 years of age, and the transitional phase in working memory between 5 and 7 years of age contribute to the delineation of the limitations in predicting aspects of EF skills later in childhood from earlier function.

Developmental Continuity

The examination of stability, as was discussed in the previous section, reflects changes in the position of individuals with respect to each other on tasks throughout development (i.e., the consistency of individual differences across age). However, longitudinal stability does not reveal the developmental advances in executive function behaviour that occur with time. The analysis of developmental continuity involved the examination of developmental profiles of performance on tasks of EF and non-EF for patterns and periods of improvement in competence over age. The terms continuity and discontinuity refer to linear and non-linear patterns of change in level of competence that occurs with development, respectively.

Specific results of the analysis of developmental continuity will be discussed below within the sections of “Non-executive function measures” and “Executive function measures”. More general issues that arose in the investigation of developmental

continuity (i.e., continuous versus discontinuous development, EF versus non-EF behaviour and gender differences) will be discussed following the specific task results.

Non-executive Function Measures

Development of verbal, non-executive functioning skills is continuous from early school age through to early adolescence, as demonstrated on the PPVT-R and the two digits forward tasks (i.e., Numerical Memory 1 and the Digits forward portion of WISC-III Digit Span task) analysed between 3 and 12 years of age. However, on a non-verbal, non-EF task, the TMT-A, no developmental progression of skills was noted between 10 and 12 years of age. This disparity in development of non-EF skills that is observed between 10 and 12 years of age is most likely attributable to task difficulty. On both the PPVT-R and the digit span tasks, the items are of increasing difficulty, maintaining the challenge posed by the task as the subject's performance improves. The TMT-A is a visual motor task that requires subjects to connect numbers in sequence. Such simplistic demands likely render this task too easy for children as they approach their adolescent years. If development in the performance of the TMT-A task had been examined prior to early adolescence, continuous progression on this task may have been apparent.

Executive Function Measures

Working Memory

Working memory can be conceptualized as a complex process involving retrieval from past experience, transient storage of information that is used to guide future

responding and anticipation and planning for future action. Functioning of the working memory system can be tapped through a variety of domains of function. In the present study, working memory was indexed using a series of tasks that appear very different in terms of underlying function (e.g., verbal or spatial), but that share a common demand for the working memory skills outlined above. Based on the examination of these verbal and spatial tasks, there appears to be a common pattern in the development of the ability to utilize the working memory system. Development of working memory ability appears to be a continuous process from childhood through to early adolescence (i.e., 3 to 10-12 years of age). In terms of verbal behaviour, this overall developmental pattern of change in working memory ability across age suggests that development of verbal working memory appears to be no different from development of verbal, non-EF behaviour.

Gaulin & Campbell (1994) examined verbal working memory across age as measured by performance on a task modelled after the procedure employed and referred to in the present study as the Auditory Working Memory task (Daneman & Carpenter, 1980). In their version of the Auditory Working Memory task, called the Competing Language Processing Task (CLPT), the sentences were shorter and less difficult than those in the original task. On the CLPT children were found to improve with increasing age between age 6 and 10 years, but no improvement was noted between 10 and 12 years of age.

Consistent with Gaulin and Campbell's findings, in the present study, no developmental progression was observed between 10 and 12 years of age on the Auditory Working Memory Task. Similarly, on numerous other working memory tasks used in the

present study, including, the Block Design, Object Assembly, and Picture Arrangement subtests of the WISC-III no developmental advances in performance were noted between 10 and 12 years of age. These findings are suggestive of the attainment of a developmental plateau in working memory ability by early adolescence.

However, development does continue into early adolescence on certain working memory tasks, as evidenced by continued improvement in task performance between 10 and 12 years of age on the WRAT-R Spelling subtest, and Digits Backward, Mazes and Similarities of the WISC-III. To account for this disparity, perhaps when administered in early adolescence, certain tasks no longer impose any demands on the EF system, as compared with when they are administered earlier in childhood. In support of this possibility, Denckla (1994) claims that the nature of the stimuli used in some tasks, such as the Block Design, Object Assembly and Picture Arrangement subtests of the WISC-III, is too familiar and practised for the core components of EF to be sufficiently challenged. That is, with familiarity and practice the performance of certain tasks may become automatized. With increases in automaticity, the execution of cognitive processes requires less effort, is a less active process, and may no longer involve EF abilities (Case, 1985). In the present study, the observed plateau between 10 and 12 years of age on the Auditory Working Memory task and the Block Design, Object Assembly, and Picture Arrangement subtests of the WISC-III is likely related to an increase in automaticity in the performance of these tasks. On the other hand, if the working memory task is designed such that the novelty and the complexity of the task is maintained as the child gets older, the working memory system is likely still activated during task performance. In the present study,

improvement in task performance continues between 10 and 12 years of age on the WRAT-R Spelling subtest, and Digits Backward, Mazes and Similarities of the WISC-III suggesting that working memory is still required to perform these tasks in early adolescence.

One task purported to involve working memory, the Block Building subtest from the McCarthy Scales, was unable to provide conclusive evidence regarding the developmental continuity of behaviour. The approach toward a ceiling effect early within the age range studied (i.e., by 4 years of age) made it difficult to claim continuous or discontinuous development based on cross-age performance of this task. Block Building was initially proposed to provide a very rudimentary assessment of concept formation ability, thus involving working memory skills. Based on the attainment of a ceiling level of performance at such an early age, the demands of the McCarthy Block Building task are considered more basic than some of the other measures employed. In addition, Block Building on the McCarthy is a copy task, and thus requires mainly visual-spatial skills. Given these two factors perhaps this Block Building task does not pose sufficient demands so as to be considered an adequate assessor of executive function.

Mental Flexibility

Mental flexibility refers to the ability to maintain and shift responding when necessary. The findings in the present study with respect to the development of mental flexibility across age are not consistent. The examination of verbal fluency, a verbal mental flexibility task, in early childhood yields differential developmental patterns

according to gender, continuous for boys and discontinuous for girls. On a spatial mental flexibility task, the Category test, development appears continuous prior to adolescence. Concerning the period from 10 to 12 years of age, cross-age performance on all of the mental flexibility tasks examined (phonological verbal fluency, the Category Test, and the Trail Making Test Part B (TMT-B)) suggests that children reach a developmental plateau in the ability to maintain and shift responding by age 10 or 11 years. The discovery of the attainment of a plateau during this developmental period on mental flexibility tasks is consistent with development on some non-EF tasks and some working memory tasks.

On the verbal fluency task of the McCarthy, although the level of performance for boys and girls was comparable at 3 years of age and then again at 7 years of age, the developmental profiles of children in this sample, within this time frame differed when the children were grouped according to gender. Between 3 and 6 years of age, while boys' development on verbal fluency was continuous, girls' development appeared stage-like or discontinuous.

Townes, Martin, Trupin, and Goldstein (1980) document that, between 5 and 8 years of age, females have been observed to be superior in verbal processing ability. A meta-analysis of 165 studies indicates that many studies show female superiority in verbal ability throughout life (Hyde & Linn, 1988). Regarding gender differences, Denckla (1994) cautions "where verbal mediation invades executive function assessment, be alert for females superiority". In consideration of these statements, given the verbal nature of the task, the developmental pattern of verbal fluency observed in the present study is consistent with the literature. It is possible that the more rapid progression in verbal

fluency behaviour that is observed for girls between 3 and 6 years of age may be due to a superiority in verbal ability relative to boys at this age, irrespective of the executive function requirements of the task.

However, the pattern of gender differences in development of verbal fluency across age was not observed on two other verbal tasks examined in the present study, the PPVT-R or the WRAT-R Spelling subtest. The PPVT-R is a receptive vocabulary task that is classified for the present purposes as a verbal, non-EF task. On the PPVT-R, no gender differences were noted until after 7 years of age, at which time boys' performance very slightly surpassed that of girls. The WRAT-R Spelling test is an oral dictation requiring the subject to utilize working memory skills to produce the correct spelling of words. No gender differences were noted in the cross-age examination of the WRAT-R Spelling test. Verbal fluency involves mental flexibility in order to spontaneously generate the maximum number of words within a specified category. As mentioned, gender differences in verbal fluency were indicative of female superiority between 3 and 6 years of age. Given the differential EF requirements and the disparity in observed gender differences for each of these verbal tasks (PPVT-R, WRAT-R Spelling and verbal fluency), it is possible that the differential developmental course between the sexes on verbal fluency could be understood in terms of EF behaviour. While girls and boys experience the same pattern of development of verbal skills between 4 and 7 years of age in the absence of any EF demands (PPVT-R) or with additional working memory demands (WRAT-R Spelling), upon the addition of a mental flexibility requirement to a verbal task, girls develop earlier than boys between 3 and 6 years of age. Further investigation is

needed to determine whether the difference in developmental course of verbal fluency between girls and boys is in fact related to mental flexibility, a component of EF, or to the development of the underlying verbal ability.

On another mental flexibility task, the Category test, the continuity findings are consistent with those found by other researchers for the Wisconsin Card Sorting Test (WCST). The WCST is very similar to the Category test, both tasks involving abstraction, concept formation, and maintenance and shifting of response sets in accordance with the task. The period between 6 and 10 years of age is deemed by other researchers as the most significant period of development of the skills required for the WCST (Chelune & Baer, 1986; Levin et al., 1991). In examination of the performance across age on the WCST, it has been noted that improvement is linear with age up to 10 years, at which time adult levels of functioning are achieved (Chelune & Baer, 1986; Levin et al., 1991). Consistent with these findings, in the present study, improvement on the Category test between 5 and 7 years of age was linear and no change in performance between 10 to 12 years of age was noted, indicating the attainment of a developmental plateau. Unfortunately, due to the limited data available and the use of two separate versions of this task, one between 5 and 7 years and the other between 10 and 12 years, there was no data available on the Category Test in the interim between age 7 and age 10. However, based on concordance between the present findings within the time frame examined and previous findings with this type of task, it is speculated that developmental change on the Category test is likely to continue in a linear fashion between 7 and 10 years of age.

Interference Control

The concept of interference control comprises both response inhibition (i.e., inhibition of competing, prepotent information) and sustained attention. The developmental continuity findings with respect to both of these aspects of interference control can be summarized as follows. Response inhibition appears to be characterized by distinct patterns of development depending on the specific measure used for assessment of this ability. Two indices from the GDS, the efficiency ratio (# rewards / # responses) from the Delay Task and the number of commission errors from the Vigilance Task were employed as indicators of response inhibition and yielded differential developmental results. Based on the efficiency ratio of the Delay task, impulse control appears to progress in a discontinuous fashion across development, indicating at least one specific period where a marked improvement occurred, between 6 and 7 years of age, and perhaps again between 11 and 12 years of age. On the other measure, the number of errors of commission on the Vigilance task of the GDS, development of response inhibition was measured as linear and gradual across age between 6 and 10 to 12 years of age. Maturation on a measure of sustained attention, the omission errors on the Vigilance Task of the GDS, was also continuous from 6 to 10-12 years of age.

In a previous study, investigating developmental trends across childhood on a Continuous Performance Test called the Test of Variables of Attention (TOVA) revealed that attention and impulse control appear to develop in a non-linear fashion between 6 and 16 years of age (Greenberg & Waldman, 1993). The paradigm of the TOVA is very similar to the GDS Vigilance task, involving measures of omission and commission, thus

indexing sustained attention and response inhibition. As measured by the TOVA, development of these two components of interference control was rapid early in childhood, then continued at a slower rate into later childhood and adolescence. That is, the number of omission and commission errors decreased curvilinearly with increasing age up to 16 years of age. The findings of other studies also suggest that the period of greatest developmental change in interference control occurs early in development, prior to adolescence (Becker, Isaac, & Hynd, 1987; Levin et al., 1991; Passler, Isaac, & Hynd, 1985).

The study by Greenberg and Waldman (1993) extended up to 16 years of age, 4 years beyond the oldest age tested in the current study. If the age range in the present study had extended beyond 12 years of age, development on the Vigilance task would likely have exhibited a similar curvilinear trend to development on the TOVA as observed by Greenberg and Waldman (1993). In the present study improvement in attention and response inhibition, as measured by the errors of omission and commission on the Vigilance task of the GDS, appears linear with age. However, it was also noted that improvement in performance did not continue into early adolescence (i.e., between 10 and 12 years of age). In addition, other researchers have identified 12 years of age as significant in terms of mastery of the skills of interference control (Becker, Isaac, & Hynd, 1987; Passler, Isaac, & Hynd, 1985). Given that children seem to reach a developmental plateau in the ability to control interference by 10 to 12 years of age, if the age range covered in the present study had extended beyond this point in development (e.g., up to 16 years of age as in the study by Greenberg and Waldman referred to previously), the

plateau in interference control may have been observed to continue into later adolescence. Under these circumstances development across age on sustained attention and response inhibition would likely have exhibited a curvilinear trend. Similar to the developmental trend described for sustained attention and response inhibition by Greenberg and Waldman (1993), results for the present study would most likely have exhibited the period of greatest development for these functions early in development, followed by less rapid change as children approach adolescence.

In summary, both the efficiency ratio and the commission errors assessed in the present study suggest that response inhibition (or impulsivity) develops in a non-linear, discontinuous manner. Development on the efficiency ratio indicates identifiable phases of development between 6 and 7 years of age and between 11 and 12 years of age. The pattern of development across age on the commission errors of the Vigilance task indicates that progression on this measure is rapid in the school age child and development appears to level out as the child approaches adolescence.

Although the developmental patterns of change described for both of these measures can be considered discontinuous, they are distinct. Initially, the efficiency ratio and the number of commission errors were similarly presumed to assess the ability to inhibit prepotent responding. To understand the disparity between these two measures in the developmental progression of response inhibition across age it may be of importance to consider the differences between the two tasks from which these indices were drawn. The number of commission errors is collected during the Vigilance Task which is described as a task that provides a direct assessment of interference control. In this task

the child is required to sustain attention, and selectively respond to a specified target stimulus in the absence of any reinforcement. The Delay Task, which yields an efficiency ratio, should perhaps be considered a task that is more complex than the Vigilance task. In addition to requiring the ability to inhibit responding to obtain rewards, this paradigm also involves anticipation of when to respond and the use of feedback to guide responding, as it is the subjects task to determine the reinforcement schedule. It is possible that the complex interplay of the numerous demands of the Delay task is reflected in the efficiency ratio, thus leading to the collection of a measure that perhaps should not be considered comparable to the number of commission errors on the Vigilance task. This difference may contribute to the differential patterns of discontinuous developmental progression across childhood that were observed with these two measures.

Based on all three of the measures used to assess the interference control component of executive function in the present study, development of impulse control and sustained attention has reached a plateau by 10 years of age. Similar to the findings for non-EF behaviour and the other components of EF at this point in development, this finding provides evidence of the approach toward a developmental plateau in many different aspects of behaviour, EF and non-EF, between 10 and 12 years of age.

A summary of the findings on developmental continuity are presented below. Development on non-EF measures, working memory tasks and on some measures of mental flexibility, appears to be continuous within the age range studied, from 3 to 10-12 years of age. In terms of EF abilities, from childhood through to adolescence, children

appear increasingly able to cope with the complexity of tasks requiring working memory, and mental flexibility without displaying any identifiable stages of functional development.

Development on one measure of mental flexibility (verbal fluency) and measures of interference control demonstrated discontinuity in their maturational course. Girls tend to develop verbal fluency skills (i.e., spontaneous flexibility, mental search and organization skills) earlier than boys between 3 and 6 years of age, after which time girls and boys progress on verbal fluency at the same rate. There is some uncertainty in the interpretation of this finding with respect to why development of verbal fluency is discontinuous for girls prior to 6 years of age, and not for boys. As previously discussed, this discrepancy may be due to female superiority in verbal ability at this time or perhaps girls' ability to manage the additional complexity of a mental flexibility component to this type of verbal task at an earlier age than boys. On the efficiency ratio from the Delay Task of the GDS, during the period from 6 to 10-12 years of age, there appears to be identifiable phases of development in impulse control, specifically from age 6 to 7 and again from 11 to 12 years of age. Based on the Vigilance task of the GDS, aspects of interference control develop in a non-linear manner such that changes early in childhood occur rapidly and level out as children approach adolescence. Therefore, the development of verbal fluency and of the components of interference control, is considered discontinuous relative to underlying non-EF skills, working memory, and mental flexibility.

In an attempt to tie together all of the information presented above several summary statements can be made regarding developmental continuity and discontinuity. Based on the present findings it would appear that development of behaviour such as

executive functioning may include both stage-like and continuous progression across age. Continuous and discontinuous development are not differentiated based the division of the construct of EF into the components outlined in the present study. The finding that children's executive functions can progress gradually and continuously over time or in a more stepwise fashion is likely dependent upon the specific demands of the tasks and the differences between the measures collected as indices of executive functioning abilities. According to Uzgis (1989), most theories do not describe development of behaviour in general as either continuous or discontinuous. Rather, most theories of development "recognize both types of change [continuous and discontinuous] in relation to different aspects of functioning" (Uzgis, 1989).

Subsumed under the rubric of EF are numerous different behaviours. For this reason, traditionally, the construct of EF is argued to be a non-unitary concept. Factor analytic studies conducted with batteries of executive function measures have yielded multiple factors (Levin et al., 1991; Shute & Huertas, 1990; Welsh, Pennington, & Grossier, 1991). Although EF is multifaceted, it is an integrative process and its constituents are not mutually exclusive. Most tasks used to index EF ability involve multiple aspects of the construct, therefore, researchers are not able to completely isolate its components with the use of different tasks. In the present context, tasks were argued to be predicated mainly on one aspect of EF (working memory, mental flexibility or interference control), although most do involve the other aspects as well, to some degree.

The present study offered an opportunity to explore whether EF assessment reflects a unitary or non-unitary aptitude throughout development. The finding that stability and continuity of development was achieved across age on many tasks of EF, regardless of task differences (i.e., verbal, spatial demands), provides some support for the conception of EF as a process that represents the integration and unification of a set of higher level functions. However, certain tasks included in the present investigation indicated that stability and continuity were not universal findings across EF tasks. Patterns of instability were apparent on working memory tasks requiring abstraction and concept formation from mental representations, and on tasks assessing the response inhibition component of interference control. Discontinuity of developmental change was observed on verbal fluency (a mental flexibility task) and on measures on interference control. Unfortunately, the different patterns of stability and continuity that were observed were not differentiated solely on the three components of EF; working memory, mental flexibility and interference control. Perhaps the development of the components of EF, as outlined, are not as distinct prior to adolescence as might have been expected or maybe the division of the tasks in the present study was not appropriate for the question of developmental continuity. Given that most of the research in the area of EF has been conducted with adults, the partitioning of the construct of EF into components is based mostly on adult functioning. It is possible that the fractionation of EF in the present study is inappropriate for the study of executive functioning in children. Given these preliminary findings, does the domain of EF need to be fractionated or differentiated to the degree that

it has been? Based on the developmental evidence, perhaps EF is better understood as a composite representing the combination and coordination of numerous processes.

EF versus Non-EF abilities

In general, development of both EF and non-EF behaviour occurs with increasing age. However, the developmental timing of the emergence of non-EF skills and EF abilities appears distinctive. Based on the comparison between specific EF tasks and their analogous non-EF counterparts (i.e., Numerical Memory I and II, digits backward and digits forward from the WISC-III Digit Span task, and TMT-A and TMT-B), non-EF skills tend to develop earlier than skills involving working memory, or mental flexibility, two of the component processes of executive function. For example, based on the combined analyses of the McCarthy Numerical Memory tasks, on forward digits, not only did subjects demonstrate successful performance at the earliest age tested (i.e., 3 years of age) but the most significant progression on this task occurred by age five. Development on reverse digits did not begin until after age 4 years of age, later than on forward digits. On the other tasks included in this section (WISC-III Digit Span and the TMT), the level of competence on the non-EF tasks was consistently better than on the corresponding EF tasks at each point in development within the time frame studied.

The non-EF measures used in this portion of the study provided an assessment of the rudimentary skills required for successful performance of the analogous EF portion of the task. The addition of EF demands, such as working memory or mental flexibility, to those underlying skills adds complexity to a task rendering it more difficult to perform and

resulting in slower onset of that behaviour. Due to the integrative, higher-order nature of the construct of EF, performance of EF tasks involving components of working memory and mental flexibility require more developmental maturity than non-EF tasks posing otherwise similar demands. Perhaps the addition of an EF component to a task, in the area of working memory or mental flexibility, requires additional resources and/or more processing space that are not available at the same time the subjects are able to perform the non-EF portion of the task.

With respect to interference control, there were no measures available for inclusion in the present study that provided indices of both non-EF behaviour and the aspects of interference control (i.e., sustained attention and response inhibition) sharing the same scale of measurement.

In addition to differential timing in terms of the emergence of behaviour, working memory and underlying non-EF skills may display differential patterns of development. The examination of performance across age on digit span tasks raised this possibility. Between 3 and 7 years of age, although the emergence of reverse digits (EF) occurred later than forward digits (Non-EF), developmental progression on reverse digits was faster and by 7 years of age, children had achieved the same level of competence on both portions of this task, executive function and non-executive function. On the WISC-III Digit Span task, a task very similar to Numerical Memory, subjects between 10 and 12 years of age performed the digits forward portion with greater success than the digits backward portion. Unfortunately, no data was available from 7 to 10 years of age, in between the administration of the Numerical Memory and Digit Span tasks. However, the

present findings may be suggestive of diverging levels of competence between digits forward and digits backward tasks between age 7 and 10 years of age, resulting in superior performance on the former, non-EF task, by 10 to 12 years of age. Development on digits forward and digits backward occurs at different rates from 3 to 7, and by age 7 competence on both tasks appears equal. Between 7 and 10 years of age children may again display differential rates of development on digits forward and digits backward tasks. Further research is needed to determine the contribution and influence of the non-frontal components to tasks on the development of executive function (Smith, Kates, & Vriezen, 1992).

Gender

Certain behavioural differences that arise in development are gender related. However, the literature available on the subject of sex differences in cognitive functioning is replete with inconsistencies, and in many instances sex differences in performance on cognitive tasks are not pronounced relative to the individual differences within each sex (Burstein, Bank, & Jarvik, 1980; Lezak, 1995). Thus, findings with respect to gender differences in cognitive functioning should be interpreted with caution.

In the present study, certain gender differences were apparent in the observation of the development of EF behaviour. The developmental profiles of children in this sample differed when the children were grouped according to gender on specific tasks. Most of the gender differences found in the present study, with the exception of verbal fluency, are likely unrelated to executive functioning and can be attributed to the most common sex-

related differences observed in cognitive functioning, those within the domains of verbal and spatial skills (Spreeen, Risser, & Edgell, 1995).

In the domain of verbal abilities, the results of the present study are inconsistent. On the PPVT-R, a verbal non-EF task, boys improve very slightly faster than girls between 7 to 10-12 years of age. None of the other verbal tasks employed in the current study provide corroborating evidence for male superiority in verbal ability (i.e., the WRAT-R Spelling subtest, digit span tasks, the McCarthy verbal fluency task). A meta-analysis combining the results of 165 studies indicates that a small portion of studies (about 6%) report that boys perform better than girls on verbal tasks across development (Hyde & Linn, 1988).

In the development of verbal fluency behaviour, boys' progression was gradual and relatively constant across the ages tested. The girls tended to experience more discontinuous or curvilinear development of verbal fluency between 3 and 7 years of age. By age 6 both boys and girls were performing at the same level and developing at the same rate. There is some uncertainty in the interpretation of why development of verbal fluency is discontinuous for girls prior to 6 years of age, and not for boys. As discussed in a previous section, this discrepancy may be due to female superiority in verbal ability between 3 and 6 years of age or perhaps girls' ability to manage the additional complexity of a mental flexibility component to this type of verbal task at an earlier age than boys.

Within the realm of spatial functioning, performance on two tasks in the present study suggest male superiority in the area of spatial abilities: the Block Design of the WISC-III and the six subtest version of the Category test between 10 and 12 years of age.

These findings are consistent with previous research which has shown that boys tend to outperform girls in visuospatial function in early adolescence (Kirk, 1992; Lezak, 1995; Maccoby and Jacklin, 1974; McGee, 1979; Townes, et al., 1980). Based on the spatial nature of both the Block Design and Category Tasks, this gender-related difference in performance is likely related to a common underlying spatial aspect of the tasks rather than their EF demands.

Between 10 and 12 years of age on the Vigilance task of the GDS girls were committing significantly fewer errors of omission and commission, indicating better capacity for sustained attention and better impulse control than boys. Corroborating evidence of the aforementioned gender differences in interference control were found in a study conducted by Greenberg and Waldman (1993), observing performance on a Continuous Performance Test that is very similar to the GDS Vigilance task. Greenberg and Waldman (1993) found that males display more omission, and commission errors than females between 6 and 16 years of age. It appears that girls' ability to sustain attention and inhibit responding throughout childhood and early adolescence develops earlier than boys'.

Limitations

Conducting the present study was not foreseen when the OPPS was originally planned and initiated. Therefore, consistent with the nature of an archival study, from the perspective of the sample, the parts of the developmental timetable that were investigated,

and the specific tasks that were administered, there were some limitations that were inherently imposed at the outset of this study.

Given the longitudinal design of this study and the desire to explore the most extensive period of development possible, only a limited number of subjects could provide data for each testing session, thus 53 subjects were retained. In this sample there was an over sampling of children who were prenatally exposed to drugs due to the original purpose of the study when subjects were collected. Therefore, certain steps were taken to exercise caution with respect to the impact of this over representation on the results. The sample was reduced to make it more representative than the original sample, analyses were recomputed, and the results were examined and compared to those computed with the original sample. For the most part, the findings remained unchanged when the number of children exposed was limited. However, the significance of certain results within the analyses of stability and continuity did change. These differences will be discussed briefly below.

In terms of longitudinal stability, cross-age correlations for the original sample of 53 subjects were stable from 4 to 7 years of age on the Verbal Fluency subtest of the McCarthy but, all of the correlations computed with performance at 3 years of age, the earliest age tested, were lacking stability. Performance on the Verbal Fluency task at 3 years of age was found to be negatively correlated with prenatal exposure to nicotine ($r = -.38$). Examination of the issue of the effects of prenatal drug exposure is beyond the scope of this paper. By removing some of the subjects who were prenatally exposed to drugs from the original sample to make it more representative of the general population,

and computing the correlational analysis with this reduced sample of 45 subjects, complete cross-age stability in verbal fluency was obtained between 3 and 7 years of age. Since the reduced sample is considered more representative and the focus of the present paper is not the effects of prenatal exposure to drugs, it was concluded that mental flexibility on this verbal task appears to display stability of individual differences across age.

In terms of developmental continuity (i.e., the progression of skills with age) the results on a few of the tasks studied differed in terms of significance between the original and the reduced sample; the Mazes subtest of the WISC-III, the time recorded for the Trail Making Test Part B analysed separately and the analysis of the time recorded for Parts A and B together. In each of these cases the means at each age (10, 11, and 12 years of age) between the two samples were very similar in magnitude demonstrating the same trend, and the standard deviations remained unchanged. Although both the Mazes test and the time for Part B of the Trail Making Test were significantly correlated with prenatal exposure to drugs (Table 9), the same pattern of results was observed with both the original and reduced samples. In addition, when the number of subjects was reduced there was a significant loss of power to the analyses, likely causing the changes in significance of the results. Therefore, the findings with respect to the Mazes task and the time to complete the Trail Making test that are reported are based on those obtained with the original sample and are interpreted irrespective of drug exposure *in utero*. Any drug relationships in the field of the development of prefrontal functioning are not central to this thesis but would be of interest for future research.

Throughout the OPPS, neuropsychological testing was conducted yearly from 3 to 7 years of age, and then once in the period between 10 and 12 years of age. This data does not address any developmental issues prior to age 3 or specifically at 8 and 9 years of age. Therefore, the basic findings that are evidenced with the current data may not capture everything that is happening throughout development. Conclusions that are drawn with respect to the periods of development that were not directly studied are speculative and require empirical investigation.

With regard to the cognitive/behavioural measures that are used to empirically examine executive functioning there are a number of concerns. Firstly, given the lack of clarity among researchers with respect to the definition of executive function, there is also a lack of consensus on the measures that should be used as indices of the construct of executive function, especially in children. Evidence of the expression of prefrontal lobe function throughout ontogeny reinforces the importance of the use of developmentally appropriate tasks in order to detect and understand aspects of prefrontal functioning in children. However, many of the developmentally appropriate measures used are not designed to assess prefrontal functions. Most of them originate as developmental or neuropsychological measures. The psychometric adequacy of assessment tools used to investigate executive function require neurological validation in order to justify conclusions that frontal lobe function is in fact involved in performance on particular tasks. Although the measures used in this study are not traditionally considered tasks of executive function, as covered extensively in the introductory section of this paper, there is evidence in support of their association with prefrontal lobe function.

Despite the shortcomings that are outlined above, this study provided a unique opportunity to achieve a more detailed understanding of the development of behaviour that is hypothesized to be subsumed under the construct of executive function, prior to adolescence and within a longitudinal framework.

Future Research Directions

The body of neuropsychological evidence in support of the primary association of executive function processes with the prefrontal region of the brain is extensive. Developmentally, ongoing from gestation and extending into adulthood, the anatomical and biochemical maturation of the frontal lobes is likely to relate to the cognitive functions associated with the prefrontal lobes (Case, 1992; Dennis, 1991; Stuss, 1992; Thatcher, 1992). However, our understanding of this relation is incomplete. Attempts must be made to further bridge the gap between the fields of the physiological maturation and the developmental progression of behavioural correlates of the prefrontal lobes. Investigation into the correspondence between the development of prefrontal function as measured by performance on executive function tasks and the timing of the structural development of the prefrontal lobes would be an area of interest for future research.

There is evidence in the literature for differential association between specific executive functions and regions of the prefrontal cortex (Fuster, 1989; Goldman-Rakic, 1987; Petrides, et al., 1993; Smith, Kates, & Vriezen, 1992; Stuss & Benson, 1984). However, as mentioned in the introduction, the relationship between the subdivisions of the prefrontal cortex and specific cognitive functions is not completely understood

(Denckla, 1993; Grattan & Eslinger, 1991). Given that the present study is not an anatomical paper, it is difficult to speculate on the correspondence between patterns of development on tasks involving executive function and the developmental progression of the subdivisions of the prefrontal cortex (i.e., the dorsolateral, orbitomedial and orbital (basal) prefrontal cortices). Further investigation into the role of the development of the subdivisions of the prefrontal cortex in the psychological maturation of the frontal lobes in children is needed.

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APPENDIX A
Outlier Information

Appendix A: Outlier Information

Variable Name		Test Age (in years)	Subject ID #	Raw Score	Standardize d Score	New Value
McCarthy Scales of Children's Abilities	Numerical Memroy II	3	5901	4	7.14	1
		4	3801	4	3.36	1
		4	5692	6	5.16	2
		4	5901	4	3.36	1
	Block Building	4	6411	4	-4.57	5
		5	5351	7	-4.74	8
		5	6152	7	-4.74	8
		6	5352	8	-7.14	9
	Puzzle Solving	3	3801	12	3.59	10
		5	5352	2	-3.18	4
		7	5721	9	-3.10	**
GDS Delay Task	# of rewards	5	2142	5	-3.38	*
		6	5531	12	-3.57	*
		7	5351	12	-3.58	*
		10-12	5901	22	-3.04	*
GDS Vigilance Task	# of errors of omission	10-12	6041	30	-3.82	33
	# of errors of commission	5	5981	99	5.12	55
		6	6321	82	3.22	75
		10-12	6041	15	3.82	12
		10-12	6171	37	3.66	32
WISC-III	Picture Arrangement	10-12	5352	1	-3.02	4
Trail Making Test	Part B - # of errors	10-12	5692	4	3.25	3
			6321	6	5.10	4
	Part B - time to completion	10-12	6321	90.81	3.57	69.53
	total # of errors	10-12	5692	4	3.01	**
			6321	6	4.78	5
WRAT-R Spelling		5	6081	26	3.24	23
		10-12	6151	16	-3.57	27

*This value was used to compute the efficiency ratio on the GDS Delay task and therefore, was not adjusted.

** The next most extreme score in the distribution for this variable is the same as the value obtained and identified as an outlier.

APPENDIX B
Relationship Between Outcome Variables and Prenatal Exposure to
Marijuana, Nicotine and Alcohol

Appendix B
Correlations between drug exposure and outcome variables

Tasks	Age in years (in months)																			
	3 (36)						4 (48)			5 (60)			6 (72)			7 (84)			10-12 (120-144)	
	MAR	NIC	ALC	MAR	NIC	ALC	MAR	NIC	ALC	MAR	NIC	ALC	MAR	NIC	ALC	MAR	NIC	ALC		
PPVT	--	--	--	-.11	-.25	.17	.03	-.13	-.002	-.03	-.31*	.20	.05	-.19	.07	.12	-.27*	-.03		
NM1	-.09	-.12	-.20	.005	-.13	-.02	.03	-.19	-.10	.18	-.36**	-.18	.17	-.12	-.28*	--	--	--		
NM2	-.10	-.12	-.10	-.16	-.20	-.16	-.16	-.20	-.14	.12	-.14	.004	.11	-.20	-.05	--	--	--		
BB	-.01	-.06	.13	.02	-.22	-.09	-.17	-.02	-.02	.10	-.28*	-.11	.	.	.	--	--	--		
PS	-.06	-.19	-.10	-.01	-.11	-.07	-.03	-.21	-.16	-.01	-.23	-.08	-.08	-.17	-.07	--	--	--		
VF	-.09	-.38**	.04	.10	-.09	.22	.07	-.03	.19	.23	-.21	-.003	-.02	-.21	.14	--	--	--		
DIGFWD	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.25	-.02	-.22		
DIGBKD	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.16	-.23	.15		
BD	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-.06	-.26	.03		
OA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.10	-.07	.12		
PA	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.18	-.26	.06		
SIM	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.20	-.18	-.12		
MAZES	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-.09	-.31*	-.01		

Appendix B cont'd:

Correlations between drug exposure and outcome variables

Tasks	Age in years (in months)																				
	3 (36)						4 (48)			5 (60)			6 (72)			7 (84)			10-12 (120-144)		
	MAR	NIC	ALC	MAR	NIC	ALC	MAR	NIC	ALC	MAR	NIC	ALC	MAR	NIC	ALC	MAR	NIC	ALC			
	PVF	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--		
	CATERR	--	--	--	--	--	.23	-.002	.01	-.08	.12	.06	-.13	.17	-.05	.05	.26	.12			
AUDWWM	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.25	-.11	.04			
TMTATIME	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-.29*	.00	.10			
TMTAERR	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	.07	-.05	-.15			
TMTBTIME	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-.36**	.08	.10			
TMTBERR	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	-.29*	.02	.001			
DELEFF	--	--	--	--	--	--	.18	.07	.10	-.02	-.14	.16	-.12	.20	.25	.13	-.05	.05			
DELREW	--	--	--	--	--	--	.18	.01	-.00	-.16	-.21	-.11	-.07	.06	-.04	.30*	.00	-.06			
VIGCOM	--	--	--	--	--	--	.15	-.02	.04	-.08	.07	.05	-.02	.07	.03	-.15	-.02	-.07			
VIGOMIS	--	--	--	--	--	--	.15	.24	.22	.11	.24	.08	.11	.20	.12	-.13	.20	.02			
WRATRSPEL	--	--	--	--	--	--	.03	-.20	.09	-.07	-.22	-.03	.21	-.13	-.21	-.03	-.15	-.04			

* indicates $p < .05$

** indicates $p < .01$

MAR=Prenatal exposure to marijuana (Maternal use of marijuana during pregnancy: no use, 1-5

joints/week, > 5 joints/week)

NIC=Prenatal exposure to nicotine (Maternal use of nicotine during pregnancy: no use, 0.1-15.9

mg./day, >16.0 mg./day)

ALC=Prenatal exposure to alcohol (Maternal use of alcohol during pregnancy: no use, 0.1-0.13

oz. AA/day, 0.14-0.85 oz. AA/day, > .86 oz. AA/day)

PPVT=Peabody Picture Vocabulary Test

NM1=Numerical Memory I- McCarthy Scales of Children's Abilities

NM2=Numerical Memory II-McCarthy Scales of Children's Abilities

BB=Block Building-McCarthy Scales of Children's Abilities

PS=Puzzle Solving-McCarthy Scales of Children's Abilities

VF=Verbal Fluency-McCarthy Scales of Children's Abilities

DIGFWD=Digits Forward-Digit Span subtest of the Weschler Intelligence Scale for Children III

DIGBKD=Digits Backward-Digit Span subtest of the Weschler Intelligence Scale for Children III

BD=Block Design-Weschler Intelligence Scale for Children III

OA=Object Assembly-Weschler Intelligence Scale for Children III

PA=Picture Arrangement-Weschler Intelligence Scale for Children III

SIM=Similarities-Weschler Intelligence Scale for Children III

MAZES=Mazes-Weschler Intelligence Scale for Children III

PFV=Phonological Verbal Fluency

CATERR=Catergory Test-Total errors

AUDWM=Auditory Working Memory Test

TMTATIME=Time-Trail Making Test Part A

TMTAERR=Errors-Trail Making Test Part A

TMTBTIME=Time-Trail Making Test Part B

TMTBERR=Errors-Trail Making Test Part B

DELEFF=Efficiency Ratio-Delay Task on the Gordon Diagnostic System

DELREW=Total Rewards-Delay Task on the Gordon Diagnostic System

VIGCOM=Errors of Commission-Vigilance Task on the Gordon Diagnostic System

VIGOMIS=Errors of Omission-Vigilance Task on the Gordon Diagnostic System

WRATSPEL=Spelling Subtest on the Wide Range Achievement Test Revised

IMAGE EVALUATION TEST TARGET (QA-3)

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