DEVELOPMENT OF EXECUTIVE PROCESSES
IN EARLY CHILDHOOD

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ABSTRACT

Although the paediatric literature in the area of executive function has expanded significantly over the past 20 years, there is still an imbalance of knowledge when compared to the adult literature. The present project sought to redress the balance in executive function research by (1) investigating the development of a wide range of executive processes in children between the ages of 3 and 7 years, and (2) examining the effects of early frontal lobe damage on the ongoing development of these skills.

Executive processes were examined within four domains of executive function: attentional control, cognitive flexibility, information processing, and goal setting. A neuropsychological test battery was administered to 99 healthy Australian children between the ages of 3 and 7 years, divided into five age groups (i.e., 3-, 4-, 5-, 6-, and 7-year-olds). To examine the impact of early frontal lobe damage on the development of executive skills, two case studies of children with lesions to anterior regions of the brain were also conducted. The utility of a newly developed test was determined via a pilot study, where 84 children between the ages of 3 and 7 years were administered the Object Classification Task for Children (OCTC), a measure of concept generation and mental flexibility. As the OCTC was found to be a useful executive function measure for use with young children, it was decided to include this task in the test protocol of the larger study.

Findings from the normative study reveal different developmental trajectories for the executive processes under investigation. In particular, the results suggest that the four executive function domains develop at different rates, with subprocesses following similar developmental profiles. Findings from the case studies reveal that early frontal brain damage may interrupt the development of these domains, resulting in a number of executive impairments. The results from this project support the conceptualisation of executive function as a functional system, and suggest that the pattern of developmental profiles may assist clinicians in explaining the range of executive impairments following early frontal brain damage.
DECLARATION

This is to certify that

(i) this thesis compromises only my original work,
(ii) due acknowledgment has been made in the text to all other material used,
(iii) this thesis is less than 100,000 words in length, exclusive of tables, maps, references, appendices, and footnotes.

Diana Petra Smidts
PREFACE

Parts of this thesis were presented at the Annual Meetings of the International Neuropsychological Society in Toronto (February 2002), Hawaii (February 2003), and Berlin (July 2003).


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And finally, I would like to thank the children and parents who participated in the study, without whom this project would not have been possible.
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CHAPTER ONE
Introduction

1.1 A closer look at executive function: definition and theoretical framework

The present study draws upon a number of key concepts enunciated in the field of executive function. The aim of this section is to provide a definition of executive function and to present the theoretical framework used in this study.

1.1.1 Definition of executive function

The term “executive function” is often used as a label for a set of psychological processes necessary for adaptive and future-oriented behaviour. Although the set of cognitive capacities included varies across definitions, the construct of executive function generally denotes a range of “high-level” thought processes, such as planning, problem solving, cognitive flexibility, initiation of action, self-monitoring, inhibition of automatic responses, and self-regulation. These psychological processes allow the individual to coordinate the activities required to attain a goal: to formulate intentions, develop action plans, implement strategies to execute those plans, monitor performance, and evaluate actions (e.g., Glosser & Goodglass, 1990; Levin et al., 1991; Luria, 1973; Stuss, 1992; Stuss & Benson, 1987). In addition to these cognitive activities, executive skills are also implicated in social-emotional processes, such as the modulation of emotions, personal and social decision making, perspective taking, affect, and social self-awareness (e.g., S.W. Anderson, Bechara, Damasio, Tranel, & Damasio, 1999; S.W. Anderson, Damasio, Tranel, & Damasio, 2000; Barrash, Tranel, & Anderson, 2000; Benton, 1991; A.R. Damasio, 1998; Eslinger, Biddle, & Grattan, 1997; Eslinger & Damasio, 1985; Eslinger, Grattan, Damasio, & Damasio, 1992; Stuss & Alexander, 2000).

Much of the early literature concerning executive function has been developed within the context of the psychological outcome from frontal lobe lesions. Damage to the frontal regions of the brain, in particular the prefrontal cortex, is often associated with significant impairments in executive processes, such as poor self-regulation, inability to plan, impaired initiative and spontaneity, and rigid thinking (e.g., Barrash et al., 2000; Grattan, Bloomer, Archambault, & Eslinger, 1994; Lezak, 1995; Stuss &
Impairments in executive processes have not only been reported in adults with lesions to the prefrontal cortex, but also in children (e.g., Benton, 1991; Eslinger, Biddle, Pennington, & Page, 1999; Grattan & Eslinger, 1991; Marlowe, 1992; Mateer & Williams, 1991; Williams & Mateer, 1992). The most prominent sequelae after early frontal lobe damage include poor attention, impulsivity, distractability, poor self-regulation, and difficulty learning and acquiring skills effectively. As will be discussed later in this chapter, the prefrontal cortex is functionally heterogenous, with specific regions of the brain commonly associated with discrete cognitive and behavioural aspects of executive function. For example, the dorsolateral region of the prefrontal cortex has been primarily associated with cognitive, “cool” aspects of executive function (e.g., Diamond, 2002; Diamond, O’Craven, & Savoy, 1998; Kroger et al., 2002; Rezai et al., 1993; Stuss et al., 2000; Weinberger, Berman, & Zec, 1986), whereas the orbitofrontal region is generally linked to more behavioural, “hot” aspects of executive function (e.g., Barrash et al., 2000; H.C. Damasio, Grabowski, Frank, Galaburda, & Damasio, 1994; DeLuca & Diamond, 1995; Tranel, Anderson, & Benton, 1994).

Following observations of executive deficits in patients with frontal lobe pathology, some researchers have used the terms “executive functions” and “frontal functions” interchangeably, thereby presuming anatomically localised functions (Stuss, 1992). According to Stuss and Alexander (2000), however, the relationship between “executive” and “frontal” functions is not that straightforward, since the anatomical underpinnings of deficits in executive processes have not yet been clearly defined. For instance, dysfunction in executive skills have also been identified in patients with lesions outside the prefrontal cortex (e.g., S.W. Anderson, Damasio, Jones, & Tranel, 1991; Glosser & Goodglass, 1990; Walsh, 1985), while the absence of executive deficits has been observed in patients with prefrontal pathology (e.g., Shallice & Burgess, 1991; Stuss, Shallice, Alexander, & Picton, 1995). Thus, although the frontal lobes play an important role in the mediation of executive processes, a strict localisationist approach is inappropriate. Stuss (1992) therefore argues that “executive functions” and “frontal lobe functions” may best be considered as separate constructs, with the term “executive functions” relating more directly to the psychological concept of frontal system functions, without any reference to neuroanatomical substrates.
The debate on the interchangeable use of the terms “executive functions” and “frontal functions” not only reflects a localisation issue, but also emphasises the controversy of conceptualising executive function as a unitary mechanism versus a distinct functional system. This question has been addressed by a number of methodological approaches, including neuropsychological links to statistical methods utilising techniques such as factor analysis (e.g., Della Sala, Gray, Spinnler, and Trivelli, 1998; Levin et al., 1991; Welsh, Pennington, & Groisser, 1991), cognitive neuropsychological approaches (e.g., Goldman-Rakic, 1995a, 1995b, 1996; Shallice, 1990), and, more recently, functional neuroimaging methods (e.g., D’esposito et al., 1995).

While some authors, such as Duncan (1995) and Della Sala et al. (1998) argue for a single, central executive, others (e.g., P. Anderson, in press; Lezak, 1995; Baddeley, 1990, 1996; Burgess, 1997; Kelly, 2000; Stuss & Alexander, 2000; Stuss & Benson, 1986; Walsh, 1985; Welsh et al., 1991; Zelazo, Carter, Reznick, & Frye, 1997) reason that the term “executive function” is a general concept incorporating distinct cognitive processes, each of which is activated in a relatively limited range of tasks.

Using a factor analytic paradigm, Della Sala and colleagues (1998) attempted to investigate the role of a single general executive in the performance of frontal lobe patients on a range of neuropsychological tests. The test battery included five tasks generally thought to measure executive processes (which the authors called “frontal tests”) and five tests not specially devised to tap these skills (“nonfrontal tests”). Factor analysis was applied to the entire test battery and to the five executive function tests specifically, which in both cases yielded a single general factor. Therefore, it was argued that one kind of frontal lobe activity, or a single central executive, may underlie performance on all tests, with the nonfrontal tasks requiring frontal lobe involvement to at least some extent (p. 675). This view, however, leaves a number of unanswered questions about the cognitive structure of such a central executive. Clearly, this conceptualisation of executive function involves a homunculus and is incapable of resolving more technical and specific issues, such as which processes converge on such a general executive factor. In other words, how is executive function accomplished?
In a recent study by Kelly (2000), factor analysis was employed to investigate underlying processes in the area of executive function within a developmental context. While a single factor model appeared to be the most parsimonious adequate solution according to statistical criteria, the findings also supported a multifactor model of child executive function. In particular, a four factor solution provided evidence for different developmental trajectories within the areas of fluency/speeded response, verbal concept formation, motor organisation, and planning/strategy.

A similar multifactor model was suggested by Welsh et al. (1991) and Levin et al. (1991). Welsh et al. documented a three factor model, suggesting the following factors: fluid/speeded response, hypothesis testing/impulse control, and planning. Similarly, Levin et al. reported a three factor model, which included semantic association/concept formation, perseveration/disinhibition, and planning/strategy. These findings suggest that executive function may be conceptualised as a functional system, consisting of different but interrelated processes. While such a multifactor model supports the view of several subdomains within the area of executive function, the factor analytic method does not appear to capture the findings from recent clinically based research, which focuses on executive impairments following focal frontal lesions.

Perhaps a more adequate approach to characterise executive function comes from Walsh (1985), who argues for separate functions, based on clinical observations of patients with focal frontal lobe damage. According to Walsh, the frontal cortex is essential for adaptive behaviour, and plays an important role where there is (1) novelty, (2) complexity, and (3) need for integration. Based on the neuropsychological test performance of frontal lobe patients, Walsh reported that cognitive difficulties often become apparent in situations that require new learning, or adapting old “programmes” to new activities, with patients demonstrating an inability to cope with the demands of a new situation. Another common difficulty of frontal lobe patients is observed in activities that require a mental shift, such as when one is required to shift behavioural action, based on a change in the present situation. Impairments in this area often manifest in an inability to apply newly acquired principles or rules, with patients responding to future occasions with previously learned actions. A third set of cognitive difficulties often observed in frontal lobe
patients involves situations that require the integration of information, such as when one is required to generate a solution to a problem or abstract information in order to categorise. Walsh reported that frontal lobe patients often experience difficulty when they are required to organise material, so that an appropriate task strategy can be set out. Therefore, patients often employ inefficient strategies, resulting in poor task performance.

According to Walsh (1985), the cognitive difficulties accompanying damage to the frontal cortex reflect different functions, which play an important role when an individual is confronted with novel material, particularly when it is lengthy or complex. Cognitive impairments arise from the absence of a frontal guidance system, which is needed to adequately evaluate one’s own actions, recognise errors, and utilise existing information to modify behaviour (pp. 153-154). The conceptualisation of a supervisory guidance system that regulates voluntary behavioural action was further developed by Shallice (1990), who provided a theoretical account for the cognitive difficulties often observed in frontal lobe patients when they are required to cope with non-routine situations. Details of Shallice’s model will be discussed in the next section.

The approach adopted by Walsh (1985) has influenced a number of other researchers, and has set the foundation for a functional systems approach to executive function within a clinical context. For example, based on clinical observations, Lezak (1995) divides executive function into the following subdomains: (1) volition; (2) planning; (3) purposive action; and (4) effective performance. Lezak describes the term “volition” as the mental capacity necessary for intentional behaviour, which includes the ability to formulate goals, initiate activity, and to be aware of oneself in relation to one’s surroundings. Planning is needed to carry out an intention or achieve a goal, and includes the ability to conceive of alternatives, sustain attention, and look ahead. Purposive action involves programming sequences of complex behaviour in an orderly and integrated manner and is needed to translate a plan into a productive activity. Effective performance of the activity depends on the ability to monitor, self-correct, and regulate behaviour. Lezak suggests that these four mental components enable a person to engage successfully in independent, purposive, self-serving behaviour (p. 42). In other words, executive function is the outcome of a number of
interacting subprocesses within domains of volition, planning, purposive action, and effective performance.

Based on their focal frontal lesion work, Stuss and Alexander (2000) have recently conceptualised executive function as a set of specific processes that are related to different neurobiological systems within the frontal lobes (p. 291). Within this conceptual view, the executive function system is related to the frontal lobes, but is not necessarily equivalent to the anterior region of the brain. From a clinical viewpoint, this notion is particularly important, as it provides a supporting framework for explaining the range of executive impairments observed in patients with brain lesions that do not directly impact the frontal lobes. According to Stuss and Alexander, distinct cognitive processes converge on a general executive control function. Thus, a central supervisory system controlling the actions required for a particular task is the sum of the cognitive processes recruited at that moment (p. 296). Clearly, such an approach avoids the frontal homunculus that is implicated in a unitary mechanism, and therefore, appears to be a more adequate conceptualisation of executive function, as observed in the brain damaged patient. However, as such a characterisation is based on studies of adult patients, it is not clear if (1) such differentiation is present from birth, or gradually developing, and (2) consequences of insult are the same as in adults, but more global.

Consistent with the functional system conceptualisation, in the present study, executive function is defined as multiple functional processes that are necessary for goal-oriented and adaptive behaviour. These cognitive processes are thought to be related to distinct but interrelated neurobiological systems within the frontal lobes.

1.1.2 Theories and models of executive function

Due to an interest in understanding the nature of executive function and how human behaviour becomes goal-directed and adaptive, a number of theories and models have emerged. Such frameworks provide a means for investigating and understanding the complex processes involved in executive function, and may assist in the assessment of executive skills. This section aims to review a number of influential theories and models of executive function and to describe the theoretical framework used in the present study.
### 1.1.2.1 The Lurian approach

Perhaps the most influential theory in neuropsychology comes from Luria (1963, 1973), whose approach was primarily based on the observation and assessment of soldiers with focal brain lesions following gunshot/misile wounds during world war II in Russia. Luria views the brain as a “functional mosaic”, with multiple neuroanatomical regions interacting to mediate complex mental capacities (1963: pp. ix-x; 1973: pp. 11, 26-30). According to Luria (1973), cognitive functions, including executive skills, consist of flexible and interactive subcomponents, that are mediated by equally plastic, interactive, neuroanatomical regions (pp. 26-30). He views the central nervous system (CNS) as comprising three interactive functional units, which are subsumed by three distinct neuroanatomical regions. The first unit regulates basic physiological functions that support life, such as wakefulness, mental tone, and heartbeat. The neuroanatomical basis of the first unit includes the subcortex and brain stem structures, particularly the reticular activating system. The second unit is subsumed by posterior brain regions, including occipital, temporal, and parietal cortices, and their connections. This unit is responsible for receiving, analysing, and storing information from visual, auditory, and tactile modalities. The third unit is located in the anterior regions of the brain and is important for the programming, regulation, and verification of mental activity. In other words, this unit acts as a controlling force, regulating higher mental processes, such as planning and self-regulation, and is responsible for the organisation of human behaviour. Thus, the interactive subcomponents that cooperate to establish cognitive functions reflect the activity of specific regions within the brain and the transmission of neural information between these systems. This notion is central to Luria’s work and has had great influence on contemporary neuropsychological approaches.

In order to investigate the dynamic factors underlying neurological syndromes, Luria designed specific assessment methods, with various applications and extensions being used worldwide in contemporary clinical practice and research (Tupper, 1999). Recently, Luria’s concepts of functional systems have also been applied in child neuropsychological approaches (e.g., Korkman, 1999; Korkman, Kirk, & Kemp, 1998; Zelazo et al., 1997).
Only a few researchers have addressed the theoretical aspects of executive function from a developmental perspective. Following the Lurian approach, Zelazo and colleagues (1997) attempted to ground the construct of executive function from a developmental neuropsychological perspective. According to Zelazo et al., the construct of executive function refers to a complex activity with an outcome that is taken to be the solution to a problem. The general principles of complex functions also apply to the problem-solving framework: (1) there are many different ways to get to the same outcome, and (2) the structure is hierarchical in nature (pp. 199-200). The problem-solving framework proposed by the authors is designed to integrate four temporally distinct phases of problem solving: representation, planning, execution, and evaluation. According to this model, solving a problem involves four distinct steps (and additional substeps), which the authors take to be the main aspects of executive function (p. 201). Zelazo et al. suggest that each step incorporates a number of cognitive processes. For example, in order to construct a representation of the problem (step 1), the individual is dependent on the ability to selectively attend to different aspects of a situation (selective attention) and to shift between attentional sets (cognitive flexibility). Thus, in this framework, executive function is treated as a macroconstruct that summarises how subcomponents are coordinated to accomplish the higher-order function of problem solution (p. 201). From a developmental perspective, a major advantage of such a framework is that it breaks down the subcomponents of executive function, and therefore allows for the investigation of the development of key processes, within different aspects of goal-directed behaviour. While this model appears to be useful within a developmental context, it may not address all aspects that fall within the domain of executive function.

1.1.2.2 Information-processing models

Information-processing models emerged in the 1950s, advocated by the British psychologist Broadbent (1958), who used a filter model to describe the processing of information. According to this theory, there is a central cognitive processing system, which contains a selective filter that sifts incoming stimuli, excluding all irrelevant information. Despite its simplicity, Broadbent’s model provided important insights on which later information-processing models were built. Since its emergence, Broadbent’s model has been modified to incorporate several stages, with the physical properties of stimuli being analysed in the lower stages, and
further processing of information occurring in the higher levels (Treisman, 1960, 1964; Van Zomeren & Brouwer, 1994).

Using a similar framework, Neisser (1967) provided the groundwork for the development of an information-processing paradigm from which to describe executive function. He presented a theory, in which the executive system is compared to a computer program, which consists of independent “subroutines”. Neisser referred to “executive control” as the orchestration of basic cognitive processes (such as perception and memory) during goal-oriented problem solving. In other words, the executive component is superordinate to other routines. The main activity of the executive routine is to control the order in which the subroutines are applied, which varies from one occasion to the next. Thus, in this framework, the executive system is the aggregation of the subroutines applied at any moment, for any task. This conceptualisation of executive function was further elaborated by Norman and Shallice (1986), who suggested that non-routine behaviours, such as learning how to drive a car, are coordinated by a cognitive mechanism, which they called the “supervisory attentional system” (SAS). In contrast to the framework proposed by Neisser (1967), this cognitive model distinguishes between routine and non-routine activities. According to Norman and Shallice (1986), routine activities do not require a central controller, but are governed by what they call schemas. Schemas are standard programs for controlling overlearned skills, such as making breakfast. Individual schemas might include lower-order schemas as subroutines. For example, the schema for making breakfast might call up subordinate schemas for buttering bread, pouring tea, and other breakfast activities (Stuss & Benson, 1986). The selection of appropriate schemas for the execution of a routine task is called “contention scheduling”. Contention scheduling is adequate for routine actions, however, whenever novel situations or changes in activities are encountered, this sort of action planning is inadequate. In such cases, the SAS becomes effective by inhibiting or priming task schemas. Thus, the concept of SAS actually refers to the coordination and regulation of complex actions, which is often regarded as the main characteristic of executive function.

According to Shallice’s (1990) “cognitive neuropsychology approach”, impairments to the SAS may account for the neurological implications of attention in
patients with frontal lobe lesions. These “frontal lobe syndromes” are often characterised by an inability to cope with non-routine activities, and are just what would be expected if the SAS was disconnected from the contention-scheduling system (p. 336). In other words, when the SAS is not working properly, frontal lobe patients are primarily dependent on the contention-scheduling system, which is a process that only carries out routine operations and does not allow the individual to deal with novel, unfamiliar situations. The model described by Shallice not only attempts to describe a system that underlies the control of action and thought operations, it also attempts to localise such a system, thereby enhancing its applicability in neuropsychological contexts. However, within the frontal lobes, no further distinctions between particular neurobiological systems are made.

Attention and executive function are closely related, with considerable overlap between subfunctions (Fletcher, 1998). Attention is usually described as a multidimensional concept, consisting of several components, including selective attention, sustained attention, vigilance, and divided attention (e.g., Cooley & Morris, 1990; Mirsky, 1989). For example, the ability to inhibit a prepotent response is dependent on the capacity to select target information from an array of alternatives, while ignoring irrelevant stimuli. This involves the ability to regulate attentional processes, and more generally, requires self-monitoring of behaviour. Therefore, the capacity to selectively attend to stimuli comes under the umbrella of executive function.

The model proposed by Shallice (1990) was expanded by Stuss et al. (1995), who took the specific information-processing elements of attention, and attempted to describe its various aspects according to Shallice’s approach. Specifically, they attempted to relate attentional processes to different frontal lobe systems by using a new approach, in which they used different experimental methods to provide evidence for specific prefrontal functions. These methods were anatomical, neuropsychological, and physiological, allowing for investigating the relationships between lesion location, behavioural tests, and event-related potentials or ERPs. Using the basic building blocks of subroutines, and solutions derived from information-processing paradigms, they proposed seven attentional components, in which different combinations of independent supervisory processes (such as inhibiting
schemata or adjusting contention scheduling) are activated. The attentional subprocesses include: (1) sustaining attention, which may be linked to the right frontal lobe, (2) concentrating attention, which may be associated with the anterior cingulate, (3) sharing attention, where the orbitofrontal cingulate may be involved, (4) suppressing attention, which may be linked to the dorsolateral area of the prefrontal cortex, (5) shifting attention, which may involve the dorsolateral and medial frontal areas, (6) preparing attention, which may be associated with the dorsolateral area, and (7) setting attention, with the left dorsolateral region of the prefrontal cortex as a possible anatomical basis. Thus, in this framework, areas outside the frontal cortex are also important in attentional control, in keeping with the functional systems model postulated by Luria. This idea is consistent with neuroanatomical findings, which have shown that the frontal lobes are highly interconnected with other areas of the brain, including the posterior cortices, the brainstem, the limbic structures, the thalamus, and the hypothalamus (e.g., Cummings, 1993; Fuster, 1989; Goldman-Rakic & Porrino, 1985; Rezai et al., 1993; Zald & Kim, 1996).

The framework proposed by Stuss et al. (1995) suggests that the multifunctional executive system is related to segregated frontal–(sub)cortical circuits. These circuits are essential for the integration of information from different cortical areas, which is believed to take place within the frontal lobes. This view provides support for (1) the specific patterns of executive impairments observed in patients with focal frontal lobe lesions, and (2) the existence of individual subprocesses within the domain of executive function.

1.1.2.3 Executive function as a central control system

The models outlined above conceptualise executive function as comprising of multiple functional domains. These domains have been associated with different frontal lobe systems, which are believed to underpin specific cognitive processes. According to the demands of the situation, these processes are activated, allowing for goal-directed and adaptive behaviour. Thus, executive function may be conceptualised as a central control system, which coordinates and controls a number of subprocesses. This characterisation has been fine-tuned by a number of researchers investigating cognitive processes necessary for working memory.
A well-known functional model of working memory comes from Baddeley (1990, 1996). Baddeley proposed a framework, where a central executive component is coordinating the simultaneous operation of two subsidiary systems: (1) the phonological loop, which handles speech-based information, and (2) the visuo-spatial sketch pad, which deals with visuo-spatial information. The central executive component is defined as a “work space” with limited capacity to store information, which is necessary to hold information in mind for complex information-processing tasks. Thus, in this model, executive function can be seen as a multifunctional system, comprising two subroutines that are essential for processing visuo-spatial and phonological information, respectively. From this perspective, executive functioning involves coordinating and controlling the activation of specific modalities. Thus, there is a superordinate control entity that evaluates the information that needs to be processed, and calls for the different subroutines accordingly.

A slightly different view has been proposed by Goldman-Rakic (1995a, 1995b, 1996), who suggested a multiple domain model, based on her studies of the nonhuman primate prefrontal cortex. In contrast to Baddeley’s model described above, Goldman-Rakic suggests that the central executive is composed of multiple domains, each subserving different aspects and types of sensory, mnemonic, and motor control elements. Thus, in this model, there are additional domains within the executive control system besides those for phonological and visuo-spatial information. Goldman-Rakic suggests that the prefrontal cortex is the seat of executive operations, as part of an integrated network of domain-relevant areas. In particular, different areas within the prefrontal cortex process different types of information, with each region being part of an independent network of domain-specific cortical areas (Goldman-Rakic, 1996). For example, the prefrontal areas that process spatial information are part of a network that includes portions of posterior parietal cortex (Cavada & Goldman-Rakic, 1989). This view of a central control system has played an important role in our knowledge regarding the neuroanatomical substrates of executive function. More broadly, it has contributed to an understanding of how the organisation of the mind maps onto the anatomical landscape of the brain.

Although the model described by Goldman-Rakic (1995a, 1995b, 1996) has been developed from nonhuman primate research, it has also shown to be applicable
to humans. Many of the concepts included in this view of a central executive have been integrated with child neuropsychological approaches. For example, similar to the delayed-response paradigm used with infant rhesus monkeys (Diamond & Goldman-Rakic, 1989; Goldman-Rakic, 1987), the A-not-B task has been employed to investigate the neuroanatomical substrates of working memory in human infants (e.g., Diamond, 1985, 1988b, 1990; 1991b; Diamond & Doar, 1989). Findings from these human infant studies support the view of the prefrontal cortex, in particular the dorsolateral region, as a neural mechanism underlying working memory. The model proposed by Goldman-Rakic has also been supported by case studies of patients with damage to the prefrontal cortex (e.g., Eslinger & Damasio, 1985; Fuster, 1989; Stuss & Benson, 1986), who frequently experience executive deficits. In addition, neuroimaging studies have provided evidence for the important role of the prefrontal cortex in working memory (e.g., Bor, Duncan, & Owen, 2001; D'Esposito et al., 1995; Smith & Jonides, 1997). However, recent findings have shown that the domain-specific networks may overlap, or may combine with each other, depending on the task requirements, and therefore, some authors have suggested the need to reconsider the model proposed by Goldman-Rakic (Carpenter, Just, & Eichle, 2000; Fiez, 2001). Further research, however, is necessary to investigate how these domain-specific networks interact.

1.1.2.4 Social-emotional aspects of executive function

The models outlined above primarily focus on the cognitive, “cool” aspects of executive function, however, when conceptualising executive function, it is also important to consider behavioural, “hot” aspects. The control or regulatory processes of executive function not only organise and direct cognitive activity, but are also implicated in emotional responses, and more generally, social functioning.

The interest in the social aspects of executive function dates back more than 150 years, when Harlow (1848, 1868) described a dramatic personality change in patient Phineas Gage, a railroad worker who sustained frontal lobe damage as a result of an accidental explosion. In contrast to his personality prior to the accident, Phineas Gage was noted to display inappropriate social behaviour, characterised by poor inhibition and self-regulation. Since the case report conducted by Harlow, several case
studies of patients with prefrontal cortex damage have been reported (e.g., Ackerly & Benton, 1947; Brickner, 1934; Eslinger et al., 1992; Hebb & Penfield, 1940).

Eslinger and Damasio (1985) describe the case of patient EVR, whose orbital frontal surface and the frontal pole were excised bilaterally, due to a large orbitofrontal meningioma. Premorbidly, EVR was described as a loving husband and father, and a cooperative and productive employee. Postoperatively, however, EVR was noted to display a number of executive impairments, including the inability to make decisions in everyday situations, poor self-monitoring, and impulsive behaviour. These behavioural observations indicate that the effects of frontal brain damage extend far beyond cognitive impairments, and may have a significant effect on a patient’s social interactions, and more broadly, quality of life.

Social-emotional deficits following frontal lobe lesions are not restricted to adults, but have also been observed in children. Behavioural impairments in children may manifest as a failure to learn from mistakes, difficulties sustaining friendships, low frustration tolerance, and poor impulse control (e.g., Benton, 1991; Marlowe, 1992; Mateer & Williams, 1991; Eslinger et al., 1997). A more detailed discussion regarding the effects of early frontal brain damage on the social-emotional aspects of executive function will be presented later in this chapter.

Although the work by Walsh (1985) focused primarily on cognitive impairments following frontal brain damage, social deficits were also examined. Walsh suggested that specific social-emotional subprocesses were subsumed by different regions within the frontal cortex and their connections (p. 150). Based on Walsh’s work, later studies have further investigated the role of the prefrontal cortex in social-emotional processes. Specific behavioural deficits have been associated with different regions within the prefrontal cortex. For example, while patients with damage to the orbital frontal cortex primarily experience difficulty inhibiting behaviours, often resulting in hyperactivity (e.g., Eslinger & Damasio, 1985; Fuster, 1989; Grattan et al., 1994; Harlow, 1848, 1868), lesions to the medial prefrontal cortex are often associated with a lack of interest and low awareness, often resulting in hypoactivity (e.g., Lezak, 1995; Fuster, 1989; Stuss & Benson, 1986). These findings suggest that, similar to cognitive aspects, social-emotional processes may fall
within distinct domains of executive function, and may be subsumed by different regions of the brain.

A.R. Damasio (1994, 1995, 1998) proposed a theoretical framework that accounts for the behavioural deficits often observed in patients with prefrontal injuries. Damasio’s idea for the so-called somatic marker theory was based on his observations of neurological patients with damage in the ventral and medial regions of the frontal lobes, who showed severe impairments in personal and social decision making, even though other intellectual abilities were largely preserved. He reasoned that the neurobiological underpinnings of this condition were linked to the compromised ability of these patients to express emotion, and that these aspects played an important role in the pathological process. According to Damasio, the ventromedial region of the brain holds linkages between factual information (such as possible options of action) and the emotional state that in past experience has been associated with the situation. Thus, after a situation has been evaluated, factual knowledge of that situation triggers a bodily response (“somatic marker”), which in turn is used by the individual to guide in the process of reasoning and decision-making. Patients with ventromedial frontal lobe damage fail to link the facts of a situation with the somatosensory state associated with a similar experience in the past (A.R. Damasio, 1998, p. 43). Consequently, the ability to make decisions in one’s personal life is impaired, since decision-making is largely dependent on the somatic markers. In other words, the somatic markers provide the emotional or motivational colouring to factual information, which contributes to the process of decision making. According to Damasio, the absence of a connection between factual information and somatic markers therefore impedes on the ability to consider a cost-benefit analysis of possible options and outcomes.

Evidence for Damasio’s framework comes from a series of experiments aimed at examining the decision-making ability of patients with ventromedial frontal damage in a card gambling task (Bechara, Damasio, Damasio, & Anderson, 1994). This contingency task is thought to tap the capacity to decide in a domain for which an exact calculation of future outcomes is not possible, and choices must be based on approximations. Thus, subjects are dependent on the ability to consider gains and losses, which are related to emotional states associated with these alternatives.
Findings showed that patients with ventromedial frontal damage performed significantly worse on this task in comparison to normal subjects (Bechara et al., 1994).

The framework proposed by A.R. Damasio (1994, 1995, 1998) supports the view of different functional systems within the frontal lobes and appears to be complementary to the cognitive models described earlier. In particular, this framework provides a plausible account for the role of the neuroanatomical and neurophysiological mechanisms underlying social functioning. However, future studies, in particular functional neuroimaging research, are necessary to further investigate the role of the prefrontal cortex in social-emotional processes.

1.1.3 Theoretical framework for the present study

The theories and models discussed above offer useful guiding principles for investigating the factors and processes underlying executive function. While each model may provide unique information regarding the nature of executive function, to some extent, the concepts within each model also overlap. The present study draws upon a number of key concepts enunciated in the frameworks above, and follows the basic tenet of these theories – the characterisation of executive function as a multidynamic system, comprising a number of separate domains.

Following the Lurian approach, the cornerstone for the theoretical framework of the present study is the conceptualisation of interactive components that cooperate to establish executive function and are mediated by distinct neurobiological systems within the brain. These components are considered functionally distinct aspects of executive function, characterised by various subprocesses. Similar to the problem-solving framework proposed by Zelazo et al. (1997), the theoretical framework of the present study treats executive function as a macroconstruct that encapsulates how subcomponents are coordinated to accomplish higher-order complex functioning. Thus, goal-directed and adaptive behaviour is the outcome of a complex activity that involves the interaction of several functional subdomains.

Consistent with information-processing models, the theoretical model of this study incorporates a notion that is central to information-processing models – the
separation between routine and nonroutine activities. The supervisory role of executive function within a complex functional system comes to play in situations that require voluntary control of behaviour, in order for the individual to adapt to changing situations or carry out activities to achieve a goal. Thus, the supervisory executive system activates different combinations of subprocesses, based on the specific demands of a situation. To coordinate and control cognitive activities, the executive system is dependent on attentional control functions, as these processes are necessary for attending to particular stimuli, choosing between alternatives, and monitoring actions. The suggestion that these attentional control processes may involve separate anatomical systems within the frontal lobes, as postulated by Stuss et al. (1995), is also translated into the theoretical framework of the present study.

The models proposed by Baddeley (1990, 1996) and Goldman-Rakic (1995a, 1995b, 1996) provide a comprehensive view of the interconnected levels of brain/behaviour relationships that are essential for working memory. The theory of this study draws upon the basic foundation proposed by these models, in that it is based on a conceptualisation of a central executive, which is composed of several domains, each subserving different functions. However, in the theoretical framework of the present study, the construct of a central executive is not restricted to working memory, but applied within the broader context of goal-directed and adaptive behaviour.

Executive function is not exclusive to cognitive processes, but is also important for social functioning. Consistent with the somatic marker theory proposed by A.R. Damasio (1994, 1995, 1998), behavioural aspects of executive function may be partly related to specific underlying neuroanatomical and neurophysiological mechanisms within the frontal lobes. Incorporating behavioural aspects of executive function is particularly important within a clinical context, as frontal brain damage may have significant effects on the regulation of social-emotional responses, and as a result, impede on a patient’s daily functioning. Taking into account social-emotional aspects of executive function, the theoretical framework of the present study may be applied to investigate impairments of cognitive processes that underlie social deficits following brain damage.
The models discussed earlier provide important insights into the nature of executive function, and consequently, may be important tools for investigating executive processes. However, most of these frameworks have been developed for adult populations, and as a result, developmental expectations have not been considered. As pointed out by V. Anderson (1998), executive impairments in adults are commonly considered “deviant”, while such deficits in children may reflect cognitive processes that are not yet functional. Therefore, caution is required when applying adult models to paediatric populations.

In recognition of the importance of the integration of developmental aspects within a model of executive function, Anderson and colleagues (V. Anderson, P. Anderson, Northam, Jacobs, & Catroppa, 2001) proposed a framework designed for the use with paediatric populations. This theoretical model was based on several studies with school-age children, including normative investigations (e.g., V. Anderson, Lajoie, & Bell, 1996; Levin et al., 1991; Welsh et al., 1991), studies of pathological groups (e.g., Catroppa & Anderson, 1999, Jacobs, Northam, & Anderson, 2001), and assessment development research (e.g., P. Anderson, V. Anderson, & Garth, 2001; P. Anderson, V. Anderson, & Lajoie, 1996). The theoretical model proposed by V. Anderson and colleagues (2001a), and expanded by P. Anderson (in press), is presented in Figure 1.1.

In this framework, executive function is conceptualised as four distinct functional domains. The following specific executive domains were identified: attentional control, cognitive flexibility, information processing, and goal setting. These functional domains are considered to be discrete functions, however, they are highly dependent on each other, with attentional control playing a key role in executive function. Each domain involves a number of integrated subprocesses and receives input from various regions within the brain, including subcortical, motor, and posterior areas (P. Anderson, in press).
Figure 1.1  Theoretical framework used in present study
Support for the view that these domains are discrete, but interactive functions comes from a number of studies investigating the development of executive processes in middle childhood and adolescence (e.g., Levin et al., 1991; Luciana & Nelson, 1998; Welsh et al., 1991; Kelly, 2000; Passler, Isaac, & Hynd, 1985), showing that executive processes within these functional domains have different developmental trajectories. However, as pointed out by P. Anderson (in press), studies investigating the development of executive skills in children are limited and therefore, this assumption requires verification in future developmental research. Nevertheless, an important contribution of this framework is that it hypothesises how different functional domains might work together as an integrated system to direct/manage thought operations and behavioural actions, thereby breaking executive function into groups of interrelated processes. Fractionating executive processes into different functional domains allows us to investigate the different cognitive capacities, strategies, and actions that are necessary to complete tasks.

Since the model proposed by V. Anderson et al. (2001a) has been devised from studies investigating executive processes in middle childhood and adolescence, the subprocesses within the functional domains may not be relevant to a preschool population, where cognitive processes are not well differentiated and, as a result, are difficult to isolate with the use of traditional assessment methods. Therefore, for the purpose of this study, the cognitive processes within the executive function domains have been adapted in order to investigate executive skills in children between 3 and 7 years. For each functional domain, Table 1.1 presents the executive processes that will be the focus of the present study.
Table 1.1
Overview of Executive Processes Within Each Functional Domain

<table>
<thead>
<tr>
<th>Attentional control</th>
<th>Cognitive flexibility</th>
<th>Information processing</th>
<th>Goal setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selective attention</td>
<td>Working memory</td>
<td>Speed of output</td>
<td>Planning and problem-solving</td>
</tr>
<tr>
<td>Inhibition of motor</td>
<td>Concept generation</td>
<td>Efficiency of output</td>
<td></td>
</tr>
<tr>
<td>responses</td>
<td>Shifting between</td>
<td></td>
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<tr>
<td></td>
<td>concepts</td>
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<tr>
<td>Inhibition of verbal</td>
<td>Shifting between</td>
<td></td>
<td></td>
</tr>
<tr>
<td>responses</td>
<td>complex rules</td>
<td></td>
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<tr>
<td></td>
<td>Utilisation of feedback</td>
<td></td>
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</tbody>
</table>

1.1.3.1 Attentional control

The attentional control domain includes the ability to selectively attend to specific stimuli, both visual and auditory, and inhibit prepotent verbal and motor responses. As attentional control plays an important role in a number of cognitive activities (such as deciding between alternatives or monitoring actions), processes within this domain are thought to underlie the more complex processes within the domains of cognitive flexibility, information processing, and goal setting. Deficits in attentional control processes are likely to be reflected by impulsive and inattentive behaviour, poor self-monitoring, and failure to check for mistakes or to complete tasks. Attentional difficulties may have wide-reaching implications for children who may experience difficulty learning new skills, attending to social cues, and acquiring knowledge.

1.1.3.2 Cognitive flexibility

Executive processes within the cognitive flexibility domain include working memory, concept generation, shifting, and feedback utilisation. Working memory refers to the ability to keep information in mind for a certain period of time and use this information flexibly to guide behavioural actions. Concept generation involves the ability to extract information from a group of different stimuli, and is thought to
underlie cognitive activities that require the organisation of perceptions, thoughts, or actions. The ability to shift involves a change in focus, which include switching between different dimensions and switching between complex rules. A response feedback system is also thought to fall within the domain of cognitive flexibility, with the utilisation of feedback thought to be necessary for adapting ongoing action in order to successfully complete activities. Children with impairments within this domain are likely to experience difficulty moving freely from one situation or activity to another, and as a result, may show perseverative behaviour. Further, specific working memory impairments may impact on a child’s ability to hold information in mind, and therefore, whilst performing tasks, the child may experience problems remembering what he or she was supposed to do. A child with such deficits may experience significant problems in daily functioning, for example, a child may get stuck on a topic during conversations.

1.1.3.3 Information processing

Information processing refers to speed and efficiency of cognitive activities and is thought to play an important role in the quantity and quality of output. The rate at which information is processed is believed to be closely related to the status of underlying neural transmission within the entire brain. Deficits in processes within the information processing domain include slowed performance, hesitancy, and reduced response output. Such impairments may restrict the child within his or her social environment, as they may experience difficulty keeping up with peers or siblings in play, learning, and acquiring knowledge.

1.1.3.4 Goal setting

Processes within the goal setting domain incorporate the capacity to plan ahead, set goals, solve problems, anticipate future events, and, within an assessment context, formulate the necessary steps to complete a task. Children with impairments in this domain are likely to experience difficulty coping with complex situations, use inefficient strategies, be easily overwhelmed by lengthy tasks, or unable to plan actions in advance. These difficulties may impact on a number of daily skills, such as efficiently packing a bag, getting dressed, or planning homework. Although simple planning and problem solving skills have been observed in young children (e.g., Welsh et al., 1991; Espy, Kaufmann, Glisky, & McDiarmid, 2001), research has
indicated that the most significant development of these skills takes place after the age of 7 years (e.g., P. Anderson et al., 1996; Krikorian & Bartok, 1998). Therefore, in the present study, most emphasis will be placed on the domains of attentional control, cognitive flexibility, and information processing.

Although the focus of the current theoretical framework is on cognitive aspects of executive function, it may also be applied to investigate social-emotional, or “hot” executive function aspects.

1.2 Development and assessment of executive processes

The theory of Piaget has been a cornerstone of developmental (neuro)psychology for nearly 40 years. In his theory on cognitive development, Piaget (1963) postulated that children progress through four developmental stages and that they do so in the same order: (1) sensorimotor period (0 – 2 years), in which the child’s cognitive system is limited to motor reflexes; (2) preoperational period (2 – 7 years), in which the child becomes capable of representational skills, such as language, mental imagery, and drawing; (3) concrete operational period (7 – 9 years), in which logical reasoning can be applied to concrete objects; and (4) formal operational period (early adolescence), in which the child becomes capable of reasoning on the basis of theoretical possibilities as well as concrete realities. Piaget’s framework has been highly criticised in the past, in particular from the 1960s through the early 1980s (e.g., Ausubel, 1965; Elkind, 1967; Kugelmass & Breznitz, 1967; Vygotsky, 1962). However, his techniques have been widely used to study early cognitive development, including the area of executive function. For example, a number of his paradigms have been used by contemporary researchers to investigate the development of working memory and inhibition in early childhood (e.g., Diamond, 1985; Diamond & Doar, 1989; Espy, Kaufmann, McDiarmid, & Glisky, 1999). In addition, Piaget’s theory has shown to be largely compatible in current understandings of the association between the “spurt-like” development of executive function and growth periods identified within the frontal lobes. In particular, the timing of transitions between the stages proposed by Piaget appears to coincide with growth spurts in frontal lobe development (V. Anderson, 1998). In recent years, the interest in frontal lobe maturation and related development of executive function has burgeoned,
with several researchers suggesting that the improvements in executive processes observed during childhood may be partly related to neuroanatomical and biochemical changes in the frontal lobes (e.g., Bell & Fox, 1992; Levin et al., 1991; Luciana & Nelson, 1998; Thatcher, 1991, 1992). The assumption that the development of executive function is associated with growth processes in the anterior regions of the brain will be the cornerstone of this section. Empirical data and case studies supporting this notion are organised into the following developmental phases: infancy (0 – 2 years), preschool period (3 – 5 years), and middle childhood (6 – 12 years) through adolescence (3+ years).

Before embarking on a discussion regarding the development and assessment of executive function, it is necessary to point out a number of limitations that have hampered the measurement of executive skills in paediatric populations. First, executive skills can only be assessed through tests that also incorporate lower-order functions, such as visual perception, motor skills, and processing speed. Thus, impaired performance on these tasks can either be a result of pure executive function deficits, or emerge secondary to deficiencies in lower-order skills. Moreover, the use of an “endpoint” or summary score (e.g., total score) often used in traditional assessment measures provides little information regarding the role of specific cognitive processes contributing to poor performance. Perhaps a more adequate approach is to use “microanalytic” techniques, such as the use of individual variables from test measures, as opposed to standard or total scores. A second limitation involves the design of assessment measures, with most available tasks developed for adult populations, and few providing normative data with respect to performance of children (P. Anderson, in press). Despite these limitations, several studies have attempted to map the development of executive processes, primarily using tests that have been developed and validated in adult populations. However, in recent years, a number of tasks have been devised specifically for use with children (e.g., Delis, Kaplan, & Kramer, 2001; Espy, 1997; Gerstadt, Hong, & Diamond, 1994; Jacobs, Anderson, & Harvey, 2001; Jacques & Zelazo, 2001; Korkman et al., 1998; Smidts & Anderson, 2002).

1.2.1 Infancy (0 – 2 years)

Studies investigating executive processes in infancy have primarily focused
on the development of inhibitory control, working memory, and focused attention. Historically, the investigation of cognitive development in infants was extrapolated from the findings of research aimed at examining brain function in nonhuman primates. It was found that rhesus monkeys with lesions to the prefrontal cortex showed impaired performance on the classic Delayed Response task (Diamond & Goldman-Rakic, 1989). This task involves hiding an object in one of several locations, imposing a delay of variable time, and then allowing the subject to search for it. The Delayed Response task is almost identical to the A-not-B task, which is typically used to study cognitive development in human infants. In the A-not-B task, which was originally devised by Piaget (1954), an object is hidden in one of two locations, and after a certain time limit, the subject is encouraged to find the hidden object. The primary difference between the Delayed Response task and the A-not-B task involves the sequence of locations in which the object is hidden across trials. In the Delayed Response task, the object is hidden in one of the locations according to a random schedule, whereas in the A-not-B task, the object is consistently hidden in the same location (A) on subsequent trials, until the infant is correct, then the object is hidden at the other location (B), and the procedure repeated. Although the sequence of locations varies in the two tasks, the procedures within trials are identical.

Accurate performance on the Delayed Response/A-not-B task is believed to be dependent on two cognitive processes: (1) the ability to hold a representation in mind (working memory), and (2) the ability to inhibit a motor response (Diamond, 1985, 1988b, 2002; Diamond & Goldman-Rakic, 1989; Goldman-Rakic, 1987). In the A-not-B task, a perseverative error, or “A-not-B error”, is made when infants incorrectly search in location A, while the object is hidden in location B. To account for A-not-B errors, a number of underlying cognitive processes have been proposed, such as deficits in memory and lack of inhibitory control (Diamond, 1991b). Improvement in performance on the Delayed Response/A-not-B task is reflected by the prolonged delay that can be tolerated between hiding and search.

Research has indicated that as infants grow older, they are able to tolerate longer and longer delays on this task, and show marked improvements in their performance between 7 – 12 months of age (Diamond, 1985, 1990). At 12 months, infants can succeed with delays of almost 10 seconds long (Diamond, 1985; Diamond
This developmental pattern was found to be similar in infant monkeys, with mastery achieved by 4 months (Diamond & Goldman-Rakic, 1986). The ability to keep a representation in mind during the time delay between hiding and search is believed to be mediated by the prefrontal cortex, in particular the dorsolateral region. Evidence for involvement of the dorsolateral prefrontal cortex in the memory aspects of the Delayed Response/A-not-B task comes from a number of animal studies. For example, Diamond and Goldman-Rakic (1989) showed that monkeys with lesions to the dorsolateral prefrontal cortex failed on the task whenever a delay was imposed, whereas they performed well when there was no delay. This appeared to be true for both infant and adult monkeys (Diamond, 1990). In contrast, monkeys with hippocampal formation lesions did not impair performance (Diamond, Zola-Morgan, & Squire, 1989).

The development of inhibitory control in infants has also been investigated in a separate task called “object retrieval” (Diamond, 1988a, 1991b). In this task, an object is placed in a clear box that is open on one side. The infant sees the object through one of the closed sides of the box, but must reach through a different side in order to obtain the object. Thus, in this task, the infant is required to inhibit the prepotent response of reaching straight for the object, and instead detour around to the opening. Between 6 and 12 months, human infants improve significantly on the object retrieval task, with mastery achieved by the age of 11 – 12 months (Diamond, 1988a, 1991b). Infant monkeys show a similar developmental pattern between 1 and 4 months (Diamond & Goldman-Rakic, 1986). This developmental pattern is similar to the developmental improvements on the Delayed Response/A-not-B task, suggesting similar neuroanatomical underpinnings. As with the Delayed Response/A-not-B task, it is believed that the dorsolateral prefrontal cortex plays an important role in successful performance on the object retrieval task. It was found that monkeys with lesions to the dorsolateral prefrontal cortex had great difficulty inhibiting the impulse to reach directly to the object (Diamond & Goldman-Rakic, 1985), whereas unoperated monkeys and monkeys with lesions to the parietal or hippocampal regions detoured to reach in the opening (Diamond et al., 1989).

At 12 months, infants can learn to inhibit a simple motor response, but the ability to delay gratification, control emotions, and regulate behaviour develops later.
The development of self-regulation in infants is generally conceptualised as a process in which control is initially undertaken by the caregiver, but is gradually shifted to the infant (Bugental & Goodnow, 1998; Kopp, 1989; Maccoby, 1992; Maccoby & Martin, 1983). According to Kopp (1982), between 12 and 36 months, the child acquires a number of fundamental skills that eventually result in the ability to regulate behaviour: First, between 12 and 18 months, infants become capable of control, which includes the awareness of social demands and the ability to comply with caregivers' requests. Then, by 24 months, children acquire self-control, which further includes the ability to delay on request and begin to regulate behaviour. And finally, at 36 months, they begin to be capable of self-regulation. A similar developmental pattern has been found by Kochanska, Murray, and Harlan (2000), who showed that effortful control (i.e., the ability to delay, slow down motor activity, suppress/initiate activity to signal, effortful attention, and lowering voice) improved considerably between 22 and 33 months.

Similar to the underlying processes of performance on the Delayed Response/A-not-B task, there is strong evidence from neurobehavioural studies that self-regulation is associated with the frontal lobes, in particular the orbitofrontal cortex (S.W. Anderson et al., 1999; S.W. Anderson et al., 2000; Barrash et al., 2000; Benton, 1991; Eslinger et al., 1997; Eslinger & Damasio, 1985). Improvements in cognitive processes observed during infancy appear to coincide with a number of anatomical and biochemical growth processes in the frontal regions of the brain, such as maturation of pyramidal neurons (Koenderink, Ulyings, & Mrzljiak, 1994), increase of glucose metabolism (Chugani, Phelps, & Mazziotta, 1987), synaptogenesis (Huttenlocher, 1990, 1994; Huttenlocher & Dabholkar, 1997; Johnson, 1997), myelination (Holland, Haas, Brant-Zawadski, & Newton, 1986; Kinney, Brody, Kloman, & Gilles, 1988; Klinberg, Viadya, Gabrieli, Moseley, & Hedehus, 1999), and changes in acetylcholinesterase (AchE) staining (Kostovic, 1990). These findings suggest that the period of cognitive growth during infancy may be partly related to neuroanatomical and biochemical changes in the frontal lobes.

In summary, research has indicated a number of cognitive growth processes during the first two years of life. Between 7 and 12 months of age, infants show marked improvements in their ability to keep a representation in mind (working
memory) and to inhibit a prepotent action tendency. They also become capable of withstanding short delays. During the same period, a similar developmental pattern has been found in regards to basic learning skills and simple planning abilities. Then, in the second year of life, infants acquire basic self-control, which includes awareness of their social environment, the ability to endure longer delays, focus attention, and inhibit a natural response in order to perform a modified or different response. These findings indicate that some functions of the frontal lobes (i.e., inhibition, working memory, attentional control, delay on request, simple planning behaviour, and self-control) become effective even before the age of 2 years.

### 1.2.2 Preschool period (3 – 5 years)

Although interest in the development of executive skills during the preschool period has recently burgeoned, there remains a paucity of appropriate measures to assess these processes. Most traditional measures that tap executive capacities have been developed for older children and adults, and are often inappropriate or irrelevant for use with preschoolers. Adult measures often require a number of complex instructions, thereby placing a large demand on working memory capacity and receptive language, skills that are relatively immature in young children. Furthermore, traditional measures are not particularly sensitive to developmental changes in early childhood, and therefore, few normative data with respect to the performance of children are provided. Despite these limitations, a number of researchers have attempted to investigate the development of executive processes in preschoolers by (1) using tasks adapted from adult measures (Gerstadt et al., 1994; Jacques & Zelazo, 2001; Smidts & Anderson, 2001; Welsh et al., 1991), (2) applying designs from developmental and neuroscience literature (Espy et al., 1999; Espy et al., 2001; Welsh, Pennington, Rouse, Ozonoff, & McCabe, 1990), or (3) developing new tasks (Espy, 1997; Korkman et al., 1998).

In order to investigate the developmental pattern of preschoolers’ performance on the A-not-B task, Espy et al. (1999) administered this task to 117 children between 23 and 66 months. It was found that performance on the A-not-B task steadily improved in this age period, with older children retrieving the object on more trials, while making less perseverative errors, than younger children. Using a standard delay of 10 seconds across children and age, it was also found that most children older than
5 years achieved perfect performance on the A-not-B task, suggesting that if a 10-second delay is imposed, the ability to keep a representation in mind and inhibit a motor response reaches ceiling effect around the age of 5 years. However, in some children, perseverative errors may have been minimised, since a 10-second delay may not have been sufficient to elicit these errors (Espy et al., 1999). In addition to the A-not-B task, Espy et al. examined age-related performance on a number of other tasks believed to tap working memory and/or inhibition. These tasks included Self-Control (Lee, Vaugh, & Kopp, 1983), Delayed Alternation (Goldman, Rosvold, Vest, & Galkin, 1971), Spatial Reversal (Kaufmann, Leckman, & Ort, 1989), and Color Reversal (Kaufmann et al., 1989). Performance on these tasks was also related to age, however, performance on Spatial Reversal and Color Reversal did not vary as consistently as the other tasks. This may be due to methodological issues, reducing task variability in the youngest children and thereby reducing the power to detect age effects on these tasks (Espy et al., 1999).

Another task designed to measure working memory and inhibition is Luria’s tapping task, in which the subject is required to tap once when the experimenter has tapped twice, and to tap twice when the experimenter has tapped once (Luria, 1966). In this task, the subject is required to hold two rules in mind and to inhibit the natural tendency to imitate the experimenter. Diamond and Taylor (1996) used Luria’s tapping task to examine age-related development in these skills during the preschool period. They found that between the ages of 3½ and 7 years, children became faster and more accurate, with most of the improvement occurring by 6 years of age.

In addition to tasks that measure inhibitory control of motor responses, a few tests have been developed in order to measure inhibition of verbal responses. One of those measures is the Stroop-like Day-Night test (Gerstadt et al., 1994). In this task, which is based on the Stroop color-word task for adults (Stroop, 1935), children are shown 16 cards with either a sun on it or a moon with stars. The children are asked to say “night” whenever shown a suncard and to say “day” whenever shown a mooncard (see chapter 3 for a detailed description of this task). Thus, children have to keep two rules in mind (working memory) and inhibit a natural response. It was found that children between 3½ and 4 years experienced considerable difficulty on this task, reflected by their difficulty in passing the pretest, the relatively low percentage of
correct responses, and the relatively long time it took for them to respond. Older children did not only pass the pretest with relative ease, but also gave more correct responses, and showed shorter response latencies (Gerstadt et al., 1994). A second task that measures inhibitory control of verbal responses is the Shape School (Espy, 1997). The Shape School is a colourful storybook that was designed to measure inhibition and switching processes in young children. The task involves four conditions: (1) control, where the child is required to name the colours of the depicted figures, (2) inhibit, where the child is asked to only name the colours of figures with happy faces, but skip the figures with sad faces, (3) switch, where the child is required to switch between naming rules, and (4) both, where the child must inhibit and switch simultaneously (see chapter 3 for a detailed description of this task). Espy (1997) found significant age-related changes in performance across all conditions in children between 32 and 68 months old. In particular, 4-year-olds inhibited more efficiently than 3-year-olds, whereas switching efficiency improved between 4 and 5 years of age. The switch condition assesses the capacity to shift between response sets and was only administered to children older than 4 years, as younger children may not be able to process the principles of shape and colour automatically.

In a recent study, Jacques and Zelazo (2001) investigated switching processes in preschoolers using a new task called the Flexible Item Selection Task (FIST). This task was adapted from the Visual-Verbal test developed by Feldman and Drasgow (1951). On the FIST, children are required to select two cards from a set of three cards. These two cards match each other on a particular dimension (i.e., size, number, shape, or colour). This is called Selection 1. Then, using the same set of cards, children are required to select a different pair of cards that match each other on another dimension, which is Selection 2. Thus, there is always one test card that needs to be selected twice according to two different dimensions (Jacques & Zelazo, 2001). Matching two nonidentical cards along a common dimension requires the ability to think in abstract terms and is measured by Selection 1. Selecting one of the cards according to two dimensions reflects the ability to switch between concepts and is measured by Selection 2. Jacques and Zelazo found that 3-year-olds had difficulty identifying a common dimension in two nonidentical cards (Selection 1), whereas 4-year-olds performed as well as 5-year-olds on this condition. Selecting a card according to two different dimensions, however, appeared to be very difficult for
4-year-olds, with 5-year-olds outperforming them on Selection 2.

These results integrate the findings from a line of research primarily investigating rule use in preschoolers, using Dimensional Change Card Sort (e.g., Frye, Zelazo, & Palfai, 1995; Zelazo & Frye, 1997; Zelazo, Frye, & Rapus, 1996; Zelazo & Jacques, 1996). In the Dimensional Change Card Sort, two target cards are presented, each of which is affixed to a sorting tray. Children are asked to sort a series of test cards according to a particular dimension (e.g., for colour, they are told: “Put the blue ones here and put the red ones there”). After several trials, the sorting rules change and children are asked to sort the cards according to a different dimension (e.g., shape). It was found that most 3-year-olds could sort the cards according to one dimension, but had difficulty switching and sorting the cards according to the other dimension. In contrast, the majority of 4- and 5-year-olds had no difficulty switching to the new dimension. In one study (Zelazo et al., 1996) asked the 3-year-olds whether they understood the new rules. Even though the children had knowledge about the new rules, they perseverated by sorting the test cards according to the first dimension. According to the Cognitive Complexity and Control theory (CCC theory: Zelazo & Frye, 1998), 3-year-olds know both pairs of rules, but have difficulty deciding which pair to use, since they lack a higher-order rule to determine which of these pairs to use. In this theory, age-related changes in control over behaviour and environment are explained by the acquisition of increasingly complex rule systems. This view supports the idea that the switching difficulty of 3-year-olds results from limitations in flexible thinking, and not from a lack of inhibitory control of motor responses.

Advances in switching ability between the ages of 3 and 5 appear to coincide with age-related changes in children’s theory of mind (Astington, 1993; Diamond, 2002; Frye et al., 1995; Russel, Mauthner, Sharpe, & Tidswell, 1991). The term “theory of mind” refers to a framework for predicting and explaining what people think and do (Hala & Carpendale, 1997). A theory of mind involves understanding other people’s beliefs, in other words, being aware that different people have different representations of the world. According to Perner (1991), in order to understand beliefs as representations of the world, you need to understand that misrepresentations also occur. Thus, when children acquire a theory of mind, they demonstrate an understanding of conflicting representations, and therefore, the possibility of false beliefs. Since the ability to take another person’s
perspective is dependent on flexible thinking, it is not surprising that the development of children’s theory of mind co-occurs with changes in the ability to switch.

A classic task to measure theory of mind is the “unexpected transfer” or “Maxi” task, developed by Wimmer & Perner (1983), in which the child watches a scene played out with dolls. In this scene, the child is shown that one of the dolls, called Maxi, puts a piece of chocolate in location A, while the other doll is absent. When Maxi leaves the room, the other doll appears and moves the chocolate to location B. Maxi then returns and the child is asked the key question “Where will Maxi look for the chocolate?” Children who understand that beliefs can be mistaken will respond with location B, whereas children who are unable to understand conflicting representations are likely to respond with the first location. Most 3-year-olds respond incorrectly, while 4- and 5-year-olds do quite well on this task (Hala & Carpendale, 1997).

A second traditional task to measure theory of mind is the “appearance-reality” task, in which the child is presented with an object that is later shown to be something else (Flavell, 1986, 1993; Flavell, Green, & Flavell, 1990). For example, the child is presented with a sponge that looks like a rock. Most 3-year-olds have difficulty with this task, while 4- and 5-year-olds typically respond that the object looks like a rock, but really is a sponge (Rice, Koinis, Sullivan, Tager-Flusberg, & Winner, 1997).

In addition to inhibition, working memory, and cognitive flexibility, planning and problem solving skills have also been investigated in preschoolers. Using the 3-disk Tower of Hanoi, Welsh et al. (1991) found significant improvements in performance between the ages of 3 and 4, with mastery of achievement between 5 and 6 years. The Tower of Hanoi, first used by Gange & Smith (1962), is a disk-transfer task, in which children are required to rearrange three disks across pegs to transform the initial state into the model configuration. Despite the use of a shorter, two-trial administration format of the Tower of Hanoi, Espy et al. (2001) found similar results, with older preschoolers being able to solve more problems than younger ones.

In attempting to apply Luria’s theory and methods to children, Korkman et al. (1998) have developed a comprehensive neuropsychological test battery for use with children between 3 and 12 years. The NEPSY, A Developmental Neuropsychological
The *Assessment*, consists of 27 subtests, divided into five functional domains: (1) Attention/Executive Functions; (2) Language; (3) Sensorimotor Functions; (4) Visuospatial Processing; and (5) Memory and Learning. A major advantage of the NEPSY, when compared to other neuropsychological tasks measuring executive function, is that it has been normed on a large standardised sample, allowing for comparison of between-test differences observed in the performance of an individual child. Another advantage of this test battery is that it allows for the investigation of developmental trajectories across different neuropsychological domains (i.e., language, memory).

Within the domain of Attention and Executive Functions, the NEPSY contains six subtests. Although these subtests have been designed to tap several executive processes, within tasks, no clear distinction between subprocesses is made, and therefore, hampers the use of a microanalytic approach. However, to date, the NEPSY is the only comprehensive neuropsychological test battery available for use with preschool children.

In summary, the preschool period is a phase of rapid cognitive development, as reflected by marked improvements in performance on a range of executive function tasks. Between the ages of 3 and 5 years, the ability to inhibit a prepotent response increases significantly, with most of the improvement occurring between 3 and 4 years. When children are required to inhibit and shift simultaneously, difficulties arise for most children younger than 4 years, as reflected by their poor performance on a number of switching tasks. Thus, the capacity to shift between response sets, or think flexibly, appears to emerge around the age of 4, when children also become capable in taking another person’s perspective. In addition to the ability to shift, around the age of 4 years, children also begin to plan ahead and employ simple strategies. These functional improvements may be reflected by the rapid growth processes in the frontal regions of the brain, such as myelination (Holland et al., 1986; Kinney et al., 1988; Klinberg et al., 1999) and the strengthening of connections within the anterior region and from the frontal lobes to posterior and subcortical areas (Hudspeth & Pribram, 1990).

1.2.3 Middle childhood (6 – 12 years) through adolescence (13+ years)

As children grow older, and are required to function more independently, activation of executive processes increases. Research has indicated that these processes develop rapidly in early and middle childhood, and slow considerably
during adolescence (e.g., V. Anderson et al., 2001a; Kelly, 2000; Krikorian & Bartok, 1998; Levin et al., 1991). One of the earliest and most influential studies investigating executive processes in childhood is that of Passler et al. (1985). Using a range of tasks measuring both verbal and nonverbal inhibition in children between 6 and 12 years, Passler et al. (1985) found that (1) some measures tend to reach performance plateaus earlier than others, and (2) some executive processes continue to develop beyond 12 years of age. Subsequently, a number of studies have attempted to map developmental trajectories and pinpoint the ages at which different executive competencies are achieved.

Inhibition processes have been shown to reach adult levels around 6 years of age, with slight improvements through middle childhood (Becker, Isaac, & Hynd, 1987; Passler et al., 1985). Generally, the tasks used to measure these skills in middle childhood are similar to those used with preschoolers, and require the ability to inhibit perseverative responses (conflict tasks) or motor actions in a decision paradigm (go-no go tasks). Further, by the age of 6 years, most children are able to demonstrate basic self-control and regulation of affect, motivation, and arousal (Barkley, 1997; Kopp, 1989).

In contrast to inhibition, the ability to shift between response sets continues to develop beyond the age of 6 years, as reflected by significant improvements in performance on a number of cognitive flexibility tasks between the ages of 6 to 12 years (Chelune & Baer, 1986; Kelly, 2000; Levin et al., 1991; Welsh et al., 1991). Using the Wisconsin Card Sorting Task (WCST: Grant & Berg, 1948), Chelune and Baer (1986) found that children between 6 and 10 years showed marked improvements in their performance, with children older than 10 years performing at adult level. These findings were replicated by Welsh et al. (1991), who showed that adult-level skill on the WCST was attained by age 10, with considerable improvement occurring between the ages of 7 to 8 years.

The WCST not only requires cognitive flexibility, but successful performance on this task is also dependent on the ability to perceive and generate abstract concepts. Other measures that have been used to tap conceptual reasoning skills in children include the Twenty Questions Test (Laine & Butters, 1982), Contingency Naming
Test (Taylor et al., 1990), Verbal Fluency (Gaddes & Crocket, 1975) and the Concept Generation Test for Children (CGT-C: Jacobs et al., 2001). The Twenty Questions Test is a verbal reasoning task, in which the child is presented with 42 pictures, and is asked to guess which picture the examiner has in mind by asking as few yes-no questions as possible. It is believed that the level of abstract thinking is reflected by the number of constraint-seeking questions the child asks. A constraint-seeking question eliminates several alternatives (such as “Is it a living thing?”), and requires the ability to perceive a common concept between a subset of the pictures. Levin et al. (1991) found that the number of constraint-seeking questions increases significantly between the ages of 7 and 15 years, suggesting that conceptual reasoning skills are rapidly developing in middle childhood. Using the CGT-C, Jacobs et al. (2001) also found age-related changes in performance. In this task, which was based on the adult Concept Generation Test (B. Levine, Stuss, & Milberg, 1995), children are asked to sort six stimulus cards according to seven predetermined groupings (i.e., animal habitat, colour of the card outline, shape of the card, direction of the lines, size of the animal, size of the writing, and location of the writing) that are unknown to the child at the time of administration. The task includes three performance levels, with increasing levels of structure. Jacobs et al. found a significant developmental progression in performance in children between 7 and 15 years, with unstructured sorting and switching between concepts most difficult for children younger than 9 years. Since most 15-year-olds were not able to perform at adult levels, it may be suggested that conceptual reasoning skills continue to develop beyond this age.

Other cognitive abilities that continue to develop through middle childhood are planning and problem solving skills. A well known neuropsychological task purported to measure these skills is the Tower of London (Shallice, 1982). This task was originally developed for adults, however, it has also shown to be sensitive to developmental changes in childhood, and is therefore commonly employed in paediatric research and clinical protocols (P. Anderson et al., 1996).

In contrast to the Tower of Hanoi, in which children are required to rearrange three disks across pegs to transform the initial state into a model configuration, in the Tower of London, the subject is required to rearrange three balls on pegs in a prescribed number of moves, so that the new configuration matches the pattern on a
stimulus card. Normative data by Krikorian, Bartok, and Gay (1994) and P. Anderson et al. (1996) suggest that planning and problem solving skills develop steadily in middle childhood. Furthermore, Anderson and colleagues identified specific developmental “spurts” between 7 and 9 years and between 11 and 12 years.

Other tasks that have been used to measure planning and problem solving skills in middle childhood include the Complex Figure of Rey (Rey, 1964), the Tower of Hanoi (Welsh et al., 1991), the Mazes subtest of the WISC-III (Wechsler, 1989), and Porteus Maze Test (Porteus, 1959). The Complex Figure of Rey requires the ability to copy a complex design and, after a time delay, draw the pattern from memory. The level of accuracy and organisation appears to increase steadily from childhood through adolescence (V. Anderson et al., 2001a; Waber & Holmes, 1985). Using the Mazes subtest of the WISC-III, Kelly (2000) found age-related changes in performance between 7 and 13 years, with increments in performance between 7 to 8 years and between 10 to 11 years. Similar findings were reported by Krikorian and Bartok (1998), who reported significant increments in performance on the Porteus Maze Test in children between 7 and 9 years. Thus, planning and problem solving skills are developing rapidly in middle childhood, with specific developmental spurts occurring between 7 to 9 years and 11 to 13 years.

More efficient executive functioning in older children is thought to be a reflection of greater memory capacity, more advanced language skills, and improved information processing (V. Anderson, Northam, Hendy, & Wrennall, 2001). It has been found that, as children mature, they are able to process information more quickly and complete tasks faster (V. Anderson et al., 2001a; Hale, 1990; Kail, 1991a., 1991b, 1993). Attempting to reveal the nature of this developmental trend, Hale (1990) tested four age groups (i.e., 10-, 12-, 15-, and 19-year-olds) on four different tasks: choice reaction time (RT), letter matching, mental rotation, and abstract matching. Her results showed that, across all tasks, the adolescent group required less time to complete the tasks when compared to younger children, suggesting that processing speed changes as a function of age (Hale, 1990). According to Kail (1991a), this developmental pattern can be described by an exponential (nonlinear) function, with initially rapid and then progressively more gradual improvements in processing speed throughout childhood and into adolescence. The increase of processing speed appears
to have a global effect, with speeded performance on a range of different tasks increasing in concert (Fry & Hale, 2000; Hale, 1990; Hale, Fry, & Jessie, 1993; Kail, 1991a; Kail & Park, 1992; Kail, 1993).

Improvement of information processing and more efficient executive functioning is thought to be related to the ongoing maturation of the central nervous system during middle childhood and adolescence. In particular, the increasing myelination of axons is believed to result in faster neural transmission and therefore, allows for more rapid processing of information (V. Anderson et al., 2001b).

In summary, during middle childhood and adolescence, executive processes are likely to develop further, with distinct processes following different developmental trajectories. Inhibition processes, including basic self-control, have been shown to reach adult levels around 6 years of age, with slight improvements through middle childhood. Cognitive flexibility appears to improve between the ages of 6 and 12 years, with considerable progress occurring before the age of 10. Between 7 and 15 years of age, children also improve in their ability to think in abstract terms and generate concepts, with older children less dependent on structure. Planning and problem solving skills also appear to mature rapidly in middle childhood, with specific developmental spurts occurring between 7 to 9 years and 11 to 13 years, and are likely to demonstrate further development in adolescence.

1.2.4 Summary

Executive processes appear to emerge in a spurt-like manner, with several marked improvements occurring between birth and adulthood. Inhibition processes appear to be functional in children as young as 12 months, and develop rapidly between 1 and 6 years of age. The capacity to shift between response sets, or think flexibly, appears to emerge around the age of 4, and continues to develop throughout middle childhood, with most of the improvements occurring between the ages of 6 and 10 years. In addition to the ability to shift, around the age of 4 years, children also begin to plan ahead and employ simple strategies. Planning and problem solving skills appear to mature rapidly in middle childhood, with specific developmental spurts occurring between 7 to 9 years and 11 to 13 years, and are likely to demonstrate further development in adolescence. Speed of information processing improves
throughout childhood and is believed to underlie improved performance on a number of executive function tasks.

The functional improvements observed during childhood can be aligned with neurophysiological developments within the frontal lobes, in particular the prefrontal cortex, suggesting that executive processes are dependent on the integrity of the frontal lobe systems. The next section reviews the role of the frontal lobes in the mediation of executive processes.

1.3 The role of the frontal lobes

Since the case report of Phineas Gage (Harlow, 1848, 1868), a number of case studies (e.g., Ackerly & Benton, 1947; S.W. Anderson et al., 2000; Eslinger & Damasio, 1985; Eslinger et al., 1992), frontal lobectomy studies (e.g., L.A. Miller, 1992; Richer et al., 1993; Suchy & Chelune, 2001), and experimental studies (e.g., Luria, 1966; Petrides & Milner, 1982; Shallice, 1982) have emerged, leading to rapid knowledge development and growth of interest in the role of the frontal lobes in executive function. Moreover, knowledge of the neuroanatomical underpinnings of executive processes has recently expanded, with advances in technology providing non-invasive methods to investigate this relationship. These methods include structural neuroimaging techniques (e.g., magnetic resonance imaging [MRI], computed tomography [CT]), as well as functional imaging measures (e.g., angiogram, position emission tomography [PET], functional magnetic resonance imaging [fMRI]). The present section aims to highlight the underlying neurobiological aspects related to executive processes.

1.3.1 The frontal lobes: structure and function

1.3.1.1 Anatomy and connectivity

The human frontal lobes constitute about half of the entire cerebrum and extend from the central sulcus to the anterior limit of the brain. Based on cytoarchitectonic features, the frontal lobes are traditionally divided into four sections: limbic, motor, premotor, and prefrontal regions. These divisions are largely based on the classic Brodmann’s map of cytoarchitectonic fields, which delineates 43 cortical regions (Brodmann, 1909, 1994). The limbic region is located deep in the medial
portion of the frontal lobe and includes the anterior cingulate and the posterior section of the orbital frontal surface (H.C. Damasio, 1991; Kaufer & Lewis, 1999). The primary motor cortex (Brodmann’s area 4) lies along the lateral surface of the frontal lobe, in front of the central sulcus. Parallel to the lateral and medial section of the primary motor cortex lies the premotor cortex, or secondary motor association area, which extends from Brodmann’s area 4 to the anterior limit of areas 6 and 44 (Kaufer & Lewis, 1999). However, the division between the premotor cortex and the prefrontal region is somewhat arbitrary (H.C. Damasio, 1991). The medial portion of the premotor area is called the supplementary motor area. In addition to this area, the premotor cortex also contains the frontal eye field (Brodmann’s area 8) and Broca’s area (areas 44 and 45). The fourth region, the prefrontal cortex, is the largest structure within the frontal lobes and is commonly subdivided further into dorsolateral prefrontal cortex, orbitofrontal cortex, and paralimbic regions. The dorsolateral prefrontal region is located along the lateral convexity of the frontal lobes and includes Brodmann’s area 46 and part of area 9. Brodmann’s areas 11 and the rostral portion of area 12 correspond roughly to the orbitofrontal cortex, while the paralimbic regions comprise of the anterior cingulate (area 24) and the caudal portion of area 32 (Kaufer & Lewis, 1999).

The frontal lobes have rich connections with other areas of the brain, including the posterior cortices, the brainstem, the limbic structures (hippocampus and amygdala), the thalamus, and the hypothalamus. Of all cortical regions, the prefrontal cortex is the most highly interconnected, receiving afferent fibres and projecting efferent fibres to numerous structures within the central nervous system (e.g., Cummings, 1993; Goldman-Rakic & Porrino, 1985; Fuster, 1989; Rezai et al., 1993; Zald & Kim, 1996). Data obtained from both monkeys and humans show that the three subareas of the prefrontal cortex appear to have different connections (e.g., Alexander & Stuss, 2000; Barbas, 1992; Carmichael & Price, 1995; Cummings, 1993; Giguere & Golman-Rakic, 1988; Ilnisky, Jouandet, & Goldman-Rakic, 1985; Zald & Kim, 1996). The dorsolateral prefrontal cortex is primarily connected to the dorsolateral region of the caudate nucleus, the lateral thalamus, the hippocampus, and the neocortex (e.g., Barbas, 1992; Cavada & Goldman-Rakic, 1989; Fuster, 1989; Petrides & Pandya, 1984). The orbitofrontal region is primarily connected to the ventromedial caudate, the medial thalamus, the hypothalamus, and the amygdala (e.g.,
Fuster, 1989; Ilinsky et al., 1985; Johnson & Rosvold, 1971; Selemon & Goldman-Rakic, 1985; Zald & Kim, 1996). The medial region of the prefrontal cortex accommodates the anterior cingulate circuit, in which input travels from Brodmann’s area 24 to the ventral striatum, which includes the ventromedial caudate, ventral putamen, nucleus accumbens, and olfactory tubercle (e.g., Selemon & Golman-Rakic, 1985; Goldman-Rakic & Porrino, 1985). In addition to the anatomically linked circuits mentioned above, several neurotransmitter systems also converge on the prefrontal cortex, with each circuit employing the same neurotransmitters. The most prominent among them are glutamate, dopamine, acetylcholine, serotonin, and various neuropeptides (Fuster, 1989).

1.3.1.2 Functional organisation

The frontal lobes are functionally heterogenous (e.g., Alexander & Stuss, 2000; Goldberg, 1990; Lezak, 1995), with anatomically distinct regions subserving a number of different functions, ranging from fine motor control to complex social behaviours. Much of what is known about the association between frontal lobe structures and human behaviour has been inferred from studies of nonhuman primates, including normal development and recovery patterns after early prefrontal lobe damage (e.g., Diamond & Goldman-Rakic, 1989; Goldman-Rakic, 1987). However, more recent neuropsychological research, including case studies of patients with specific frontal lobe pathology, and neuroimaging studies have also been important for identifying behavioural correlates of anatomically distinct regions within the frontal lobes (e.g., Barrash et al., 2000; Fletcher et al., 1995; Grattan & Eslinger, 1991; Haxby, Ungerleider, Horwitz, Rapoport, & Grady, 1995; Moscovitch, Kapur, Kohler, & Houle, 1995).

Findings of anatomical and physiological experiments using electrical stimulation methods have shown that the primary motor cortex is in charge of the execution and adaptation of elementary movements, such as wrist flexion (e.g., Krakauer & Ghez, 2000; Fuster, 1999; Lezak, 1995). Lesions in this area often result in weakness or paralysis of body parts (Stein, 1985). While the primary motor cortex mediates simple features of movement, the premotor cortex plays an important role in planning more complex action sequences, such as coordinated hand shaping (e.g., A.R. Damasio & Anderson, 1993; Krakauer & Ghez, 2000; McGlone & Young,
Therefore, lesions in this area may disrupt coordinated movements, resulting in discontinuous and impaired motor skills (e.g., Heilman & Watson, 1991; Jason, 1990). The supplementary motor area of the premotor cortex appears to be responsible for the preparatory arousal before a self-initiated voluntary movement begins, and is therefore essential in motor preparation (Krakauer & Ghez, 2000). Thus, lesions in this area may disrupt the initiation of movement (e.g., Brown, 1987; Heilman & Watson, 1991). In the left hemisphere, Broca’s area mediates the motor organisation and patterning of speech, with lesions in this area often resulting in motor aphasia (e.g., Broca, 1861; A.R. Damasio & Geschwind, 1984; Kertesz, 1979; Kertesz & Phipps, 1977).

While the primary motor cortex and the premotor area have primarily been associated with motor functions, the prefrontal cortex appears to be essential for specific cognitive processes and the organisation of behaviour. Much of what is known about the functions of the prefrontal cortex has resulted from case studies of patients with focal frontal lobe damage (e.g., S.W. Anderson et al., 2000; Benton, 1991; Grattan & Eslinger, 1991; Marlowe, 1992). Although localisation of function has been less marked in patients with prefrontal cortex damage in comparison to patients with damage in other cortical areas, some functional localisation is evident (Lezak, 1995). In particular, three major clusters of symptoms have been identified, depending on the specific lesion site. Each of these clusters appears to result from damage to one of three subareas within the prefrontal cortex: dorsolateral, orbital, or medial/cingulate (e.g., Alexander & Stuss, 2000; Fuster, 1999; Lezak, 1995).

1.3.1.3 Dorsolateral regions of the prefrontal cortex

Research with patients who had sustained focal frontal lesions has indicated that the dorsolateral area of the prefrontal cortex may be associated with working memory, planning, problem solving, attention, set shifting, reasoning, and organisation of information (e.g., A.R. Damasio & Anderson, 1993; Fuster, 1999; Grattan et al., 1994; Grattan & Eslinger, 1991; Kroger et al., 2002; Stuss et al., 2000). Due to strong reciprocal connections with the parietal, occipital, and temporal cortices, the dorsolateral prefrontal cortex receives higher-level auditory, somatosensory, and visual information (Kaufer & Lewis, 1999). In contrast, the
The dorsolateral area of the prefrontal cortex has relatively sparse direct connections with limbic structures.

The consequences of damage to the dorsolateral region can be readily recognised on observation of the patient’s daily behaviour and can be substantiated by formal neuropsychological testing. Patients with damage to this area often show little or no interest in the environment, have difficulty in the temporal integration of behavioural sequences, and demonstrate poor judgment (e.g., Fuster, 1989; Grattan & Eslinger, 1991). A neuropsychological task that has been widely used to assess cognitive impairments in patients with dorsolateral prefrontal cortex damage is the WCST, which has been found to be highly sensitive to several functions mediated by this area, in particular cognitive flexibility (e.g., Cicerone, Lazar, & Shapiro, 1983; Lombardi et al., 1999; Nelson, 1976; Stuss et al., 2000). It is believed that both left and right dorsolateral regions of the prefrontal cortex are involved in cognitive flexibility (e.g., Alexander & Stuss, 2000; Gratten & Eslinger, 1991), however, lateralisation of shifting behaviour has also been observed. For example, decreased verbal fluency has been associated with damage to the left dorsolateral area (e.g., Borkowski, Benton, & Spreen, 1967; Butler, Rorsman, Hill, & Tuma, 1993; Laine, 1988), whereas impaired performance in nonverbal divergent thinking has been associated with damage to the right dorsolateral area (e.g., Guilford, Christensen, Merrifield, & Wilson, 1978).

Although the dorsolateral region of the prefrontal cortex appears to play an important role in mediating cognitive flexibility, it is most likely that other brain areas are involved as well (Eslinger & Grattan, 1989). Case studies have shown that, in addition to set shifting problems, patients with bilateral dorsolateral prefrontal cortex damage often display deficits in attention (such as impulsivity and lack of concentration), disorganisation, memory, and recency discrimination (e.g., Grattan & Eslinger, 1991; Lezak, 1995). Clinical lesion studies in aphasia have indicated an association between verbal information processing difficulties and damage to the left dorsolateral region of the prefrontal cortex (e.g., Alexander & Stuss, 2000; Butler et al, 1993; Frisk & Milner, 1990; Geschwind & Iacoboni, 1999). The relationship between language skills and the left frontal lobe has been supported by several functional imaging studies (e.g., Frith, Friston, Liddle, & Frackowiak, 1991; Just,
Carpenter, Keller, Eddy, & Thulborn, 1996; McCarthy, Blamire, Rothman, Gruetter, & Shulman, 1993). Constructional difficulties, in contrast, are commonly observed in patients with lesions to the right dorsolateral region (e.g., Benton, 1968; Jones-Gotman & Milner, 1977). These findings suggest functional asymmetries within the dorsolateral prefrontal cortex, however, the extent to which these functions are dichotomised remains unclear (Geschwind & Iacoboni, 1999). Future research, in particular neuroimaging studies, is necessary to investigate the issue of functional lateralisation within the dorsolateral prefrontal cortex.

### 1.3.1.4 Orbital regions of the prefrontal cortex

The orbital frontal cortex plays a key role in adaptive and socially appropriate behaviour, with damage to this area often resulting in a personality change, which is typically marked by a lack of empathy, irritability, lability, lack of inhibition (including instincts), euphoria, and inappropriate humour (e.g., Cummings, 1993; Eslinger & Damasio, 1985; Fuster, 1989, 1999; Grattan et al., 1994; Harlow, 1848, 1868). The orbital region of the prefrontal cortex has strong connections with the limbic area, and is believed to integrate information regarding internal states (Mesulam, 1985). Orbitofrontal lesions are often associated with the inability to inhibit instinctual drives, often resulting in hypersexuality, belligerence, or hyperphagia (Fuster, 1999). For example, in a recent study investigating brain activity related to affective changes associated with feeding, Small, Zatorre, Dagher, Evans, and Jones-Gotman (2001) found increased activity in the orbitofrontal cortex, suggesting that the reward of food is represented in this brain region.

According to Fuster (1989), the orbitofrontal cortex exerts control over the mechanisms of feeding behaviour through the hypothalamus, which keeps the hunger drive in check. Therefore, lesions to this area may result in an inability to regulate food intake. In contrast to behavioural aspects, in general, lesions to the orbital regions of the prefrontal cortex do not impair general intellect, memory, or perception (Angrilli, Palomba, Cantagallo, Maietti, & Stegagno, 1999; Stuss et al., 1983). However, damage to this area is likely to affect decision making (Bechara, Damasio, & Damasio, 2000), an activity that requires a number of cognitive processes, such as using existing knowledge, integrating available information, and considering alternatives. In addition, Elliott, Dolan, and Frith (2000) suggest that the orbital
regions of the prefrontal cortex are also involved during cognitive activities when the insufficient information is available to guide the appropriate course of action. Thus, although the orbital prefrontal cortex appears to be important in the regulation of internal states, it has also been associated with underlying cognitive processes that guide behaviour.

1.3.1.5 Medial regions of the prefrontal cortex

The medial prefrontal cortex is part of a neuronal circuit that primarily involves the anterior cingulate and the ventral striatum (Selemon & Goldman-Rakic, 1985). Thus, medial areas are predominantly affiliated with limbic structures. The medial prefrontal cortex mediates motivated behaviour, and damage to this region often induces a disorder of drive and motivation (A.R. Damasio & Van Hoesen, 1983; Fuster, 1999). Generally, the patient shows lack of interest, low awareness, lack of spontaneity, and indifference towards others and the world around him (Lezak, 1995; Fuster, 1989; Stuss & Benson, 1986).

In a study investigating the degree of disturbance and change from premorbid personality, Barrash et al. (2000) compared the consequences of brain damage on motivational behaviour in three patient groups: (1) participants with ventromedial prefrontal cortex damage; (2) patients with prefrontal lesions but not bilateral ventromedial involvement; and (3) participants with nonprefrontal lesions. In contrast to the other groups, patients with ventromedial prefrontal cortex damage developed a syndrome, characterised by a general dampening of affects and emotional responses, lack of insight, indecisiveness, apathy, and lack of persistence. This apathetic syndrome can be clinically mistaken for depression, and is therefore sometimes referred to as pseudodepression (e.g., Blumer & Benson, 1975; Stuss & Benson, 1986).

The personality disturbances following damage to the ventromedial region of the prefrontal cortex appear to be similar to the salient features of developmental psychopathy, such as shallow affect, lack of empathy, and poor emotional control (Hare, 1970). Therefore, the apathetic syndrome has also been referred to as “acquired sociopathy” (A.R. Damasio, Tranel, & Damasio, 1990). These findings have raised the question of a shared pathological mechanism, resulting in a number of studies
investigating physiological dysfunction in the prefrontal cortex of developmental psychopaths (e.g., Deckel, Hesselbrock, & Bauer, 1996; Raine, Lencz, Bihrl, LaCasse, & Colletti, 2000; Raine, Stoddard, Bihrl, & Buchsbaum, 1998; Scarpa & Raine, 1997).

Although little is known about hemispheric asymmetry in the medial prefrontal cortex (Alexander & Stuss, 2000), there is some evidence in the animal literature that the left rostral cingulate region is more sensitive to contextual cues in learning (Freeman, Cuppernell, Flanery, & Gabriel, 1996). However, in general, in this region of the prefrontal cortex, functional neuroimaging studies should be interpreted with caution, given the spatial proximity of left and right cingulate cortex (Geschwind & Iacoboni, 1999).

1.3.1.6 Functional asymmetries within the frontal lobes

Lateralisation of the human brain has been well documented, with evidence for both structural and functional differences between the hemispheres (e.g., Rosen, Galaburda, & Sherman, 1990; Witelson & Kigar, 1988; Galaburda, 1991; A.R. Damasio & Geschwind, 1984). The most salient functional difference between the cerebral hemispheres is that verbal functions are primarily mediated by the left hemisphere, while the right hemisphere has been primarily associated with nonverbal and spatial activities (Lezak, 1995). Although hemispheric specialisation has long been investigated, relatively little is known about specialised capacities within the frontal lobes (Geschwind & Iacoboni, 1999; Lezak, 1995). However, it is believed that the usual functional distinctions between both hemispheres apply here too (Lezak, 1995).

The left frontal lobe appears to be primarily involved in processing verbal information (e.g., Goldberg, Podell, & Lovell, 1994; Kertesz, 1999; Lezak, 1995). Damage to this area can result in a number of language difficulties, such as decreased verbal fluency, articulatory disturbance, simplified syntax, decreased spontaneous speech, and perseveration (e.g., Alexander, Benson, & Stuss, 1989; Frisk & Milner, 1990; B. Milner, 1964). A particular language syndrome associated with damage to the left premotor cortex is Broca’s aphasia (e.g., Broca, 1861; A.R. Damasio & Geschwind, 1984; Kertesz, 1979; Kertesz & Phipps, 1977). The syndrome of Broca’s
aphasia is characterised by decreased verbal fluency, phonological paraphasias, articulatory errors, agrammatism, and relatively preserved comprehension (Kertesz, 1999). Although the left frontal lobe plays an important role in mediating language, lesions to the right frontal lobe can also result in language disturbances, including expressive language (Kaczmarek, 1984, 1987), decreased prosodic quality of speech (Frisk & Milner, 1990), and reduction in verbal fluency (B. Milner, 1971). These findings suggest that a strict localisationist approach is not appropriate, since both frontal brain areas appear to be activated during language processes.

The right frontal lobe has primarily been associated with nonverbal functions, such as the ability to invent unique designs, interpret pictures, and estimate prices and frequency of events (e.g., Jones-Gotman, 1991; Kaczmarek, 1987; Smith & Milner, 1984, 1988). In addition, the right frontal lobe has been related to the interpretation and expression of emotions (e.g., Borod, 1992; DeKosky, Heilman, Bowers, & Valenstein, 1980; Ross, 1981; Tucker, Luu, & Pribram, 1995). Damage to this area may result in impaired expression of emotion, emotional alienation, and inappropriate social behaviour (e.g., Edwards-Lee & Saul, 1999; Ross, 1981). The reported behavioural changes produced by right-sided lesions to the frontal lobes often include decreased self-reflection and self-consciousness (e.g., Eslinger et al., 1999; Stuss, Gallup, & Alexander, 2001). Such impairments are likely to not only impact on the patient’s capacity to reflect on his or her own behaviour, but may also influence their ability to evaluate the mental state of people around them, resulting in impaired social cognition and social judgement (Stuss & Alexander, 2000; Stuss et al., 2001).

1.3.1.7 Gender differences

Cognitive differences between males and females have received widespread attention in the neuropsychological literature. Although the literature within this area is largely equivocal, reflected by several unanswered questions and contradictory findings, a few general trends can be observed with regards to gender differences in brain functioning (Lezak, 1995).

It is commonly assumed that females show superior ability on verbal tasks, while there is a male advantage in visuo-spatial ability. Maccoby and Jacklin (1974) analysed the findings from 85 studies investigating gender differences in linguistic
capacities. Based on this analysis, they suggested that females were superior to males in the ability to process verbal information. However, later studies investigating subcomponents of verbal tasks have shown that the gender issue with regards to the distinction between linguistic and nonlinguistic capacities is not that straightforward (e.g., Gordon & Lee, 1986), and therefore, it has been suggested that gender influences may be heterogeneous across verbal abilities (Hyde & Linn, 1988).

More consistent gender differences in brain functioning have been reported within the area of visuo-spatial abilities. For example, research has indicated that males outperform females on mental rotation tasks (e.g., P. Goldstein, Haldane, & Mitchell, 1990; Halpern, 1992; Masters, 1998; Voyer, 1997) and tests of spatial orientation (e.g., Lewis & Harris, 1990). Thus, there appears to be a male advantage on tests that require processing of nonverbal information.

The gender differences that have been observed in cognitive processes may be related to structural differences between the male and female brain. Neuroanatomical research has indicated, for instance, that in males, the volume of the right prefrontal cortex is greater than the left, but symmetrical in females (de Lacoste-Utamsing, Hovarth, & Woodward, 1991). Further, it has been reported that females have lower brain weights and smaller overall brain sizes, when compared to males (e.g., de Lacoste-Utamsing & Holloway, 1982; Pfefferbaum et al., 1994; Reiss, Abrams, Singer, Ross, & Denckla, 1996). Gender differences have also been observed with regards to the hypothalamus (Swaab & Fliers, 1985) and the corpus callosum (de Lacoste-Utamsing & holloway, 1982).

Cognitive differences between males and females have also been observed in children. Similar to the functional pattern noted in adults, research has indicated a female advantage on tasks measuring verbal abilities (e.g., Kraft & Nickel, 1995). In contrast, males have shown to perform better on tasks tapping visuo-spatial capacities (e.g., R.S. Levine, Huttenlocher, Taylor, & Langrock, 1999). However, the magnitude of these differences has been found to fluctuate during childhood, suggesting that there may be gender specific rates of cognitive development (Kraft & Nickel, 1995).
Within the area of executive function, Klenberg, Korkman, and Lahti-Nuuttila (2001) found a number of gender differences in children between 3 and 12 years. Using the NEPSY, Klenberg and colleagues found that girls performed better on a test of inhibition (i.e., Statue), complex tasks of selective attention (i.e., Response Set and Visual Attention), and tests of verbal fluency (i.e., Semantic Fluency and Phonemic Fluency). With respect to the Statue test, Klenberg et al. reported that a gender difference was evident in children younger than 6 years, but that in older children, the performance of boys and girls was comparable. The tasks measuring selective attention were only used with children older than 5 years, therefore, it is unclear if gender differences within the area of selective attention also exist in younger children. Cognitive differences between males and females with regards to verbal fluency were observed across the entire age range. According to Klenberg et al., the superiority of girls on these tasks is most probably related to verbal abilities (Klenberg et al., 2001), supporting the notion of a female advantage on verbal tasks.

Cognitive differences between girls and boys, and the observed fluctuation in magnitude of these differences, may be related to differences in cerebral development. Research has indicated that cortical maturation follows differential pathways in boys and girls, characterised by distinct growth patterns of grey and white matter (Giedd, Castellanos, Rajapaske, Vaituzis, & Rapaport, 1997), and a more rapid development of the left hemisphere in girls (Hanlon, Thatcher, & Cline, 1999). However, the exact relationship between gender differences in structure and function of the brain during childhood has not been established and further research is necessary to investigate this issue. In particular, advanced neuroimaging techniques, such as fMRI and PET, may enable researchers to study this relationship more directly.

1.3.1.8 Clinical limitations of functional organisation

Investigating the functional organisation of the brain in a normal, healthy population is important for two reasons: (1) it contributes to an enhanced understanding of brain/behaviour relationships, and (2) within a clinical context, knowledge about the functions of the brain is necessary for the establishment of appropriate rehabilitation and management interventions. It must be noted, however, that caution is required when applying the principles of functional localisation to diagnostic problems. First, naturally occurring lesions are generally not confined to
one particular region and can damage multiple subsystems (Grattan & Eslinger, 1991; Snyder & Nussbaum, 1998). Thus, patients often present with a range of behavioural patterns, depending on the size and location of the lesion. Second, deficits associated with frontal brain damage may also occur with lesions involving other areas of the brain, including subcortical nuclei having connections with the frontal lobes and white matter lesions disrupting the connections (S.W. Anderson et al., 1991; Cummings, 1993; Glosser & Goodglass, 1990; Walsh, 1985). Third, patients with similar lesions may present with different behavioural patterns (Shallice & Burgess, 1991; Stuss et al., 1995). Therefore, a clinician needs to take into account the age, education, gender, and intellectual level of the patient, to gain a better understanding of individual capacities (V. Anderson et al., 2001b; Brauer Boone, 1999). Thus, to increase the quality of clinical practice, the clinician is required to exercise care in observation and caution in prediction (Lezak, 1995).

1.3.2 Development of the frontal lobes

Until the early 1980s, it was believed that the frontal lobes were not functional in childhood, playing little or no role in cognitive and social development (Golden, 1981). However, an increasing number of studies have refuted this view, suggesting that the progression of frontal lobe maturation is a protracted process that encompasses both childhood and early adulthood (e.g., Cummings, 1993; Grattan & Eslinger, 1991; Reiss et al., 1996; Yakovlev & Lecours, 1967). General principles of CNS maturation, such as differentiation and hierarchical processing, also apply to the frontal lobes (Grattan & Eslinger, 1991).

Knowledge of frontal lobe maturation and related cognitive development is continually increasing, in accordance with methodological and technical advances. The developmental process of the CNS can roughly be divided into two phases: prenatal and postnatal (V. Anderson et al., 2001b). While prenatal development is primarily associated with the structural formation of the CNS, the second stage, postnatal development, is concerned with elaboration of the CNS (V. Anderson et al., 2001b). Prenatal development is thought to be genetically determined, with three major maturational processes occurring in a predetermined sequence: (1) cell proliferation, which involves the formation of young neurons; (2) migration, during which young neurons travel from the proliferative zone to the particular region where
they will be employed in the mature brain; and (3) differentiation, which involves specialisation of cells (Johnson, 1997).

The postnatal phase of CNS maturation is characterised by a “rise and fall” developmental pattern, with both progressive and regressive processes occurring (Johnson, 1997). Progressive developmental processes involve substantive additive changes to the brain, such as increase of fibre bundles, dendritic arborisation, and myelination (e.g., Huttenlocher, 1990, 1994; Parlemee & Sigman, 1983; Volpe, 1987; Yakovlev & Lecours, 1967). In contrast, regressive events include processes of selective loss, with redundant elements eliminated to ensure efficient transmission (e.g., V. Anderson et al., 2001b; Blatter et al., 1995; Hopkins & Brown, 1984; Janowsky & Findlay, 1986; Pfefferbaum et al., 1994; Reiss, Abrams, Singer, Ross, & Denckla, 1996). These processes are characterised by an initial overproduction, followed by a period of loss. For instance, during the first 8 months of life, there is an increase in density of synapses to above adult levels, followed by a period of synaptic loss (Huttenlocher, 1990, 1994). Similarly, at birth, there is an excess amount of neurons, with the redundant cells dying off during the differentiation phase of development (V. Anderson et al., 2001b).

The progression of CNS maturation is not a gradual, continuous course, but is punctuated by a series of growth spurts (e.g., Hudspeth & Pribram, 1990; Klinberg et al., 1999; Thatcher, 1991, 1992). There also appears to be a hierarchical progression within the CNS, with the brain stem and cerebellar regions developing first, followed by posterior areas, and anterior regions reaching maturity last (Fuster, 1993; Jernigan & Tallal, 1990; Risser & Edgell, 1988).

Compared to information about brain maturation in animals, developmental data in humans is limited. However, advanced non-invasive techniques to map the development of the brain (such as CT, EEG, MRI, and PET) have contributed greatly to the understanding of growth processes within the human brain. Summing the values of different EEG curves, based on EEG records from 561 children between the ages of 1 and 21 years, Hudspeth and Pribram (1990) provided evidence for five significant stages of brain maturation, with the largest increments documented between the ages of 3 and 5 years. A relatively stable period was noted between 6 and 7 years, with a
second growth spurt identified between the ages of 7 and 9 years. Other periods of relatively rapid growth were noted between 11 and 13 years, between 15 and 17 years, and again between 18 and 21 years.

Physiological evidence for growth spurts during brain maturation has also been provided by Thatcher (1991, 1992). Conducting EEG coherence analyses in children and adolescents, Thatcher suggested that growth processes within the brain are nested within 4-year cycles that are marked by transitional phases. The first cycle is from about 1½ years to 5 years, cycle two is from approximately 5 years to 10 years, and the third cycle is from about 10 to 14 years of age. Within the period of early childhood, Thatcher (1992) reported sudden changes in mean EEG coherence between 4 and 5 years, and again between 5 and 7 years. According to Thatcher, phase transitions occur around 6 and 10 years of age, and reflect a transition from rapid growth to relative stability. According to Thatcher (1991), growth spurts are associated with changes in the number or strength of cortical synaptic connections.

The notion that growth spurts within cerebral processes may be associated with structural changes in synaptic connections has been supported by findings from Huttenlocher (1990, 1994). According to Huttenlocher, synaptic changes during childhood are characterised by an initial overproduction of synapses, followed by an elimination of synaptic connections, and may be associated with the development of cognitive functions. Although most of his work focused on the development of the visual cortex, Huttenlocher has also provided important insights into the maturation of the frontal lobes. In particular, he suggested that the overproduction of synapses reaches a developmental peak around the age of 1 year, with elimination of connections not evident before the age of 7 years, and synaptic density at adult level around the age of 16 years. In contrast, synaptic density within the visual cortex reaches maturity levels between 2 and 4 years of age. These findings support a hierarchical progression in CNS development, with the frontal lobes reaching adult levels last. Other processes, including dendritic arborisation and myelination have also been reported to reach maturity last in the anterior regions of the brain (Anderson et al., 2001b).

### 1.3.3 Effects of early frontal lobe damage

Effects of early frontal lobe damage have primarily been investigated in case
studies of children with focal lesions to the prefrontal cortex. These case reports have provided instructive data about the kinds of deficits that may accompany lesions to the prefrontal brain regions, patterns of adaptation, and aspects of recovery. Findings have shown that the impact of early frontal lobe damage may be wide reaching, often resulting in a range of cognitive and behavioural deficits, such as impulsivity, irritability, inability to learn and acquire skills effectively, disorganisation, and difficulty inhibiting undesired or socially inappropriate thoughts and responses (e.g., Benton, 1991; Eslinger & Biddle, 2000; Eslinger et al., 1992; Grattan & Eslinger, 1992; Marlowe, 1992; Williams & Mateer, 1992).

Children with early frontal lobe lesions often appear to recover and develop quite normally in the initial stages post-insult, however, as they mature, cognitive and social impairments frequently emerge (e.g., Ackerly & Benton, 1947; Eslinger et al., 1992; Grattan & Eslinger, 1992; Price, Daffner, Stowe, & Mesulam, 1990). This pattern of delayed onset of impairments is not only restricted to early frontal lobe damage, but rather any significant brain insult sustained early in life may lead to late-developing deficits (e.g., V. Anderson & Moore, 1995; Eslinger et al., 1997; Taylor & Alden, 1997; Grattan & Eslinger, 1991). These impairments appear to be most significant for skills that were immature at the time of insult, with damage interfering with their ongoing development.

An influential heuristic for conceptualising the effects of early brain damage on cognitive development has been proposed by Dennis (1989). Although Dennis confined her model to language development, it has shown to be useful as a general framework for describing the impact of early brain insult on developing skills (e.g., Ewing-Cobbs, Thompson, Miner, & Fletcher, 1994; Kriel, Krach, & Panser, 1989). According to Dennis (1989), “emerging” impairments do not reflect a regression in development, but rather a failure to develop age appropriate skills in the expected time frame. Dennis (1989) suggested three sequential stages in the development of skills:

1. **emerging**, where the skill is not yet functional;
2. **developing**, where the skill is partially acquired, but not fully functional; and
3. **established**, where the skill is fully matured.
Brain damage can disrupt the development of skills at any of these stages, with consequent problems interfering with the child’s capacity to develop normally.

The theory of Dennis (1989) provides an essential tool for describing the delayed onset of executive and social deficits observed after early damage to the prefrontal cortex. Since maturation of this brain region is a protracted process that continues into early adulthood (e.g., Cummings, 1993; Grattan & Eslinger, 1991; Reiss et al., 1996; Yakovlev & Lecours, 1967), an interruption to this progression early in life may snowball the inability of the prefrontal cortex to mediate the burgeoning cognitive and social demands in middle childhood and adolescence. For example, Eslinger and colleagues (1992) investigated the long-term cognitive, emotional, and psychosocial consequences of early frontal lobe damage in patient DT, who was studied 26 years after she acquired a lesion to the prefrontal region at 7 years of age. In this case study, several aspects of outcome were investigated, including adaptive social behaviour and moral reasoning. Findings revealed a pattern of disturbed psychological development and significant social maladjustment. In particular, from adolescence onwards, DT’s capacity to learn in cognitive, affective, and social domains was clearly diminished, with cognitive and psychosocial deficits accumulating throughout adolescence and early adulthood. According to Eslinger et al., DT’s social and psychological maturation was altered by underlying defective cognitive processes and therefore resulted in an arrested development in the social sphere.

Similar findings were reported by S.W. Anderson et al. (2000), who investigated the long-term sequelae of two patients, FD and ML, who had sustained prefrontal cortex damage prior to 16 months of age. Both individuals displayed an increase of behaviour problems throughout development into adulthood, despite normal home environments and attempts at intervention. The neurobehavioural pattern displayed by these cases resulted from a failure to develop specific cognitive and behavioural competencies (S.W. Anderson et al., 2000).

Early frontal brain damage may have devastating effects on a child’s life, with the impact of insult extending far beyond pure cognitive deficits. In particular, social and interpersonal impairments often result in poor everyday functioning and quality of
life, impacting on a child’s ability to understand group interactions, engage in social events, and sustain meaningful friendships (e.g., Benton, 1991; Eslinger et al., 1992; Grattan & Eslinger, 1991; Marlowe, 1992; Price et al., 1990). Thus, early frontal brain damage not only affects biological and neurocognitive domains, but also impacts on the social environment of a child.

V. Anderson et al. (2001b) have conceptualised these wide-ranging effects in a general model designed to describe the impact of early brain damage for ongoing development. Anderson et al. suggest that early cerebral insult will impact in at least three domains: biological, neurobehavioural, and psychosocial. Biological effects of brain damage include neuranatomical and neurochemical changes, such as tissue loss or epilepsy. These factors then impact on cognitive functioning, such as deficits in attention or memory. These problems may then cause social difficulties. Over time, cumulative problems may emerge, which may result in global dysfunction. Thus, in order to explore the consequences of early frontal brain damage, and subsequently, develop and improve treatment methods and intervention techniques, it is important to consider biological, neurobehavioural, and social factors.

### 1.3.4 Recovery of function

Analysis of the available literature suggests that the outcome of early brain damage is dependent upon a number of factors, including lesion-specific aspects (such as nature and severity), gender, psychosocial context, and age at insult. In general, outcome is poorer when insult is generalised (V. Anderson et al., 2001b; V. Anderson & Moore, 1995; Taylor & Alden, 1997), in contrast to focal lesions (Kolb & Wishaw, 1996; Seidenberg et al., 1997; Stark & McGregor, 1997). Further, there is some evidence that the female brain may be better able to cope with early brain damage than the male brain, due to the more diffuse organisation of the female brain (Kolb, Gibb, & Gorny, 2000).

Psychosocial context also seems to play an important role in recovery of function following early brain damage, with children from disadvantaged social backgrounds and inadequate social resources showing poorer outcome than children with better support structures (V. Anderson et al., 2001b). Moreover, Kolb et al.
(2000) suggested that better recovery of function has been associated with stimulating environments.

Age at onset can also play an important role in the outcome following cerebral insult. If brain damage occurs at a critical developmental period, specific structures or functions may be affected (V. Anderson et al., 2001b). From their experiments with rats, Kolb et al. (2000) suggest that outcome is dependent on the developmental stage of the CNS at time of insult. For example, when the cortex is injured just after neurogenesis, functional outcome appears to be worse in comparison to damage sustained during the time of maximal dendritic and synaptic growth (Kolb et al., 2000). Whether early brain damage has a greater capacity for recovery than injury sustained in adulthood has long been debated by plasticity theorists and early vulnerability proponents. Since a range of consequences has been observed in both children and adults, neither plasticity nor early vulnerability appears to be able to explain outcome after brain lesions (V. Anderson et al., 2001b). Rather, both theories may be viewed as two extremes along a continuum (Lesser & Kaplan, 1994).

Thus, in considering recovery of function after early frontal brain damage, it is of fundamental importance to understand the variability of outcome factors. In addition, a comprehensive insight of frontal lobe maturation and operation is essential to establish appropriate rehabilitation and management interventions.

1.3.5 Summary

The frontal lobes, and in particular the prefrontal regions, support the cognitive functions that are necessary for future-oriented actions and appropriate social behaviour. Within the frontal lobes, anatomically distinct regions appear to subserve different cognitive and behavioural functions. The dorsolateral regions of the prefrontal cortex have been primarily associated with “cool” aspects of executive functions, such as working memory, planning, problem solving, attention, and reasoning. The orbital frontal cortex, in contrast, appears to play a key role in “hot” aspects of executive function, regulating adaptive and social behaviour. Drive and motivation has been primarily associated with the medial regions of the prefrontal cortex. Cerebral development appears to follow a series of growth spurts in a number of processes, such as myelination, dendritic arborisation, and synaptogenesis.
addition to these growth spurts, there also appears to be a hierarchical progress within the CNS, with the posterior areas of the brain developing first, and anterior areas reaching maturity last. In particular, the prefrontal cortex is believed to not reach maturity until the third decade of life. Thus, although there is a basic anatomical framework early in development, the frontal lobes continue to develop throughout childhood and early adulthood. An interruption to this normal developmental process may influence further maturation of the brain, thereby resulting in a number of cognitive and behavioural deficits. Recovery of function appears to be dependent on a number of factions, including nature and severity of lesion, gender, psychosocial context, and age at insult.

1.4 The present study

In this study, the construct of executive function refers to a functional system, consisting of four distinct domains, that is necessary for future-oriented behaviour and appropriate social functioning. The executive function domains include attentional control, cognitive flexibility, information processing, and goal setting. Each domain contains a number of subprocesses critical for skill acquisition, learning, and social development. Executive skills become more important as children grow older, and are required to function more independently. As described in this chapter, the development of executive processes in school-age children and adolescents follows a stage-like pattern, with growth spurts occurring around 7 – 8 years of age, 10 – 12 years of age, and in early adolescence. However, relatively little is known about how these skills mature during early childhood. Although a number of studies have examined executive processes in children younger than 7 years, most of these investigations were restricted to only one or two executive skills, and thus unable to capture developmental trajectories across executive domains. In addition, these studies were often hampered by the lack of suitable neuropsychological measures of executive function for young children. Further, the total or standard "endpoint" scores derived from traditional measures have provided limited information with respect to specific aspects of executive function.

The present project was designed to investigate the development of executive processes in children between 3 and 7 years, using a microanalytic approach. Due to a paucity of suitable neuropsychological measures for use with preschoolers, a new test was
developed in order to measure executive function in early childhood. A pilot study was designed in order to determine the usefulness of this task. Further, to examine the effects of frontal lobe damage on the development of executive processes, two case studies of children with focal frontal lobe lesions were conducted.

1.4.1 Aims and hypotheses

This study aimed to map and contrast developmental trajectories of executive processes within four domains: attentional control, cognitive flexibility, information processing, and goal setting. The present study also aimed to explore gender differences within these domains. A third aim of this study was to investigate the effects of early frontal lobe damage on the ongoing development of the four executive function domains. Specifically, it was hypothesised that:

(1) Executive processes have different developmental trajectories, with specific skills emerging at different times through early childhood

(2) Subprocesses within executive function domains have similar developmental profiles in early childhood

(3) Processes within the attentional control domain will be the first to reach adult levels and precede the development of more complex skills within the domains of cognitive flexibility, information processing, and goal setting

(4) Complex executive skills within the domains of cognitive flexibility, information processing, and goal setting will not have reached maturity by the age of 7 years

(5) Within the domains of attentional control, cognitive flexibility, information processing, and goal setting, girls will perform better than boys

(6) Early frontal lobe damage will impact the ongoing development of executive processes, as reflected by poorer performance on executive function tasks by children with frontal brain lesions, when compared to healthy children their own age.
CHAPTER TWO
Pilot study: The Object Classification Task for Children (OCTC)

2.1 Introduction

Conceptual reasoning skills are required in a range of cognitive activities, such as distinguishing what is relevant from what is irrelevant, following general rules, and making use of existing knowledge in a new situation. Based on the model developed for this thesis, these processes are considered to fall within the domain of cognitive flexibility. Conceptual reasoning skills have received widespread attention in the adult literature (e.g., Bechara et al., 1994; Luria, 1966; Stuss et al., 2000; Walsh, 1987). Although a number of studies have investigated the development of conceptual reasoning skills during middle childhood and adolescence (e.g., Chelune & Baer, 1986; Kelly, 2000; Levin et al., 1991; Welsh et al., 1991), relatively little is known about how these skills mature during early childhood.

Traditional tests of conceptual skills that have been used with adults include the Category Test (Halstead, 1947; Reitan & Wolfson, 1993), Identification of Common Objects (commonly referred to as the “Twenty Questions Test”: Laine & Butters, 1982), Raven’s Progressive Matrices (Raven, 1960; Raven, Court, & Raven, 1976), the Color Form Sorting Test (Goldstein & Scheerer, 1941, 1953; Weigl, 1941), the Contingency Naming Test (Taylor, Albo, Phebus, Sachs, & Bierl, 1987), and the WCST (Berg, 1948; Grant & Berg, 1948). While some of these tests focus primarily on abstract concept formation (i.e., Category Test and Raven’s Progressive Matrices), others also include a requirement to shift between competing concepts (i.e., Contingency Naming Test, Twenty Questions Test, and WCST). Although several of these neuropsychological tools have been adapted to assess conceptual reasoning skills in school-age children (e.g., Chelune & Thompson, 1987; Welsh et al., 1991), there are a number of limitations that undermine their utility with younger children. For instance, most of the traditional measures place a relatively large demand on working memory capacity, impeding on a young child’s ability to carry out task instructions. Moreover, these tasks often include items that are irrelevant or unattractive to young children, such as Roman numerals in the Category Test, or the complex visual patterns in Raven’s Progressive Matrices.
Due to the limited number of tasks available to measure the development of executive processes within the domain of cognitive flexibility in this project, a new test was developed with parameters appropriate for use with young children. This test, the Object Classification Task for Children (OCTC), was based on the paradigms of the Concept Generation Test (CGT: B. Levine et al., 1995) and the Concept Generation Test for Children (CGT-C: Jacobs et al., 2001a). In these concept generation tasks, subjects are required to sort a number of items according to some common feature. While the CGT is a pencil and paper task of sorting behaviour, the task devised by Jacobs et al. uses colour graphics that can be manipulated by children. In this task, children are required to sort the colour graphics according to six pre-determined groupings of varying complexity, such as animal habitat and direction of lines. As with the CGT, the CGT-C has three conditions with increasing structure to allow for greater fractionation of underlying cognitive processes contributing to sorting behaviour. Although the OCTC is similar to the concept generation tasks in its basic paradigm, it differs in the following ways: (1) the OCTC uses plastic toys, which are thought to be more appealing to young children than diagrams or graphics, (2) it has two practice trials, which allows for investigating whether children are able to make two groups without the requirement of identifying a common feature, (3) the OCTC contains two different settings (i.e., a setting with four toys and a setting with six toys), which allows for the examination of concept generation skills in even the youngest children, and (4) it has only three pre-determined groupings (i.e., colour, size, and function).

This pilot study was designed to determine the usefulness of the OCTC as a measure of conceptual reasoning skills in young children. It was hypothesised that younger children would perform more poorly on the task, due to the relative immaturity of conceptual reasoning skills. It was also predicted that there would be age-related differences in the ability to generate concepts and in the capacity to shift between concepts. Finally, it was hypothesised that older children would require less additional structure than younger children in order to perform successfully on this task.
2.2 Method

2.2.1 Participants

The sample consisted of 84 children, aged between 3 years, 1 month and 7 years, 9 months. This sample was divided into five age groups: 3-year-olds (n = 19), 4-year-olds (n = 19), 5-year-olds (n = 14), 6-year-olds (n = 22), and 7-year-olds (n = 10). Children were selected from several local childcare centres, kindergartens, and primary schools in the metropolitan area of Melbourne, Australia. Inclusion criteria were: (1) aged between 3 year, 0 months and 7 years, 11 months at time of testing; (2) no previous history of developmental, neurologic, or psychiatric disorder; and (3) English as a first language. Informed consent, based on agency ethics procedures, was obtained from parents or guardians of children who participated in the project. The response rate was 68%. Table 2.1 outlines the demographic characteristics of the sample.

<table>
<thead>
<tr>
<th>Age group</th>
<th>n</th>
<th>Number of males (females)</th>
<th>Age (in months) M (SD)</th>
<th>Age Range (in months)</th>
<th>Socio-economic status M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-year-olds</td>
<td>19</td>
<td>10 (9)</td>
<td>42.1 (2.5)</td>
<td>37 – 46</td>
<td>4.4 (1.5)</td>
</tr>
<tr>
<td>4-year-olds</td>
<td>19</td>
<td>10 (9)</td>
<td>53.3 (3.3)</td>
<td>48 – 59</td>
<td>4.6 (1.1)</td>
</tr>
<tr>
<td>5-year-olds</td>
<td>14</td>
<td>7 (7)</td>
<td>67.1 (3.4)</td>
<td>61 – 71</td>
<td>4.4 (1.1)</td>
</tr>
<tr>
<td>6-year-olds</td>
<td>22</td>
<td>13 (9)</td>
<td>77.1 (2.8)</td>
<td>72 – 83</td>
<td>4.2 (1.1)</td>
</tr>
<tr>
<td>7-year-olds</td>
<td>10</td>
<td>4 (6)</td>
<td>89.3 (2.8)</td>
<td>86 – 93</td>
<td>3.9 (1.0)</td>
</tr>
</tbody>
</table>

Note. No significant group differences were found with regards to gender or socio-economic status.

Daniel (1983)
Socio-economic status (SES) was obtained using Daniel’s Scale of Occupational Prestige (Daniel, 1983), a widely used measure to assess the class position of occupations in Australian society. This scale rates SES from 1 to 7, with a lower score representing a higher SES.

Ethics approval was received from the Human Research Ethics Committee at the University of Melbourne, before children were recruited. Permission to contact kindergartens, childcare centres, and primary schools was obtained from the Department of Education and Training of the state Victoria, Australia. A wide range of kindergartens, childcare centres, and primary schools within the metropolitan area of Melbourne were then approached. Once the principals or directors of the centres agreed to participate in the study, children who fitted the appropriate criteria were identified. The families were contacted by letter, inviting them to participate in the study. A consent form was also enclosed, and parents were asked to return the consent form to the examiner if they agreed to participate. Once the families had given consent for participation, an appointment time was scheduled.

2.2.2 Materials

2.2.2.1 OCTC Practice Trials

In the first practice trial, children were shown two identical yellow mice with blue ears and two identical purple dinosaurs with orange toes (see Figure 2.1).
The toys used in the second practice trial included two brown bears with hats and two blue stingrays (see Figure 2.2).
First, the children were given one yellow mouse with blue ears and one purple dinosaur with orange toes. After the child had examined the toys, the experimenter showed the child two toys identical to these objects and said:

*See these toys? They are the same as the ones you have there, you see? The toys that are the same go together. Can you put the toys that go together on this side of the table* (examiner points to one side of the table) *and the other two that go together on that side of the table* (examiner points to other side of the table)?

If the child did not understand these instructions, the examiner helped the child by asking:

*So can you tell me which toys are the same?* (examiner waits for child to respond) *See, they go together, because they are the same. And the other two also go together, because they are the same as well. Now put these toys (examiner points to one pair of toys) on this side of the table and put the other two toys on that side of the table.*

After the child had correctly placed the two matching pairs on either side of the table, the examiner showed the child two different sets of toys (i.e., a brown bear wearing a green hat and a blue stingray) and provided the following instructions:

*Okay, now let’s do the same thing with these toys.*

*Can you put the ones that go together on this side of the table and the other two that are the same on that side of the table?*

These practice trials were always presented with the same pairs of toys in the same order across all children in the sample.
2.2.2.2 OCTC Test Trials

The test toys included three cars and three planes that were either yellow or red, and either big or small (see Figure 2.3).

![Six test toys in the OCTC](image)

*Figure 2.3* Six test toys in the OCTC

After the two practice trials, the examiner showed the child six test toys that could be sorted into two groups in three different ways (i.e., on the basis of colour, size, or function), and provided the following instructions:

*Okay, now let’s do the same thing with these toys. Can you make two groups for me, but something has to be the same about the toys in each group. Can you put one group on this side of the table and the other ones that go together on that side of the table?*

If the child did not know what to do, or sorted the toys incorrectly, the examiner removed two toys, so that there were only four toys left (i.e., all cars). The
OCTC was then administered using four toys, which could be sorted on either colour or size. Thus, the OCTC could be administered with either six toys (setting 1) or four toys (setting 2), depending on the child’s understanding and execution of task instructions when first shown the test toys.

2.2.3 Procedure

Children who met the selection criteria described above were administered the OCTC on an individual basis in one testing session at their respective childcare centre, kindergarten, or primary school.

2.2.3.1 Performance levels

The OCTC included three conditions, each providing increasing levels of structure for the child: (1) free generation, where the child was required to generate categories with no clues or structure; (2) identification, where the examiner constructed the category for the child, and the child was asked to describe the rule used for the sort; and (3) explicit cueing, where the child received explicit instructions to group the toys. In the CGT-C (Jacobs et al., 2001a), there was also a cued generation condition, where the child was given the rule for the sort, and was asked to construct the categories according to that rule. In the OCTC, however, this condition was omitted, as the rule given by the examiner had to be provided in a similar manner as in the explicit cueing condition in order for the child to understand the instructions. The level of structure within the two possible settings was considered an indication of the child’s capacity for conceptual reasoning.

Free generation condition

After the child had grouped the toys, they were asked:

So, can you tell me what’s the same about these toys (examiner points to a group of toys)? And what’s the same about these toys (examiner points to other group of toys)?

Responses were recorded verbatim. In the free generation condition, the child received 3 points for sorting correctly and 1 point for a correct verbal response. If the
child did not group the toys according to one of the three dimensions, a score of 0 was given. If the child sorted the toys correctly, but gave an incorrect verbal response, a score of 3 was given (see appendix A for a copy of the scoring form). After the child had generated two groups, the examiner mixed up the toys and the child was asked:

*Can you make two groups for me again, but now something else has to be the same about the toys.*

Following grouping according to a second dimension, the child was once again asked:

*So, what’s the same about these toys? And what’s the same about the other toys?*

This procedure was repeated for the third grouping in setting 1.

**Identification condition**

Children who were unable to correctly sort the toys in the free generation condition proceeded to the identification condition. In this condition, more structure is provided by constructing the category for the child and asking them to describe the rule used for the sort. Any of the groupings not correctly sorted in the free generation condition were administered in the identification condition. The examiner generated the groupings and the child was asked:

*See these two groups of toys? Can you tell me what’s the same about these toys (examiner points to a group of toys)? And what’s the same about these (examiner points to other group of toys)?*

Responses were recorded verbatim. In the identification condition, the child received 2 points for a correct verbal response. If the child gave an incorrect verbal response, a score of 0 was given.
Explicit cueing condition

Children who failed to identify all sorts provided by the examiner proceeded to the explicit cueing condition, in which any of the groupings not correctly identified were administered. For instance, if the child did not correctly identify the sort according to colour in the identification condition, the examiner asked the child:

*Can you put all the red ones on this side of the table and all the yellow ones on that side of the table?*

A score of 1 was given for each correct sort. If the child was not able to sort the toys, a score of 0 was given.

2.2.3.2 Response profiles

For each child, a response pattern was produced by assigning each nonverbal response in each condition a score of either 1 or 0. A score of 1 was assigned when a child grouped the toys correctly. A score of 0 was assigned to responses that were based upon incorrect sorting of the objects. For example, if a child was able to sort the toys correctly according to two different aspects in the free generation condition, but needed more structure to identify the third grouping (i.e., identification condition), then the child’s response pattern would look like the profile shown in Table 2.2.
Table 2.2

Example of Individual Response Pattern of a Child Who Grouped the Toys Twice in the Free Generation Condition and Once in the Identification Condition

<table>
<thead>
<tr>
<th>Categorisation</th>
<th>Free Generation</th>
<th>Identification</th>
<th>Explicit Cueing</th>
</tr>
</thead>
<tbody>
<tr>
<td>First sort</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Second sort</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Third sort</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Response Profile: 110 001 000

*Note.* A score of 1 indicates a correct grouping, whereas a score of 0 is based on an incorrect sort. A response profile was created by transforming the matrix into a string of 9 figures by ranking the scores for each condition, starting with the free generation condition, followed by the identification condition and the explicit cueing condition.

Response profiles were classified into five categories, which are listed in Table 2.3.
### Table 2.3
*Overview of Profiles*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Profile 1</th>
<th>Profile 2</th>
<th>Profile 3</th>
<th>Profile 4</th>
<th>Profile 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free generation</td>
<td>111</td>
<td>110</td>
<td>100</td>
<td>100</td>
<td>Four Toys</td>
</tr>
<tr>
<td>Identification</td>
<td>000</td>
<td>00(1)</td>
<td>01(1)</td>
<td>00(1)</td>
<td>Four Toys</td>
</tr>
<tr>
<td>Explicit cueing</td>
<td>000</td>
<td>00(1)</td>
<td>00(1)</td>
<td>0(1)(1)</td>
<td>Four Toys</td>
</tr>
<tr>
<td>Performance level</td>
<td>Advanced</td>
<td>Functional</td>
<td>Developing</td>
<td>Pre-functional</td>
<td>Incompetent</td>
</tr>
</tbody>
</table>

*Note.* Categorisation performance in each condition is reflected by a 3-digit string, representing the first, second, and third sort. Note that profiles 2, 3, and 4 were produced by incorporating similar response patterns. Therefore, figures in brackets indicate that some children sorted in that particular condition, whereas other children did not.

If children grouped the toys according to profile 1 (i.e., an advanced level of functioning), they were able to sort the objects correctly by themselves according to all three aspects (i.e., colour, size, and function). Similarly, if children grouped the toys according to profile 2 (i.e., a functional level of sorting), they were able to make two groups according to two different aspects, but needed more structure from the examiner to identify the third grouping. Thus, the third sort could either be recognised in the identification condition or the explicit cueing condition. If children categorised the toys at a developing level (i.e., profile 3), they were able to group the toys according to one particular aspect, but needed more structure from the examiner to identify the second and the third sort. In this response profile, children could identify at least one aspect in the identification condition. Children who grouped the toys according to profile 4 (i.e., a pre-functional level of sorting) were able to make two groups according to one particular aspect, but even with more structure provided by the examiner in the identification condition, they were not able to identify a second or third sort. Thus, children who sorted the toys according to this response profile
required explicit instructions to group the toys. And finally, all of the children who
were not able to perform the task with six toys were grouped together into profile 5.

2.2.3.3 Data analysis

A two-way analysis of variance (ANOVA) was employed to investigate the
main effects of age and gender, and any Age x Gender interaction effects on the total
of points scored on the OCTC. Post hoc Tukey LSD pairwise comparisons were
conducted to examine differences in performance between age groups. To further
explore the relationship between age and the total of points on the OCTC, a linear
trend analysis was performed.

Age group differences with regards to the level of structure required to group
the toys were initially analysed using response profiles, which incorporated children’s
sorting performance on both shifting attempts. However, this approach did not allow
for investigating differences in performance for separate groupings. In other words,
this approach appeared to be insufficient to provide detailed information about the
level of structure that children needed to group the toys for a second time, and
consequently, if they needed more or less structure when required to sort the objects
for a third time. Therefore, a frequency analysis was also conducted for each
condition within each shifting attempt.

2.3 Results

All of the children, including the 3-year-olds, passed the second practice trial
of the OCTC. Although some children did not understand the instructions the first
time they were given, they were able to successfully complete the second trial once
the examiner had provided further instruction.

2.3.1 Effects of age

Table 2.4 presents the results for the total of points on the OCTC across age
groups.
Table 2.4

*Means, Standard Deviations, F-ratio, and p-Value of Total of Points on the OCTC*

<table>
<thead>
<tr>
<th>Age group</th>
<th>Test variable</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>F-ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total of points</td>
<td>3.3</td>
<td>3.8</td>
<td>7.0</td>
<td>8.2</td>
<td>10.5</td>
<td>F(4, 79) = 27.98</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>OCTC – M (SD)</td>
<td>(2.3)</td>
<td>(2.7)</td>
<td>(2.0)</td>
<td>(2.1)</td>
<td>(1.6)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It was found that there was a main effect of age, $F(4, 79) = 27.98, p < .01$. Thus, it appears that performance on the OCTC increases as a function of increasing age. In particular, post hoc analysis revealed a significant increase in mean total of points between the 3- and 5-year-olds ($p < .01$) and between the 5- and 7-year-olds ($p < .01$). Figure 2.4 shows the data points for performance on the OCTC.
A Pearson correlation of the data revealed that age and total of points were significantly related, $r = + .75$, $n = 84$, $p < .01$, two tailed. A regression analysis was performed to explore the underlying trend of the relationship between age and total of points. It was found that this relationship can be expressed by a straight line that underlies this analysis. The equation for this line is given by:

$$Y = 0.17x - 4.49$$

where $Y =$ the outcome determined by this equation

$x =$ age (in months)

Thus, there is a linear trend for the data of the OCTC, with increasing performance as a function of increasing age.
2.3.2 **Response type analysis**

An overview of the use of profiles for each age group is presented in Table 2.5.

Table 2.5

<table>
<thead>
<tr>
<th>Performance Level</th>
<th>Advanced</th>
<th>Functional</th>
<th>Developing</th>
<th>Pre-functional</th>
<th>Incompetent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age group</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-year-olds</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>4-year-olds</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>5-year-olds</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>6-year-olds</td>
<td>4</td>
<td>9</td>
<td>7</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>7-year-olds</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
<td>19</td>
<td>13</td>
<td>20</td>
<td>22</td>
</tr>
</tbody>
</table>

Chi-square analysis of the data from Table 2.5 revealed a significant difference in the number of children across performance levels between the 4- and 5-year-old age groups, $\chi^2 (4, n = 33) = 21.66, p < .01$. Although chi-square analysis did not reach statistical significance for the other age groups, the data in Table 2.5 show a clear trend in the expected direction, with older children performing at a more advanced or functional level when compared to younger children. It must be noted that there was one 3-year-old who sorted the toys according to a functional level, however, this valid sort was a result of playing with the toys he liked, and pushing away the ones he disliked. In other words, this child appeared unaware that he had correctly sorted the toys.
2.3.3 Frequency analysis

While all children older than 4 years were able to sort six toys (setting 1), some 3- and 4-year-olds were administered the OCTC with four toys (setting 2). Figure 2.5 presents the proportion of 3- and 4-year-old children across the two settings of the OCTC.

![Graph showing proportion of 3- and 4-year-old children across settings of the OCTC in pilot study.]

There were 7 out of 19 children (= 37 %) from the 3-year-old group who could sort the toys within a setting with six objects. From the 12 children in setting 2 (i.e., four toys), only 5 children could sort the toys correctly. As shown in Figure 2.5, 47 % of the 4-year-olds could sort the toys in a setting with six objects. From the 10 children in setting 2, only 5 children could sort the toys correctly. Thus, for most children in the 3- and 4-year-old groups, the OCTC appeared to be too difficult using six toys. When the OCTC was administered with four toys, about half of the children could sort the toys correctly. However, none of these children was able to group the objects for a second time, according to a different feature.

Although all children older than 4 years were able to group six objects, when asked to group the toys for a second time, some children were dependent on structure provided by the examiner (i.e., identification or explicit condition) to do this.
Figure 2.6 shows the proportion of children in each condition for the first switch (i.e., second sort) across age groups.

As shown in Figure 2.6, most 3- and 4-year-olds needed explicit directions to group the toys for a second time, and were not able to sort the toys independently. It must be noted that the only 3-year-old who grouped the objects without additional structure (i.e., free generation condition) appeared not aware that he had sorted the objects correctly. While all 4-year-olds required explicit instructions to group the toys, 5-year-olds required less structure to do so. In particular, 42% of the children in this age group could sort the objects without additional structure, 29% of the children could identify a second concept when the examiner had grouped the toys for them, and the remaining 29% of the children needed explicit instructions. A chi-square analysis revealed that there were significantly more children in the 7-year-old group who could sort the toys independently, when compared to the 5-year-olds, \( \chi^2 (1, n = 24) = 5.5, p < .05 \). No other significant differences were found across age groups or conditions.
Figure 2.7 shows the proportion of children in each condition for the first switch (i.e., second sort) across age groups.

As shown in Figure 2.7, all children from the 3- and 4-year-old groups required explicit instructions to group the toys for a third time. In contrast, older children required less structure in order to perform this task. In particular, a chi-square analysis showed that there were significantly more 7-year-olds who could group the toys independently, when compared to 5-year-olds, $\chi^2(1, n = 24) = 5.71$, $p < .05$. No other significant differences were found for any of the age groups or conditions.

A few children ($n = 5$) generated valid sorts that were not included in the three pre-determined groupings. These sorting categories included little wheels/big wheels and moving wheels/non-moving wheels. These categories were considered as correct
groupings. No child generated extra sorts in addition to correctly generating all three pre-determined sorts.

2.4 Discussion

Due to a lack of measures available to assess executive processes within the domain of cognitive flexibility in children between the ages of 3 and 7 years, in this pilot study, a new task was developed. This test, the Object Classification Task for Children (OCTC), was devised to assess concept generation and mental flexibility. Findings from the OCTC confirm our hypotheses and suggest that this task is a useful measure of conceptual reasoning skills in young children. In particular, the results from this pilot study revealed age-related changes in overall performance across the entire age range, providing a clear picture of developmental changes in concept generation and mental flexibility during early childhood. The two settings of the OCTC (i.e., four toys/six toys), and the use of different levels of structure within these settings, allowed for a detailed analysis of the performance of children between 3 and 7 years, suggesting the usefulness of the OCTC to investigate conceptual reasoning skills in this age range. The greatest improvement in performance on the OCTC was observed between the 4- and 5-year-old groups, indicating a rapid developmental progression of concept generation and mental flexibility in the period between 4 and 5 years of age.

Even the youngest children passed the practice trials, indicating that they are capable of grouping four objects according to overall appearance, although the majority of 3-year-olds experienced difficulty sorting the test toys according to a particular feature. This finding suggests that 3-year-olds have difficulty identifying a common feature within a group of nonidentical objects. Even when the number of dimensions was reduced to two (i.e., colour and size) in a setting with only four toys, most children from the 3-year-old group were unable to perform the task. In contrast, almost half of the children in the 4-year-old group could identify a common dimension within a group of six toys, suggesting that 4-year-old children have less difficulty generating concepts, when compared to 3-year-olds. The results from this study showed that all children older than 4 years were able to sort six toys according to a certain feature, indicating that these children are able to identify a common
These findings are consistent with a recent study conducted by Jacques and Zelazo (2001), who used the Flexible Item Selection Task (FIST) to measure abstraction and cognitive flexibility in 3-, 4-, and 5-year-old children. Jacques and Zelazo found that 3-year-olds experienced considerable difficulty detecting a dimension that was common to two nonidentical cards, when compared to older children. In addition, they found that the performance of 4- and 5-year-old children on this aspect of the FIST was comparable.

The results of the OCTC showed that, when required to shift between concepts, none of the 4-year-old children were successful. All children from this age group needed explicit instructions to group the toys, suggesting that 4-year-olds are unable to group six toys according to a second, different dimension. The majority of 5-year-olds were able to identify a second concept, albeit with additional structure provided by the examiner. In their study on abstraction and cognitive flexibility, Jacques and Zelazo (2001) found that 4-year-olds did worse on the shifting component of the FIST when compared to 5-year-olds, in keeping with our finding that there appears to be a developmental progression in mental flexibility between the ages of 4 and 5 years.

On the OCTC, it was also found that older children required less structure to group the objects for a second time, suggesting a refinement of mental flexibility skills between the ages of 5 and 7 years. Although the majority of 7-year-olds could independently group the objects according to a second dimension, when required to sort the toys for a third time, most children required additional structure. Thus, although 7-year-olds may be able to shift between two concepts, they appear to experience difficulty when shifting between more than two concepts is required, suggesting that conceptual reasoning skills continue to develop beyond the age of 7 years. This finding is supported by a number of studies investigating the development of concept generation and cognitive flexibility during middle childhood and adolescence (e.g., Jacobs et al., 2001a; Levin et al., 1991).

It must be noted, however, that the failure of 3-year-old children to group the test toys could also be due to limited knowledge about the semantic components (i.e., colour, size, and function) of the objects. Older children may perform better on the
task because they have an established understanding of physical and functional properties of objects. Ample evidence exists for the notion that during early childhood, children acquire a range of linguistic capacities, such as increased vocabulary and use of grammatical rules, which are believed to be key processes in efficient functioning and essential for learning (e.g., Chen-Hafteck, 1997; Farrar & Maag, 2002; D. Molfese & V. Molfese, 2000).

Another reason for why 3-year-olds experienced difficulty grouping the objects of the OCTC may be that these children were unable to apply the task instructions that were used with the practice toys to the testing settings. The toys in the practice trials were quite different from the test objects, with the practice toys including different “animals” with salient shapes. As the practice trials required sorting according to overall appearance, in the test settings of the OCTC, objects had to be grouped according to a particular feature. Qualitative observation from the examiner suggested this may have accounted for young children’s difficulty grouping the toys in the testing settings.

It may also be that younger children’s representations are limited by the perceptual features of objects. Indeed, research has indicated a shift between the use of perceptual cues and more abstract information as the basis for categorisation occurs in the development of conceptual reasoning skills (e.g., Bruner, Olver, & Greenfield, 1966). However, categorisation decisions cannot be conceived as being made either on the basis of perception or cognition (Deak & Bauer, 1996). For example, in their analysis of categorisation style in preschoolers, Morgan and Greene (1994) showed that categorisation style might be a function of task demands as well as competence. Complex task demands may have limited young children’s ability to use perceptual cues to sort the toys of the OCTC.

It may also be that the test toys are unusual or unfamiliar representations of cars and planes. When shown the test toys, children were not asked if they knew what the toys were, as this may have helped them to categorise the objects. Therefore, it is not known if children who could not sort the toys multiple times simply did not know what the toys represented. However, this explanation seems least likely, since toys for
young children often represent means of transport, such as trucks, breakdown lorries, and helicopters.

Alternatively, younger children may have experienced difficulty shifting between concepts due to the immaturity of skills within the domain of attentional control. Older children may perform better on the task because they are able to selectively attend to the features of the objects and exercise more inhibitory control over their behaviour, skills that are necessary to shift between concepts. Several developmental studies have shown that during early childhood, children become more capable exercising inhibitory control over their behavioural actions (e.g., Becker et al., 1987; Passler et al., 1985). The explanation that the immaturity of attentional control processes may explain young children’s difficulty switching also provides support for the assumption that cognitive skills within the domain of attentional control need to be in plan before other aspects of executive function can be functional.

While the results of this pilot study support the utility of the OCTC as a suitable neuropsychological test for children between 3 and 7 years, there are a number of factors that should be considered in interpreting the findings. The main weakness of the research involves the difficulty knowing what cognitive skills have developed and what processes have not, when interpreting performance. For example, performance on the OCTC may be limited, as children may not yet have grasped the concepts of colour, size, and function, preventing them from abstracting these features from the objects. It may therefore be needed to check the child’s knowledge of colour, size, and function, before administering the OCTC.

Another limitation of the study involves the use of practice trials. As discussed earlier, the practice trials may cause confusion in young children, as the requirements of these trials are quite different from those of the test trials. It may be that the OCTC shows different results when no practice trials are used, or when practice trials require children to sort according to a particular feature. Clearly, there is a need for replication with different designs.

It must be noted that, despite these limitations, this pilot study also has a number of strengths, when compared to other developmental studies. First, while most
other studies investigating cognitive skills in early childhood have focused on relatively narrow age ranges (e.g., Diamond, 1985; Espy et al., 2001), this study involved a relatively large number of children across a wide range of age groups. Further, subjects were recruited from several different childcare centres, kindergartens, and primary schools within the wider area of a metropolitan city, thereby recruiting a fairly representative sample of children between 3 and 7 years of age. Finally, the method used in this pilot study allowed for investigating different levels of conceptual reasoning, thereby able to map age-related differences in cognitive functions.

In summary, the present study supports the utility of the OCTC as a suitable neuropsychological test of concept generation and mental flexibility in children between the ages of 3 and 7 years. Analysis of age trends in the current study identifies a developmental course of conceptual reasoning skills and, in particular, shows evidence for a developmental spurt in mental flexibility around 4 – 5 years of age. The OCTC has the ability to discriminate between the performance of younger and older children by providing different levels of structure in three conditions (i.e., free generation, identification, and explicit cueing). Thus, the OCTC, which is specifically designed for use with children between 3 and 7 years, appears to be a useful tool for the investigation of concept generation and mental flexibility, and therefore, it was decided to include this test in the test protocol of the larger study, to assess executive processes within the domain of cognitive flexibility.
CHAPTER THREE
Method

3.1 Participants

3.1.1 Normative study

The normative sample consisted of 99 children (54 males, 45 females), aged between 3 years, 1 month and 7 years, 11 months. They were divided into five age groups: 3-year-olds (n = 16), 4-year-olds (n = 21), 5-year-olds (n = 23), 6-year-olds (n = 22), and 7-year-olds (n = 17). Children were selected from several local childcare centres, kindergartens, and primary schools in the metropolitan area of Melbourne, Australia. These centres and schools were different from those approached in the pilot phase of the study. Inclusion criteria were: (1) aged between 3 years, 0 months and 7 years, 11 months at time of testing; (2) no previous history of developmental, neurologic, or psychiatric disorder, based on a questionnaire completed by the parent or guardian (see appendix B); and (3) English as a first language. The response rate was 71%. See Table 3.1 for demographic information regarding the normative sample.

Table 3.1
Demographic Characteristics of Normative Sample

<table>
<thead>
<tr>
<th>Age group</th>
<th>n</th>
<th>Number of males (females)</th>
<th>Age (in months) M (SD)</th>
<th>Range (in months)</th>
<th>Socio-economic status* M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-year-olds</td>
<td>16</td>
<td>9 (7)</td>
<td>42.7 (3.0)</td>
<td>37 – 47</td>
<td>4.1 (1.0)</td>
</tr>
<tr>
<td>4-year-olds</td>
<td>21</td>
<td>11 (10)</td>
<td>54.6 (3.1)</td>
<td>48 – 59</td>
<td>4.0 (0.9)</td>
</tr>
<tr>
<td>5-year-olds</td>
<td>23</td>
<td>9 (14)</td>
<td>66.7 (3.3)</td>
<td>60 – 71</td>
<td>4.2 (1.0)</td>
</tr>
<tr>
<td>6-year-olds</td>
<td>22</td>
<td>15 (7)</td>
<td>77.1 (3.1)</td>
<td>72 – 83</td>
<td>4.1 (1.0)</td>
</tr>
<tr>
<td>7-year-olds</td>
<td>17</td>
<td>10 (7)</td>
<td>88.5 (3.1)</td>
<td>84 – 95</td>
<td>4.0 (0.8)</td>
</tr>
</tbody>
</table>

Note. No significant group differences were found with regards to gender or socio-economic status.

* Daniel (1983)
Before children were recruited, ethics approval was received from the Human Research Ethics Committee at the University of Melbourne. Permission to contact kindergartens and primary schools was obtained from the Department of Education and Training of the state Victoria, Australia. A mix of public and private childcare centres, kindergartens, and primary schools was then approached. Once the principals or directors of the centres agreed to participate in the study, children who fitted the appropriate age criteria were identified. The families were contacted by letter, inviting them to participate in the study. This letter was part of an information package, which also contained an information statement, a consent form, and a short parent questionnaire (see appendix B). In the letter, parents were asked to return the consent form and the parent questionnaire to the examiner if they agreed to participate. Once the families had given consent for participation, an appointment time was scheduled.

3.1.2 Case studies

From a clinical sample of seven children with frontal brain damage, two cases were identified for a more detailed analysis. The clinical sample comprised children with frontal lobe damage (congenital and acquired), between the ages of 3 years, 9 months and 7 years, 8 months. There were one 3-year-old, two 4-year-olds, three 5-year-olds, and one 7-year-old. The children were recruited through the departments of radiology and neurology at the Royal Children’s Hospital in Melbourne, Australia. Inclusion criteria were: (1) aged between 3 years, 0 months and 7 years, 11 months at time of testing; (2) documented evidence of frontal lobe damage, and (3) English as a first language. Informed consent, based on hospital ethics guidelines, was obtained from parents or guardians of children who participated in the project. Table 3.2 shows demographic and medical characteristics of the clinical sample.
Table 3.2

*Demographic and Medical Characteristics of Clinical Sample*

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age at testing (in months)</th>
<th>gender</th>
<th>Socio-economic status*</th>
<th>Nature of lesion</th>
<th>Type of lesion</th>
</tr>
</thead>
<tbody>
<tr>
<td>KS</td>
<td>45</td>
<td>female</td>
<td>5.3</td>
<td>congenital</td>
<td>frontal encephalocele</td>
</tr>
<tr>
<td>BP</td>
<td>48</td>
<td>female</td>
<td>5.6</td>
<td>congenital</td>
<td>fronto-parietal astrocytoma</td>
</tr>
<tr>
<td>BR</td>
<td>51</td>
<td>female</td>
<td>3.8</td>
<td>acquired</td>
<td>head injury</td>
</tr>
<tr>
<td>LM</td>
<td>60</td>
<td>male</td>
<td>5.9</td>
<td>congenital</td>
<td>fronto-parietal arteriovenous malformation</td>
</tr>
<tr>
<td>SB</td>
<td>61</td>
<td>female</td>
<td>2.3</td>
<td>congenital</td>
<td>frontal neuroectodermal tumour</td>
</tr>
<tr>
<td>ZM</td>
<td>64</td>
<td>male</td>
<td>3.8</td>
<td>congenital</td>
<td>tuberous sclerosis</td>
</tr>
<tr>
<td>JC</td>
<td>84</td>
<td>male</td>
<td>4.1</td>
<td>congenital</td>
<td>ischaemia/infarction</td>
</tr>
</tbody>
</table>

*Note. Subject characteristics of case studies are italicised.

*Daniel (1983)*

Before patients were recruited, Ethics approval was received from the Ethics in Human Research Committee at the Royal Children’s Hospital. Once identified, the patient’s primary consultant (usually a neurologist, neurosurgeon, or paediatrician) was contacted to seek permission to contact the family by letter about the study. Parents of children who met the selection criteria received written information regarding the study and were notified that they were free to decline to be involved at any time and that this would not affect their medical treatment in any way. For families who agreed to be involved, a mutually agreed appointment time was arranged.
From the clinical sample, two cases (i.e., BR and ZM) were identified for a more detailed analysis. These cases were selected based on a different age at testing, gender, and nature/type of lesion. Case BP and case JC were not considered for analysis, due to insufficient data resulting from unwillingness of these patients to complete all tasks. Background information for the cases of BR and ZM follows below.

3.1.2.1 Case BR

When BR was 2½ years old, she was involved in a car accident, and as a result of this, BR sustained a moderately severe head injury. She was transferred to the Royal Children’s Hospital and was unconscious for eight days after the accident. A CT scan of the brain showed left frontal bone fracture and haemorrhagic contusion of the left frontal lobe. Since the accident, Mrs R. noted that BR is easily fatigued and at times is restless and fidgety. There have also been a number of changes in BR’s behaviour since her injury, such as reduced self-regulation and impulse control. For instance, BR may pull all her clothes out of the cupboard when angry, particularly when she is tired.

BR was born after 41 weeks of uncomplicated pregnancy. She attained all developmental milestones within normal limits, with first words at 6 months, walking at 14 months, and first 2–3 word sentences at 12 months. Her parents are both educated professionals, with no family history of neurological, psychological, learning, or behavioural problems. BR is the youngest of four children, and has one older brother (6 years) and two older sisters (10 and 12 years). Both her sisters were also involved in the car accident, resulting in a mild and severe head injury, respectively. According to Mrs R., her son, the only child of the family who was not involved in the accident, is a healthy young boy, who is doing fine in school. Currently, BR is attending special integration kindergarten, which she seems to enjoy.

As BR and her family lived in rural Victoria, the neuropsychological assessment was conducted within a home environment. During the assessment, BR presented as a pleasant young girl, who was timid at the beginning, but became more at ease as the assessment progressed. She was motivated to complete tasks and maintained attention throughout the assessment. However, at times, BR was noted to
experience difficulty expressing her thoughts and ideas, often devising words pertaining to the function of an item for commonly known objects (e.g., saying “candle blowers” instead of “matches”).

3.1.2.2 Case ZM
At 4 months of age, ZM began experiencing refractory partial seizures, and was diagnosed with tuberous sclerosis at the age of 18 months. Brain CT and MRI scanning at the time of diagnosis revealed two calcified lesions located in the inferior frontal gyrus of the left frontal lobe. Over the next 5 years, ZM took anticonvulsant medication, including Epilim and Tegretol, and although seizures continued, they occurred at a reduced frequency.

ZM was born at term following an unremarkable pregnancy. As a baby, ZM had trouble sleeping and was often awake at night. He attained developmental milestones within normal limits, with crawling at 6 months, and walking at 11 months. ZM is the youngest child in an intact family unit. He has an older brother and sister, who are both healthy and developing normally. His father is a general manager and his mother is involved in home duties. During a family interview, Mrs M. described ZM as a “normal” child, who enjoys playing sports and relates well to peers. However, in the last few months, his parents reported increasing problems with concentration and inhibition.

During the neuropsychological assessment, which was conducted at the Royal Children’s Hospital, ZM was accompanied by his mother, who was sitting behind him in the room. He presented as an active young child, who readily engaged in test activities. He was motivated to participate in task activities, however, he became fidgety and restless after extended periods of time and needed frequent redirection to complete tasks. Further, during the assessment, ZM showed a number of impulsive behaviours, such as having difficulty waiting for the task instructions to be finished and skipping to the next item without having finished the previous one.
3.2 Materials

This section aims to describe the assessment measures that were used in the present study and to provide a rationale for the utilisation of these tasks. Table 3.2 presents the test protocol of the current project, and Table 3.3 shows the variables that were obtained from these measures, grouped according to executive function domain. In order to examine any behavioural deficits, parents of children in the clinical sample were asked to complete the Behavior Assessment System for Children (BASC: Reynolds & Kamphaus, 1992).

Table 3.3

Test Protocol of Study

<table>
<thead>
<tr>
<th>Test Protocol of Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comprehension of Instructions (NEPSY)</td>
</tr>
<tr>
<td>Visual Attention (NEPSY)</td>
</tr>
<tr>
<td>Statue (NEPSY)</td>
</tr>
<tr>
<td>Tower (NEPSY)*</td>
</tr>
<tr>
<td>Auditory Attention and Response Set (NEPSY)*</td>
</tr>
<tr>
<td>Object Classification Task for Children (Smidts &amp; Anderson, 2002)</td>
</tr>
<tr>
<td>Stroop-like Day-Night test (Gerstadt et al., 1994)</td>
</tr>
<tr>
<td>Shape School (Espy, 1997)**</td>
</tr>
</tbody>
</table>

* Administered to older age groups (i.e., 5-, 6-, and 7-year-olds) only

** The control and inhibition tasks were administered to all age groups, the switch and both tasks were administered to older age groups only
Table 3.4

Summary of Variables for Each Executive Function Domain

<table>
<thead>
<tr>
<th>Attentional control</th>
<th>Cognitive flexibility</th>
<th>Information processing</th>
<th>Goal setting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Selective attention:</strong></td>
<td><strong>Working memory:</strong></td>
<td><strong>Speed of output:</strong></td>
<td><strong>Planning and problem-solving:</strong></td>
</tr>
<tr>
<td>- Number of targets – Visual Attention (bunnies, cats, &amp; faces)</td>
<td>- Total score – Comprehension of Instructions</td>
<td>- Total time – Visual Attention (bunnies, cats, &amp; faces)</td>
<td>- Total score - Tower</td>
</tr>
<tr>
<td>- Efficiency score – Visual Attention (bunnies, cats, &amp; faces)</td>
<td>- Concept generation:</td>
<td>- Total time – Shape School (control, inhibition, switch, &amp; both)</td>
<td></td>
</tr>
<tr>
<td>- Total score – Auditory Attention</td>
<td>- Setting – OCTC</td>
<td>- Total time – Day-Night</td>
<td></td>
</tr>
<tr>
<td><strong>Inhibition of motor responses:</strong></td>
<td><strong>Shifting between concepts:</strong></td>
<td><strong>Efficiency of output:</strong></td>
<td></td>
</tr>
<tr>
<td>- Number of nontargets – Visual Attention (bunnies, cats, &amp; faces)</td>
<td>- Total score – OCTC</td>
<td>- Number of correct responses – Shape School (control)</td>
<td></td>
</tr>
<tr>
<td>- Total score – Statue</td>
<td>- Level of structure – OCTC</td>
<td>- Efficiency score – Shape School (control)</td>
<td></td>
</tr>
<tr>
<td><strong>Inhibition of verbal responses:</strong></td>
<td><strong>Shifting between complex rules:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Number of correct responses – Shape School (inhibition)</td>
<td>- Number of correct responses – Shape School (switch)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Number of correct responses – Day-Night</td>
<td>- Efficiency score – Shape School (switch)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Efficiency score – Shape School (inhibition)</td>
<td>- Number of correct responses – Shape School (both)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Efficiency score – Day-Night</td>
<td>- Efficiency score – Shape School (both)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Efficiency score – Day-Night</td>
<td>- Total score – Response Set</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Utilisation of feedback:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Number of rule violations – Tower</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.2.1 *Description assessment measures*

Most assessment measures that were utilised in the present study are subtests from the NEPSY, *A Developmental Neuropsychological Assessment* (Korkman et al., 1998). The NEPSY ("NE" from *neuro* and "PSY" from *psychology*) is a test battery designed to assess neuropsychological abilities in preschool and school-age children. For the purpose of this study, five subtests from the first domain (i.e., Attention/Executive Functions) and one subtest from the language domain (i.e., Comprehension of Instructions) were used. The NEPSY, which is based on the neuropsychological practice of A.R. Luria (see chapter 1 for more detail on his theory), was normed on a large, representative sample of American children between 3 and 12 years old (Kemp, Kirk, & Korkman, 2001). The subtests of the NEPSY are highly correlated within domains, suggesting sound construct validity. Reliability coefficients for the NEPSY were calculated for each age separately. Average reliability for ages 3 to 4 for scores in the Attention/Executive Function domain is .70. Average reliability for ages 5 to 12 for scores in the Attention/Executive Function domain is .82. Following is a description of each assessment measure, including the scoring system, used in the present project.

3.2.1.1 *Comprehension of Instructions (NEPSY)*

In this task, the child is asked to point to target pictures in response to verbal instructions of increasing difficulty. Comprehension of Instructions contains a total of 28 items or “instructions” in two arrays (see appendix C for the stimulus arrays). The first 13 items are used with the bunny pictures, whereas the last 15 items are used with the circles and crosses. Examples of instructions used in this task are listed below:

*Item 6* – “Show me a yellow bunny”
*Item 11* – “Show me a bunny that is little and blue”
*Item 18* – “Show me a blue circle last and a black cross first”
*Item 25* – “Show me a shape that is between two crosses and above a circle”

For each correct response, a score of 1 is given. For each incorrect response, a score of 0 is given. After four consecutive scores of 0, the task is discontinued. The total score for this test is calculated by summing the points earned on all items. Although this task was designed to tap receptive language skills (Korkman et al., 1998), it was included in the
current test protocol as a measure of working memory, since successful performance on this test is highly dependent on the ability to keep information in mind for a certain period of time.

3.2.1.2 Visual Attention (NEPSY)

In this test, the child is shown an array of pictures and is pointed out a target item (either a bunny, cat, or pair of faces). The child is then asked to put a mark through all target items, using a red crayon. There are three different arrays (see appendix D for an example of the arrays), each containing different targets:

1. Linear array (bunnies): Ages 3 to 4 only.

In this task, the child is required to selectively attend to specific stimuli, while ignoring nontargets, and therefore, this measure taps selective attention skills and the ability to inhibit a prepotent motor response. In the present study, the first two arrays (i.e., bunnies and cats) were used with 3- and 4-year-olds, and the last two arrays (i.e., cats and faces) were used with the 5-, 6-, and 7-year-olds. For each array, the following scores were obtained: total time (in seconds), number of correctly identified targets, number of nontargets, and efficiency score. The efficiency score was calculated by dividing the number of targets by the total time.

3.2.1.3 Statue (NEPSY)

In this subtest, the child is asked to “stand still like a statue holding a flag”, during a 75-second period. During this period, the child is required to keep their eyes closed and inhibit responses such as moving and vocalising. At fixed time intervals, the examiner distracts the child by performing the following actions:

- at 10 seconds, the examiner drops a pencil on the table,
- at 20 seconds, the examiner coughs once out loud,
- at 30 seconds, the examiner knocks on the table twice,
- at 50 seconds, the examiner says “Ho Hum!”
- at 75 seconds, the examiner says “Time’s up!”
The 75-second period is divided into 15 time frames of 5 seconds. For each error-free time interval, 2 points are scored. A score of 1 is given for each interval with only one error indicated. For each interval with two or more errors, a score of 0 points is given. The behaviours in the following list, and any comparable movements, are considered errors:

- dropping the right hand or arm more than 45 degrees
- turning the head
- lifting a foot or sliding a foot on the floor
- voicing
- laughing

(Korkman et al., 1998).

For the present study, the total score of the Statue task is used as an indication of the ability to inhibit motor responses to noise distracters.

### 3.2.1.4 Tower (NEPSY)

In the tower task, children are shown a picture stimulus, where three coloured balls are located on three pegs of different lengths. The child is then presented with a peg model containing three coloured balls in a standard starting position, and is asked to rearrange the balls, so that the new configuration matches the picture stimulus. This must be accomplished in a prescribed number of moves (see Figure 3.1 for an example). To do this, the child has to remember three rules:

1. only one ball may be moved at the time;
2. the balls must be kept on the pegs when they are not being moved; and
3. a move cannot be changed once their hand is taken off the ball.

The tower task consists of one teaching example and 20 items, with an increasing sequence of moves required to match the stimulus picture. For items 1 – 4, the time limit to complete the problem is 30 seconds, and for the remaining items, there is a time limit of 45 seconds.
Figure 3.1  Example of a picture stimulus in the tower task that requires three moves

The tower requires the ability to make a plan in order to generate a solution and also to monitor the number of moves. Because the task involves the execution of a long sequence of moves that cannot be changed once executed, correct solution depends on how successfully the child planned the initial sequence (Kemp et al., 2001). Further, the tower measures the use of feedback in that the examiner corrects the child when a rule break is made. For each correct item, the child receives 1 point. If an item is failed, a score of 0 points is given. An item is failed if the child exceeds the time limit, if an incorrect number of moves is made, or if the end configuration does not match the
stimulus picture. The task is discontinued after four consecutive scores of 0. The total score is obtained by summing the points for items 1 – 20.

3.2.1.5 Auditory Attention and Response Set (NEPSY)

This test consists of two parts: Auditory Attention and Response Set. Although the two parts are administered together, the second part (i.e., Response Set) is dependent on the first. In the Auditory Attention task, a large number of coloured (i.e., red, yellow, blue, and black) foam squares is spread out in front of the child, with a box behind the squares. The child is then asked to put a red square in the box, every time they hear the target word “red” from a list of words played on an audiocassette player. In the second part of the test (i.e., Response Set), the rules are changed and the child has to

1. put a red square in the box at the word “yellow”,
2. put a yellow square in the box at the word “red”, and
3. put a blue square in the box at the word “blue”.

Auditory Attention measures simple, selective auditory attention to rapidly presented auditory stimuli. Response Set, in contrast, measures complex auditory attention and is dependent on the ability to shift and maintain a new set, which involves both contrasting and matching stimuli. For each correct response that occurs on the target word, 2 points are given. A score of 1 is given for each correct response that occurs as the next two words are said (1 or 2 seconds after the target word). Commission errors (such as putting a yellow square in the box at the word “yellow” or putting a square in the box at a nontarget word) are also noted. The raw scores for the individual parts are calculated by summing the number of points earned and subtracting the number of commission errors made (1 point for each commission error).

3.2.1.6 Object Classification Task for Children (Smidts & Anderson, 2002)

The OCTC is a sorting task that requires the child to group six toys according to three predetermined groupings. These groupings include:

1. colour – red or yellow
2. size – big or small
3. function – car or plane
In the OCTC, there are three conditions with increasing levels of structure:

(1) *Free generation*, where the child is required to sort the toys without any additional help from the examiner,

(2) *Identification*, where the examiner constructs a category and the child is asked to identify the sort, and

(3) *Explicit cueing*, where the child is explicitly told how to sort the toys.

For each correct sort in the free generation condition, the child receives 3 points. For each correct sort in the identification condition, 2 points are given. Finally, in the explicit cueing condition, 1 point is rewarded for each correct sort. A score of 1 is given for each correct verbal response. The total raw score is calculated by summing all the points earned and is used as an indication of children’s ability to shift between concepts. In addition to the total score, for each child, the level of structure required to complete the sort is also noted. See chapter 2 for more details regarding the OCTC.

### 3.2.1.7 Stroop-like Day-Night test (Gerstadt et al., 1994)

In this task, children are shown two sets of cards and are asked to say “day” whenever they see a black card with a moon and stars on it, and to say “night” when shown a white card with a bright sun (see Figure 3.2).

*Figure 3.2* Task stimuli used for the Stroop-like Day-Night test
This task consists of 16 items, which are presented to the child in a fixed order: night (n), day (d), d, n, d, n, d, n, d, n, d, n, d, n, d, n, d. Before these 16 items are presented, the child can get up to three practice trials for the test. The Stroop-like Day-Night test requires the ability to hold two rules in mind (i.e., say “day” to a card with a moon, and to say “night” to a card with a sun on it), and, at the same time, to inhibit a prepotent response (e.g., to say “day” to a sun card). Three scores are obtained from this task: total time (i.e., the time it takes for a child to complete 16 items), number of correct responses, and efficiency score, which is calculated by dividing the number of correct responses by the total time.

3.2.1.8 The Shape School (Espy, 1997)

The Shape School is a colourful storybook designed to measure inhibition and switching processes in children. The Shape School involves four conditions: control, inhibit, switch, and both. The story begins with an illustration of a schoolyard with colourful circle and square figures playing. In the control condition, the child is asked to name the colours of the figures as quickly as possible. In the inhibit condition, children need to give a response whenever they see a figure with a happy face, but they need to suppress a response whenever they see a figure with a sad face. In the switch condition, children hold two rules in mind and switch between those rules depending on the presence or absence of a hat in the figure. The rules they need to keep in mind are the following:

1) “The name of the figure is its colour”
2) “If the figure wears a hat, the name is its shape”

In the inhibit-and-switch condition, children need to suppress a response whenever they see a sad face, and at the same time, they need to switch between the rules described above. For each condition, the total time it takes to complete an item, the number of correct responses, and an efficiency score is obtained. The efficiency score is calculated by dividing the number of correct responses by the total time, which is different from the technique used by Espy (1997), who substracted the number of errors from the number of correct responses and divided this by the total time. To maintain calculations of
efficiency scores consistent across tasks, in this study, only the number of correct responses was considered in the numerator.

3.2.1.9 The Behavior Assessment System for Children (Reynolds & Kamphaus, 1992)

The Behavior Assessment System for Children (BASC) is a questionnaire designed to assess emotional and behavioural problems in children, in addition to adaptive and social skills. This inventory contains 131 questions in the preschool version (2½ - 5 years), and includes the following scales: Adaptability, Anxiety, Aggression, Attention problems, Atypicality, Depression, Hyperactivity, Social skills, Somatization, and Withdrawal. The BASC contains four summary scores that represent distinct but not independent behavioural dimensions: (1) Externalizing Problems composite, which consists of the Hyperactivity and Aggression scales, (2) Internalizing Problems composite, which consists of the Anxiety, Depression, and Somatization scales, (3) Adaptive Skills composite, which consists of the Adaptability and Social Skills scales, and (4) Behavioral Symptoms Index, which combines the central scales from the clinical composites.

For each item, the respondent can circle his or her response: N if the behaviour never occurs, S if the behaviour sometimes occurs, O if the behaviour often occurs, and A if the behaviour almost always occurs. For each component measured by the scale, two types of normative scores are provided: (1) linear T scores, including the 90 percent confidence interval, and (2) percentiles. An indicator of the validity of a completed form is the F index, which assesses the possibility that a respondent rates the child in an overly negative manner. Coefficient Alpha reliabilities for the BASC scales and composites are high, averaging above .80 for the preschool level.
3.3 Procedure

3.3.1 Normative sample

Children were seen at their childcare centre or primary school in a single session of approximately 1½ hours, with a break in the middle. The tests were administered in fixed order, using standardised instructions. On request, families were provided with verbal and/ or written feedback regarding their child’s performance. After completion of the study, all participating families received a copy of the findings of the study in the format of a brief report.

3.3.2 Clinical sample

Children in the clinical sample were seen in either one or two sessions, depending on their concentration span. Most children from the clinical sample were seen at the hospital, however, for families who lived in rural Victoria, it was more convenient to have the assessment done at their homes. Parents completed the questionnaires while waiting. All families in the clinical sample received detailed information regarding their child’s performance in the form of a neuropsychological report. After completion of the research, they also received a copy of the findings of the study in the format of a brief report.

3.4 Statistical procedure

3.4.1 Treatment of missing data

Some of the younger children failed practice trials of specific tasks, or were not able to complete the more complex executive function tests. Missing data from these children were not included in the analyses of variance (ANOVAs), however, to investigate specific group characteristics (such as mean age) of children with missing data, separate analyses were conducted. In particular, a dummy variable was created for tasks that contained nonrandom patterns of missing values. Cases with complete data were assigned 0 and cases with missing data were assigned 1. This allowed for investigation of group differences in performance profiles on executive function tasks.
3.4.2 Data analysis

Due to missing data resulting from children’s failure to perform practice trials or complete tests, variables did not contain equal numbers of cases. As a result, the data obtained from this study did not allow for multivariate analysis within executive function domains. Therefore, two-way analyses of variance (ANOVAs) were employed to investigate main effects of age and gender, and any Age x Gender interaction effects on all variables within each executive function domain. The ANOVAs only included data from children who were able to perform the task. Post hoc Tukey LSD pairwise comparisons were conducted to investigate significant changes in performance between age groups. Further, chi-square analyses were employed to analyse the form of the frequency distributions that were obtained from the OCTC variables. Results were considered significant at the .05 level.

A principal components analysis (PCA), with varimax rotation, was employed to examine patterns of correlations among executive function variables. In order to keep a sufficiently large sample size for the analysis, nine variables with data from four age groups (i.e., 4-, 5-, 6-, and 7-year-olds) that were representative of the executive function domains under investigation were selected. However, one of these variables (i.e., number of targets on the cats subtest of Visual Attention) was excluded from the analysis, as a pairwise correlation analysis revealed that it did not correlate with other variables in the set. As suggested by Tabachnick and Fidell (2001), outliers among variables may cause factors to be unreliable and should therefore be deleted from factor analysis. Factors with eigenvalues greater than 1 were accepted, and factor loadings greater than .50 were considered to contribute to each factor. All analyses were conducted with SPSS version 9.0.
CHAPTER FOUR
Results

The present project was designed to map developmental trajectories of executive processes in a sample of children between the ages of 3 and 7 years, and to examine the effects of early frontal lobe damage on the ongoing development of these skills. Developmental changes in executive processes were investigated within the following four executive function domains: attentional control, cognitive flexibility, information processing, and goal setting.

It was hypothesised that these domains have different developmental profiles, with attentional control processes developing rapidly between the ages of 3 and 7 years, and the more complex executive function domains of cognitive flexibility, information processing, and goal setting not reaching maturity before the age of 7 years. Further, early frontal lobe damage was expected to affect the development of executive processes, as indicated by a poorer performance on executive function tests by the two frontal lobe cases, when compared to healthy children the same age. This study also aimed to explore gender differences.

This chapter presents the analyses of data in seven sections. The first section provides the results for all variables within the attentional control domain, and describes the findings for separate executive processes within this domain. The results regarding variables included in the cognitive flexibility domain are addressed in the second section. The third section presents the findings for all variables within the domain of information processing. The data analysis for the goal setting domain is described in the fourth section. The fifth section provides a summary of significant changes in executive processes within each executive function domain, for consecutive age groups. The sixth section presents the results of the principal components analysis. Case study results are addressed in the final section.
4.1 Attentional control

For each variable within the attentional control domain, a two-way ANOVA (Age x Gender) was employed. Main effects of age were found on all variables, with the exception of the number of nontargets on the faces array of the Visual Attention task. No main effects of gender or Age x Gender interaction effects were found on any of the variables. Table 4.1 presents the results for each of the attentional control variables across age groups.

4.1.1 Selective attention

As shown in Table 4.1, for each array of the Visual Attention task (i.e., bunnies, cats, and faces), the number of correctly identified targets increased significantly as a function of increasing age. Post hoc analysis showed that on the cats array, 5-year-olds identified significantly more targets when compared to 3-year-olds \( (p < .05) \). No significant differences were found between the 3- and 4-year-olds and, in addition, the 5-year-old group did not differ from the other age groups on this index. On the faces array, post hoc analysis revealed that the 7-year-old group performed significantly better than the 5-year-old group \( (p < .05) \). The performance of 6-year-olds did not differ from that of either of these age groups.

For each array of the Visual Attention task, significant overall age effects were also noted with regards to efficiency scores. A post hoc analysis indicated that efficiency scores on the cats array improved relatively gradually, with significant increments in performance demonstrated between age groups that were at least two years apart. Significant differences in mean efficiency score were found between the 3- and 5-year-old groups \( (p < .01) \), between the 4- and 6-year-old groups \( (p < .01) \), and between the 5- and 7-year-old groups \( (p < .01) \). On the faces array, post hoc analysis showed that the 7-year-old group significantly outperformed the 5-year-old group \( (p < .01) \). Performance of 6-year-olds did not differ from that of either of these age groups. Not all of the children were able to complete the faces array. Some of the younger children simply crossed out all faces \( (n = 5, \text{mean age} = 65.2 \text{ months}) \). Further, some of the children were not able to proceed line by line and required frequent redirections from the examiner \( (n = 4, \text{mean age} = 77.1 \text{ months}) \). Data from these children were not included in the ANOVA.
Table 4.1

*Means, Standard Deviations, F-Ratio’s, and p-Values of Attentional Control Variables Across Age Groups*

<table>
<thead>
<tr>
<th>Test variable</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>F-ratio</th>
<th>p-value</th>
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<tbody>
<tr>
<td>Selective attention:</td>
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<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Number of targets <em>(bunnies)</em></td>
<td>14.8</td>
<td>17.0</td>
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<td></td>
<td></td>
<td>$F(1,35) = 4.20$</td>
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</tr>
<tr>
<td>Number of targets <em>(cats)</em></td>
<td>14.9</td>
<td>17.1</td>
<td></td>
<td></td>
<td></td>
<td>$F(4,94) = 5.84$</td>
<td>.000</td>
</tr>
<tr>
<td>Number of targets <em>(faces)</em></td>
<td></td>
<td></td>
<td>13.6</td>
<td></td>
<td>17.1</td>
<td>$F(2,50) = 4.61$</td>
<td>.015</td>
</tr>
<tr>
<td>Efficiency score <em>(bunnies)</em></td>
<td>0.14</td>
<td>0.21</td>
<td></td>
<td></td>
<td></td>
<td>$F(1,35) = 9.82$</td>
<td>.003</td>
</tr>
<tr>
<td>Efficiency score <em>(cats)</em></td>
<td>0.16</td>
<td>0.25</td>
<td></td>
<td></td>
<td></td>
<td>$F(4,94) = 20.10$</td>
<td>.000</td>
</tr>
<tr>
<td>Efficiency score <em>(faces)</em></td>
<td></td>
<td></td>
<td>0.09</td>
<td>0.10</td>
<td>0.13</td>
<td>$F(2,50) = 6.44$</td>
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<td>Total score Auditory Attention</td>
<td></td>
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<td>39.7</td>
<td>47.5</td>
<td>50.7</td>
<td>$F(2,59) = 11.41$</td>
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<td>Inhibition of motor responses:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of nontargets <em>(bunnies)</em></td>
<td>0.6</td>
<td>0.0</td>
<td></td>
<td></td>
<td></td>
<td>$F(1,35) = 5.91$</td>
<td>.020</td>
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<tr>
<td>Number of nontargets <em>(cats)</em></td>
<td>2.4</td>
<td>0.3</td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td>$F(4,94) = 4.40$</td>
<td>.003</td>
</tr>
<tr>
<td>Number of nontargets <em>(faces)</em></td>
<td>7.5</td>
<td>3.3</td>
<td></td>
<td>5.2</td>
<td></td>
<td>$F(2,50) = 2.04$</td>
<td>ns</td>
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<tr>
<td>Total score Statue</td>
<td>19.1</td>
<td>25.1</td>
<td>27.7</td>
<td>27.0</td>
<td>28.2</td>
<td>$F(4,84) = 12.15$</td>
<td>.000</td>
</tr>
<tr>
<td>Inhibition of verbal responses:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of correct responses <em>(inhibition)</em></td>
<td>14.0</td>
<td>14.1</td>
<td>14.9</td>
<td>14.9</td>
<td>15.0</td>
<td>$F(4,73) = 4.00$</td>
<td>.006</td>
</tr>
<tr>
<td>Number of correct responses <em>(Day-Night)</em></td>
<td>9.2</td>
<td>9.7</td>
<td>14.9</td>
<td>15.1</td>
<td>15.7</td>
<td>$F(4,76) = 17.21$</td>
<td>.000</td>
</tr>
<tr>
<td>Efficiency score <em>(inhibition)</em></td>
<td>0.54</td>
<td>0.74</td>
<td>1.09</td>
<td>1.31</td>
<td>1.39</td>
<td>$F(4,73) = 15.66$</td>
<td>.000</td>
</tr>
<tr>
<td>Efficiency score <em>(Day-Night)</em></td>
<td>0.21</td>
<td>0.24</td>
<td>0.39</td>
<td>0.41</td>
<td>0.45</td>
<td>$F(4,76) = 18.56$</td>
<td>.000</td>
</tr>
</tbody>
</table>
On the Auditory Attention task, post hoc testing showed that 6-year-olds outperformed the 5-year-olds ($p < .01$). No significant difference in mean total score was found between the 6- and 7-year-olds.

### 4.1.2 Inhibition of motor responses

While overall age effects were found for the number of nontargets in the *bunnies* and *cats* arrays of the Visual Attention task, no significant differences were noted with regards to the *faces* array. Post hoc comparisons for the *cats* array revealed a significant decline in mean number of commission errors between the 3- and 4-year-old groups ($p < .05$). Further, it was found that the 4-year-old group did not differ from older age groups on this index.

A similar pattern was noted with regards to the Statue test, with 3-year-olds performing significantly poorer than older children. Post-hoc analysis revealed a significant increase in mean total score between the 3- and 4-year-olds ($p < .01$). No significant differences were found between the 4-year-old group and older age groups on this index. Not all of the children were able to perform the Statue task. There were 7 out of 16 children (44 %) from the 3-year-old group and 3 out of 21 children (14 %) from the 4-year-old group who were unwilling to engage in the task, or were not able to stand still at all, and therefore, no score was obtained from these children. The mean age of the 3-year-olds with missing data was 40.1 months (range = 37 – 42 months). For the 4-year-olds who were not able to complete the Statue test, the mean age was 48.6 months (range = 48 – 49 months). Chi-square analysis revealed a significant difference in the number of children who could perform the Statue test in the 3- and 4-year-old groups, $\chi^2 (1, n = 37) = 4.10, p < .05$.

### 4.1.3 Inhibition of verbal responses

As shown in Table 4.1, for the *inhibition* task of the Shape School and the Stroop-like Day-Night test, significant overall effects of age were found on both variables (i.e., number of correct responses and efficiency score). On the *inhibition* task of the Shape School, post hoc testing revealed significant changes between the 4- and 5-year-old groups on the number of correct responses ($p < .05$) and the efficiency score ($p < .01$). For both of these variables, no significant differences were found between the 3- and 4-year-olds. With regards to the number of correct responses on
this task, post hoc comparisons showed that 5-year-olds did not differ from the older age groups on this index. A different pattern was found for the efficiency score, with 7-year-olds outperforming the 5-year-olds \((p < .01)\). The 6-year-old group did not differ from either of these age groups.

Not all children were able to pass the practice trial of the \textit{inhibition} task of the Shape School. There were 10 out of 16 children (63\%) from the 3-year-old group who failed the practice trial of this task. The mean age of these children was 42.2 months (range = 37 – 45 months). In addition, there were 4 out of 21 children (19\%) from the 4-year-old group who were unable to pass the practice trial. The mean age of these children was 52.1 months (range = 48 – 54 months). Chi-square analysis revealed a significant difference between these groups with regards to the number of children who failed the practice trial of the \textit{inhibition} task of the Shape School, \(\chi^2 (1, n = 37) = 7.13, p < .01\). No children in the older age groups failed the practice trial of this task.

Similar to the findings from the \textit{inhibition} task of the Shape School, post hoc analysis of the data from the Day-Night test showed significant changes between the 4- and 5-year-old groups on the number of correct responses \((p < .01)\) and the efficiency score \((p < .01)\). On both of these variables, post hoc testing revealed no significant changes between the 3- and 4-year-olds. In addition, 5-year-olds did not differ from the older age groups on the number of correct responses and the efficiency score.

There were 9 out of 16 children from the 3-year-old group (56\%) who failed both practice trials of the Stroop-like Day-Night test. The mean age of these children was 42.3 months (range = 39 – 45 months). Of these 9 children, 5 children also failed the practice trial of the \textit{inhibition} task of the Shape School. In addition, there were 5 out of 21 children (24\%) from the 4-year-old group who were unable to pass both practice trials. The mean age of these children was 51.0 months (range = 49 – 53 months). Of these 5 children, 2 children also failed the practice trial of the \textit{inhibition} task of the Shape School. Chi-square analysis revealed a significant difference in the number of children who failed the practice trials of the Day-Night test between the 3- and 4-year-old groups, \(\chi^2 (1, n = 37) = 3.93, p < .05\). No children in the older age groups experienced difficulty completing the practice trials of this task.
4.2 Cognitive flexibility

For each variable within the cognitive flexibility domain, a two-way ANOVA (Age x Gender) was employed. While no main effects of gender or Age x Gender interaction effects were found on any of the variables, main effects of age were found on all variables, with the exception of the number of correct responses on the both task of the Shape School. Table 4.2 presents the results for each of the variables within the cognitive flexibility domain across age groups.

Table 4.2

Means, Standard Deviations, F-Ratio’s, and p-Values of Cognitive Flexibility Variables Across Age Groups

<table>
<thead>
<tr>
<th>Test variable</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>F-ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working memory:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total score (COI)</td>
<td>12.8</td>
<td>15.5</td>
<td>18.0</td>
<td>20.4</td>
<td>21.0</td>
<td>F(4, 94) = 34.38</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>(4.0)</td>
<td>(2.3)</td>
<td>(2.1)</td>
<td>(1.8)</td>
<td>(2.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utilisation of feedback:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of rule violations (Tower)</td>
<td>3.1</td>
<td>2.3</td>
<td>1.4</td>
<td></td>
<td></td>
<td>F(2, 59) = 3.99</td>
<td>.024</td>
</tr>
<tr>
<td></td>
<td>(1.8)</td>
<td>(1.5)</td>
<td>(2.1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shifting between concepts:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total score (OCTC)</td>
<td>3.8</td>
<td>4.4</td>
<td>7.9</td>
<td>9.0</td>
<td>10.2</td>
<td>F(4, 94) = 35.25</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>(2.8)</td>
<td>(1.6)</td>
<td>(1.5)</td>
<td>(2.1)</td>
<td>(1.3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shifting between complex rules:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number correct (switch)</td>
<td>13.6</td>
<td>14.4</td>
<td>14.6</td>
<td></td>
<td></td>
<td>F(2, 58) = 3.47</td>
<td>.038</td>
</tr>
<tr>
<td></td>
<td>(1.9)</td>
<td>(1.1)</td>
<td>(0.6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number correct (both)</td>
<td>14.3</td>
<td>14.2</td>
<td>14.3</td>
<td></td>
<td></td>
<td>F(2, 59) = 0.12</td>
<td>ns</td>
</tr>
<tr>
<td></td>
<td>(1.1)</td>
<td>(1.3)</td>
<td>(1.0)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efficiency score (switch)</td>
<td>0.39</td>
<td>0.53</td>
<td>0.56</td>
<td></td>
<td></td>
<td>F(2, 58) = 10.39</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>(0.11)</td>
<td>(0.13)</td>
<td>(0.13)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efficiency score (both)</td>
<td>0.50</td>
<td>0.61</td>
<td>0.69</td>
<td></td>
<td></td>
<td>F(2, 59) = 8.13</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>(0.16)</td>
<td>(0.12)</td>
<td>(0.17)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total score Response Set</td>
<td>24.9</td>
<td>34.7</td>
<td>39.8</td>
<td></td>
<td></td>
<td>F(2, 46) = 8.73</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>(10.7)</td>
<td>(11.6)</td>
<td>(7.3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.2.1 Working memory

As shown in Table 4.2, overall age effects were found for the total score on the Comprehension of Instructions task. Post hoc comparisons showed significant increments between the 3- and 4-year-olds \( (p < .05) \), between the 4- and 5-year-olds \( (p < .01) \), and between the 5- and 6-year-olds \( (p < .05) \). No significant difference in performance was found between the 6- and 7-year-old groups.

4.2.2 Concept generation

All children from all age groups passed the two practice trials of the OCTC. The first test trial of the OCTC was administered with six toys (i.e., setting 1) to all children. There were a number of 3- and 4-year-olds who were unable to group the toys in such a setting. Therefore, these children were given the OCTC with four toys (i.e., setting 2). Figure 4.1 shows the proportion of 3- and 4-year-old children across the two settings of the OCTC.

![Figure 4.1](image-url)  
*Figure 4.1* Proportion of 3- and 4-year-old children across settings of the OCTC in normative study
As shown in Figure 4.1, the OCTC was administered with four toys to most children from the 3-year-old group (56 %, n = 9) and to only a relatively small number of 4-year-olds (14 %, n = 3). The mean age of the 3-year-olds was 40.7 months (range = 37 – 44 months). For the 4-year-olds with missing data, the mean age was 50.0 months (range = 49 – 51 months).

A chi-square analysis revealed a significant difference in the number of children that required four toys across the two age groups, $\chi^2 (1, n = 37) = 7.30$, $p < .01$. In a setting with four toys, only 5 out of 12 children (42 %) were able to sort the four toys into two groups, based on either colour or size. None of these children was able to group the toys for a second time.

### 4.2.3 Shifting between concepts

As shown in Table 4.2, an overall age effect was found on performance on the OCTC, with older children achieving more points than younger children. A post hoc analysis showed a significant increment in mean total score between the 4- and 5-year-old groups ($p < .01$). All children who were administered the task with six toys could initially sort the toys by themselves, without any structure provided (note that if they were unable to do this, they were administered the task with four toys). When asked to group the toys for a second time, some children were dependent on structure provided by the examiner (i.e., identification or explicit cueing condition) to do this. Figure 4.2 shows the proportion of children in each condition for the first switch (i.e., second sort) across age groups.
As shown in Figure 4.2, older children were better able to group the toys by themselves, without any structure provided, in comparison to younger children, who were primarily dependent on the highest level of structure (i.e., explicit cueing condition) in order to group the toys for a second time. A chi-square analysis revealed that there were significantly more children in the 5-year-old group who sorted independently, in comparison to 4-year-olds, $\chi^2(1, n = 40) = 13.75, p < .01$. In addition, there were significantly more children in the 4-year-old group that required explicit instructions to group the toys, when compared to 5-year-olds, $\chi^2(1, n = 40) = 11.78, p < .01$. No significant differences were found between these age groups in regards to the identification condition. Further, across the older age groups, there were no significant differences in number of children for any of the conditions.
Figure 4.3 shows the proportion of children in each condition for the second switch (i.e., third sort).

As shown in Figure 4.3, most children in the 3- and 4-year-old groups were dependent on the highest level of structure (i.e., explicit cueing condition) to group the toys for a third time. A chi-square analysis showed that there were significantly more children in the 5-year-old group who could sort the toys with a medium level of structure (i.e., identification condition), when compared to 4-year-olds, $\chi^2(1, n = 40) = 5.89, p < .05$. In addition, there were significantly less 5-year-olds who required the highest level of structure, when compared to the 4-year-old group, $\chi^2(1, n = 40) = 6.42, p < .05$. Although some older children were able to switch independently, most 5-, 6- and 7-year-olds required at least some degree of structure in order to sort the toys for a third time.
A chi-square analysis showed that there were significantly less children in the 7-year-old group who required the highest level of structure (i.e., explicit condition) to sort the toys, when compared to 5-year-olds, \( \chi^2 (1, n = 39) = 7.63, p < .01 \). No significant differences were found in regards to the free generation or identification conditions and, in addition, 6-year-olds did not differ from either of these age groups.

In summary, on the OCTC, a pattern in seen in which performance increases as a function of increasing age. While 3-year-olds could sort toys according to overall appearance, most of them had difficulty grouping toys according to one particular feature. Almost all older children were able to identify a certain feature within a group of six toys. When children had to sort the toys for a second time, according to a different feature, most 4-year-olds were highly dependent on structure provided by the examiner, whereas most children older than 4 years could do this by themselves. In contrast, when sorting the toys for a third time, even older children were dependent on structure provided by the examiner. This pattern is similar to that observed in the pilot study.

**4.2.4 Shifting between complex rules**

As shown in Table 4.2, overall effects of age were found for both variables of the *switch* task of the Shape School (i.e., number of correct responses and efficiency score). Post hoc comparisons showed that 6-year-olds were more efficient than 5-year-olds \( (p < .01) \). No difference in mean efficiency score was found between the two older age groups. A similar pattern was found for the efficiency score on the *both* task of the Shape School, with 6-year-olds outperforming the 5-year-olds \( (p < .05) \). On the *switch* task, post hoc analysis of the data revealed that 7-year-olds made significantly less errors than 5-year-olds \( (p < .05) \). No significant difference was found on this index between the 5- and 6-year-old groups.

As shown in Table 4.2, there appears to be an overall trend for greater output efficiency as a function of increasing age on the Response Set task. Post hoc comparisons revealed a significant increase in mean total score between the 5- and 6-year-old groups \( (p < .05) \). The 6-year-olds did not differ from the 7-year-olds on this index. Similar to the findings of the Shape School, there was a developmental trend in
performance between 5- and 6-year-olds, but no significant differences were found between the older age groups.

Not all children were able to pass the practice trial of the Response Set task. There were 9 out of 23 children (39 %) from the 5-year-old group who failed the practice trial of the test. The mean age of these children was 64.2 months (range = 59 – 69 months). In addition, 4 out of 22 children (18 %) from the 6-year-old group failed the practice trial. The mean age of these children was 75.1 months (range = 72 – 78 months). Thus, a total of 13 out of 62 children (21 %) between the ages of 5 and 7 years were unable to complete the practice trial of the Response Set task.

4.2.5 Utilisation of feedback

As shown in Table 4.2, a main effect of age was found for the number of rule violations made on the Tower task. Post hoc comparisons revealed that 7-year-olds made significantly less rule violations than 5-year-olds ($p < .05$). The 6-year-old group did not differ from either age group on this variable.

4.3 Information processing

A two-way ANOVA (Age x Gender) was employed on the variables within the information processing domain. Although main effects of age were found on most variables, no age effects were observed on the total time variable of the bunnies and faces arrays of the Visual Attention task, and on the number of correct responses of the control task of the Shape School. No main effects of gender or Age x Gender interaction effects were found on any of the variables. Table 4.3 presents the results for each of the attentional control variables across age groups.
Table 4.3

Means, Standard Deviations, F-Ratio’s, and p-Values of Information Processing Variables Across Age Groups

<table>
<thead>
<tr>
<th>Test variable</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>F-ratio</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Speed of output:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total time (bunnies)</td>
<td>108.7(44.3)</td>
<td>91.3(38.0)</td>
<td></td>
<td></td>
<td></td>
<td>$F(1, 35) = 1.64$</td>
<td>ns</td>
</tr>
<tr>
<td>Total time (cats)</td>
<td>98.1(31.8)</td>
<td>80.7(36.3)</td>
<td>65.3(27.4)</td>
<td>57.1(30.6)</td>
<td>45.3(15.0)</td>
<td>$F(4, 94) = 8.53$</td>
<td>.000</td>
</tr>
<tr>
<td>Total time (faces)</td>
<td></td>
<td></td>
<td>148.1(31.2)</td>
<td>151.7(33.7)</td>
<td>138.4(27.7)</td>
<td>$F(2, 50) = 0.83$</td>
<td>ns</td>
</tr>
<tr>
<td>Total time (control)</td>
<td>25.4(10.8)</td>
<td>21.5(7.4)</td>
<td>14.8(3.6)</td>
<td>13.0(4.1)</td>
<td>11.3(2.6)</td>
<td>$F(4, 94) = 16.70$</td>
<td>.000</td>
</tr>
<tr>
<td>Total time (inhibition)</td>
<td>28.3(5.1)</td>
<td>19.2(2.4)</td>
<td>14.7(4.0)</td>
<td>12.1(3.2)</td>
<td>11.3(2.6)</td>
<td>$F(4, 73) = 28.32$</td>
<td>.000</td>
</tr>
<tr>
<td>Total time (switch)</td>
<td></td>
<td></td>
<td>36.2(10.8)</td>
<td>28.3(5.5)</td>
<td>27.0(5.0)</td>
<td>$F(2, 58) = 8.60$</td>
<td>.001</td>
</tr>
<tr>
<td>Total time (both)</td>
<td>32.2(11.8)</td>
<td>24.0(3.9)</td>
<td>21.9(4.7)</td>
<td></td>
<td></td>
<td>$F(2, 59) = 10.02$</td>
<td>.000</td>
</tr>
<tr>
<td>Total time (Day-Night)</td>
<td>54.5(9.3)</td>
<td>43.1(7.7)</td>
<td>39.7(6.7)</td>
<td>37.8(5.3)</td>
<td>35.3(3.8)</td>
<td>$F(4, 76) = 9.53$</td>
<td>.000</td>
</tr>
<tr>
<td><strong>Efficiency of output:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number correct (control)</td>
<td>14.7(0.7)</td>
<td>14.9(0.4)</td>
<td>14.9(0.3)</td>
<td>14.8(0.5)</td>
<td>15.0(0.2)</td>
<td>$F(4, 94) = 1.27$</td>
<td>ns</td>
</tr>
<tr>
<td>Efficiency score (control)</td>
<td>0.65(0.19)</td>
<td>0.75(0.19)</td>
<td>1.07(0.28)</td>
<td>1.22(0.30)</td>
<td>1.38(0.32)</td>
<td>$F(4, 94) = 25.28$</td>
<td>.000</td>
</tr>
</tbody>
</table>

**4.3.1 Speed of output**

As shown in Table 4.3, significant overall age effects were found on all total time variables, with the exception of the *bunnies* and *faces* arrays of the Visual Attention task. On the *cats* array, a post hoc analysis revealed a significant decline in mean total time between 3- and 5-year-olds ($p < .01$), and between 4- and 7-year-olds ($p < .01$).
Significant differences in mean total time between successive age groups were found on all conditions of the Shape School and on the Stroop-like Day-Night test. Post hoc comparisons showed a significant decline in mean total time between 3- and 4-year-olds on the inhibition task of the Shape School ($p < .01$) and the Stroop-like Day-Night test ($p < .05$). Significant differences in mean total time between the 4- and 5-year-old groups were found on the control task ($p < .01$) and the inhibition task ($p < .01$). Further, it was found that 6-year-olds were significantly faster than 5-year-olds on the inhibition task ($p < .05$), the switch task ($p < .01$), and the both task ($p < .01$). Post hoc comparisons revealed no significant differences between the 6- and 7-year-old groups on any of the variables.

4.3.2 Efficiency of output

With regards to the control task of the Shape School, there is an overall trend for greater efficiency as a function of increasing age. A post hoc analysis revealed a significant increment in efficiency between the 4- and 5-year-old groups ($p < .01$), and between the 5- and 7-year-old groups ($p < .01$). As shown in Table 4.3, in the control condition, the number of correct responses did not differ with age. Total time to complete the task did decrease significantly across age groups. Post hoc testing revealed a significant decline in mean total time between the 4- and 5-year-old groups ($p < .01$). Thus, while the mean efficiency score increased between the 4- and 5-year-olds groups, the mean time to complete the task decreased. No such pattern was found in the older age groups. While the mean efficiency score increased significantly between the 5- and 7-year-old groups, a post hoc analysis revealed no significant difference in total time means. Since the efficiency score is calculated by dividing the number of correct responses by the total time, a greater result is accomplished when a child gives a relatively large number of correct responses in a relatively short time. It is likely that there are more of such individual combinations in the 7-year-old group, in comparison to the 5-year-old group. Within the younger age group, it may be that patterns of relatively few correct responses combined with a relatively fast performance are counterbalanced by patterns of relatively many correct responses combined with a relatively long time to complete. While 7-year-old children were more efficient on the control task of the Shape School than 5-year-olds, in the older age groups, no significant differences were found with regards to total time and number of correct responses.
4.4  Goal setting

A two-way ANOVA (Age x Gender) was performed on the total score variable of the Tower task. Although no main effect of gender and no Age x Gender interaction effect were found, there was a significant effect of age on the total score of the Tower task. Table 4.4 presents the results for this variable.

Table 4.4

Means, Standard Deviations, F-Ratio, and p-Value of Total Score Tower task Across Age Groups

<table>
<thead>
<tr>
<th>Test variable</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>F-ratio</th>
<th>p-value</th>
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<tbody>
<tr>
<td>Planning and problem-solving:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total score (Tower)</td>
<td>10.5</td>
<td>11.6</td>
<td>12.7</td>
<td></td>
<td></td>
<td>F(2, 59) = 8.06</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>(1.7)</td>
<td>(1.7)</td>
<td>(1.9)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.4.1  Planning and problem-solving

On the Tower task, there appears to be a relatively gradual developmental pattern, with older children solving more problems in comparison to younger children. A post hoc analysis revealed a significant increase in the mean total score between the 5- and 7-year-olds ($p < .01$). Further, it was found that the 6-year-old group did not differ significantly from either of these age groups.
4.5 Significant changes in executive processes across consecutive age groups

The separate executive function domain analyses presented above revealed a number of significant improvements in performance between specific age groups. Table 4.5 summarises the significant changes in executive processes between the 3- and 4-year-old children, between the 4- and 5-year-old groups, and between the 5-, 6-, and 7-year-olds. Although the results of this study revealed a number of significant differences between 5- and 6-year-olds, and also between 5- and 7-year-olds, no significant differences were found between the 6- and 7-year-old groups on any of the variables. Therefore, these age groups were merged with the 5-year-old group.

Table 4.5

<table>
<thead>
<tr>
<th>Between 3- and 4-year-olds</th>
<th>Between 4- and 5-year-olds</th>
<th>Between 5-, 6-, and 7-year-olds</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Attentional control:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Selective attention</td>
<td>Selective attention</td>
<td></td>
</tr>
<tr>
<td>Inhibition of motor responses</td>
<td>Inhibition of verbal responses</td>
<td></td>
</tr>
<tr>
<td>Cognitive flexibility:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working memory</td>
<td>Working memory</td>
<td></td>
</tr>
<tr>
<td>Concept generation</td>
<td>Shifting between concepts</td>
<td></td>
</tr>
<tr>
<td>Information processing:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed of output</td>
<td>Speed of output</td>
<td></td>
</tr>
<tr>
<td>Efficiency of output</td>
<td>Efficiency of output</td>
<td></td>
</tr>
<tr>
<td>Goal setting:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planning and problem solving</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.6 Relationships among variables

To examine patterns of correlations among executive function variables, a principal components analysis (PCA), with varimax rotation, was performed. To keep a sufficiently large sample size without including variables with nonrandom patterns of missing values, eight variables with data from 4-, 5-, 6-, and 7-year-old groups (n = 69) were included in the analysis. Using the Kaiser-Meyer-Olkin measure (Dziuban & Shirkey, 1974) as an indication of the reliability of the relationships between pairs of variables, it was found that the correlation matrix was factorable, with a sampling adequacy of .82.

Table 4.6 shows the Pearson correlation coefficients for all eight variables. As shown in Table 4.6, variables were highly interrelated, with each variable correlating with at least four other variables. A pattern of relatively high correlations was found between variables tapping inhibition skills, for example, the number of correct items on the Stroop-like Day-Night test and the number of correct items on the inhibition task of the Shape School. Total time variables from the cats array and the inhibition task were found to correlate relatively highly with several variables from different domains, such as Comprehension of Instructions and OCTC.
Table 4.6

*Pearson Correlations between Executive Function Variables*

<table>
<thead>
<tr>
<th></th>
<th>Nontargets cats</th>
<th>Statue</th>
<th>N° correct Inh.</th>
<th>N° correct DN</th>
<th>COI</th>
<th>OCTC</th>
<th>Total time cats</th>
<th>Total time Inh.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nontargets cats</td>
<td>1.00</td>
<td>-.10</td>
<td>.01</td>
<td>-.28**</td>
<td>-.18</td>
<td>-.35**</td>
<td>.36**</td>
<td>.36**</td>
</tr>
<tr>
<td>Statue</td>
<td></td>
<td>1.00</td>
<td></td>
<td></td>
<td>.44***</td>
<td>.39***</td>
<td>.21*</td>
<td>-.22*</td>
</tr>
<tr>
<td>N° correct Inh.</td>
<td></td>
<td></td>
<td>1.00</td>
<td>.43***</td>
<td>.24*</td>
<td>.25*</td>
<td>-.26*</td>
<td>-1.16</td>
</tr>
<tr>
<td>N° correct DN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.51***</td>
<td>.50***</td>
<td>-.47***</td>
<td>-.45***</td>
</tr>
<tr>
<td>COI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.00</td>
<td>.57***</td>
<td>-.40***</td>
<td>-.57***</td>
</tr>
<tr>
<td>OCTC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Total time cats</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.00</td>
</tr>
<tr>
<td>Total time Inh.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p < .05, ** p < .01, *** p < .001
Using the criterion of eigenvalues greater than one, the PCA extracted two independent factors, together explaining 59.8% of the variance (see Table 4.7). It appears that the first factor taps cognitive skills that are essential for efficiency and complexity of information processing. The first factor included two speeded performance variables, one based on an inhibition task and the other based on a selective attention test. Both these variables loaded in a negative direction. Another variable that loaded in this direction was a variable from the Visual Attention task tapping inhibition of motor responses. Although this variable is quite different from the speeded performance variables, all three competencies are important for efficient performance. The first factor also included two variables from the cognitive flexibility domain, one measuring conceptual reasoning skills and the other verbal working memory. Both these variables loaded on the first factor in a positive direction. In the tasks that load positively on the first factor, the cognitive set that needs to be kept in mind is quite complex and competes with response alternatives. These skills play an important role when cognitive demand increases. The second factor incorporated variables associated with “attentional control”, two based on verbal tasks and one based on a test measuring inhibition of motor responses.

Table 4.7

*Principal Components Analysis of Executive Function Variables*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Factor 1</th>
<th>Factor 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total time Inhibition</td>
<td>-.80</td>
<td></td>
</tr>
<tr>
<td>Total score OCTC</td>
<td>.74</td>
<td></td>
</tr>
<tr>
<td>Comprehension of Instructions</td>
<td>.69</td>
<td></td>
</tr>
<tr>
<td>Nº nontargets cats</td>
<td>-.68</td>
<td></td>
</tr>
<tr>
<td>Total time cats</td>
<td>-.67</td>
<td></td>
</tr>
<tr>
<td>Nº correct Inhibition</td>
<td>.85</td>
<td></td>
</tr>
<tr>
<td>Total score – Statue</td>
<td>.75</td>
<td></td>
</tr>
<tr>
<td>Nº correct Day-Night</td>
<td>.54</td>
<td></td>
</tr>
</tbody>
</table>

| Eigenvalues  | 3.55 | 1.24 |
| Variance explained | 44.3 % | 15.5 % |
4.7 Results case studies

Table 4.8 and Table 4.9 show the neuropsychological test results for both cases.

Table 4.8

*Neuropsychological Test Results for Case BR*

<table>
<thead>
<tr>
<th>Test results</th>
<th>Case BR</th>
<th>4-year-old controls (M, SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Executive function domain</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Attentional control</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Selective attention:</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of targets – bunnies array</td>
<td>15</td>
<td>17.0 (2.9)</td>
</tr>
<tr>
<td>Number of targets – cats array</td>
<td>10**</td>
<td>17.1 (2.6)</td>
</tr>
<tr>
<td>Efficiency score – bunnies array</td>
<td>0.13</td>
<td>0.21 (0.07)</td>
</tr>
<tr>
<td>Efficiency score – cats array</td>
<td>0.14</td>
<td>0.25 (0.09)</td>
</tr>
<tr>
<td><strong>Inhibition of motor responses:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of nontargets – bunnies array</td>
<td>4**</td>
<td>0.0 (0.3)</td>
</tr>
<tr>
<td>Number of nontargets – cats array</td>
<td>0</td>
<td>0.3 (0.7)</td>
</tr>
<tr>
<td>Total score – Statue</td>
<td>17**</td>
<td>25.1 (3.6)</td>
</tr>
<tr>
<td><strong>Inhibition of verbal responses:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of correct resp. – Shape School (inhibition)</td>
<td>15</td>
<td>14.1 (1.5)</td>
</tr>
<tr>
<td>Number of correct resp. – Day-Night</td>
<td>10</td>
<td>9.7 (4.4)</td>
</tr>
<tr>
<td>Efficiency score – Shape School (inhibition)</td>
<td>0.38**</td>
<td>0.74 (0.12)</td>
</tr>
<tr>
<td>Efficiency score – Day-Night</td>
<td>-</td>
<td>0.24 (0.12)</td>
</tr>
<tr>
<td><strong>Cognitive flexibility</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Working memory:</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total score – Comprehension of Instructions</td>
<td>7</td>
<td>15.5 (2.3)</td>
</tr>
<tr>
<td><strong>Concept generation:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Setting – OCTC</td>
<td>6 toys</td>
<td>6 toys (86 %) of sample</td>
</tr>
<tr>
<td><strong>Shifting between concepts:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total score – OCTC</td>
<td>4</td>
<td>4.4 (1.6)</td>
</tr>
<tr>
<td>Level of structure – first switch</td>
<td>explicit</td>
<td>explicit (80 %)</td>
</tr>
<tr>
<td>Level of structure – second switch</td>
<td>explicit</td>
<td>explicit (86 %)</td>
</tr>
<tr>
<td><strong>Information processing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Speed of output:</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total time – bunnies array</td>
<td>119 sec</td>
<td>91.3 (38.0)</td>
</tr>
<tr>
<td>Total time – cats array</td>
<td>74 sec</td>
<td>80.7 (36.3)</td>
</tr>
<tr>
<td>Total time – Shape School (control)</td>
<td>40 sec**</td>
<td>21.5 (7.4)</td>
</tr>
<tr>
<td>Total time – Shape School (inhibition)</td>
<td>32 sec**</td>
<td>19.2 (2.4)</td>
</tr>
<tr>
<td>Total time – Day-Night</td>
<td>not measured</td>
<td>43.1 (7.7)</td>
</tr>
<tr>
<td><strong>Efficiency of output:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of correct resp. – Shape School (control)</td>
<td>15</td>
<td>14.9 (0.4)</td>
</tr>
<tr>
<td>Efficiency score – Shape School (control)</td>
<td>0.38*</td>
<td>0.75 (0.19)</td>
</tr>
</tbody>
</table>

*Note.* The efficiency score for the Day-Night test could not be calculated, as the total time was not measured, due to examiner’s error.

* Performance at least one standard deviation below the mean of the normative sample

** Performance at least two standard deviations below the mean of the normative sample
Table 4.9
Neuropsychological Test Results for Case ZM

<table>
<thead>
<tr>
<th>Test results</th>
<th>Case ZM</th>
<th>5-year-old controls (M, SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Executive function domain</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Attentional control</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Selective attention:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of targets – cats array</td>
<td>19</td>
<td>17.8 (4.0)</td>
</tr>
<tr>
<td>Number of targets – faces array</td>
<td>5**</td>
<td>13.6 (3.8)</td>
</tr>
<tr>
<td>Efficiency score – cats array</td>
<td>.12*</td>
<td>0.31 (0.10)</td>
</tr>
<tr>
<td>Efficiency score – faces array</td>
<td>.03**</td>
<td>0.09 (0.03)</td>
</tr>
<tr>
<td><strong>Inhibition of motor responses:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of nontargets – cats array</td>
<td>0</td>
<td>0.0 (0.0)</td>
</tr>
<tr>
<td>Number of nontargets – faces array</td>
<td>4</td>
<td>7.5 (7.8)</td>
</tr>
<tr>
<td>Total score – Statue</td>
<td>18**</td>
<td>27.7 (1.5)</td>
</tr>
<tr>
<td><strong>Inhibition of verbal responses:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of correct resp. – Shape School (inhibition)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Number of correct resp. – Day-Night</td>
<td>9**</td>
<td>14.9 (1.9)</td>
</tr>
<tr>
<td>Efficiency score – Shape School (inhibition)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Efficiency score – Day-Night</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Cognitive flexibility</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Working memory:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total score – Comprehension of Instructions</td>
<td>17</td>
<td>18.0 (2.1)</td>
</tr>
<tr>
<td><strong>Concept generation:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Setting – OCTC</td>
<td>6 toys</td>
<td>6 toys (100 % of sample)</td>
</tr>
<tr>
<td><strong>Shifting between concepts:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total score – OCTC</td>
<td>6*</td>
<td>7.9 (1.5)</td>
</tr>
<tr>
<td>Level of structure – first switch</td>
<td>explicit</td>
<td>explicit (23 %)</td>
</tr>
<tr>
<td>Level of structure – second switch</td>
<td>explicit</td>
<td>explicit (44 %)</td>
</tr>
<tr>
<td><strong>Utilisation of feedback:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of rule violations – Tower</td>
<td>7**</td>
<td>3.1 (1.8)</td>
</tr>
<tr>
<td><strong>Information processing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Speed of output:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total time – cats array</td>
<td>180 sec**</td>
<td>65.3 (27.4)</td>
</tr>
<tr>
<td>Total time – faces array</td>
<td>180 sec*</td>
<td>148.1 (31.2)</td>
</tr>
<tr>
<td>Total time – Shape School (control)</td>
<td>34 sec**</td>
<td>14.8 (3.6)</td>
</tr>
<tr>
<td>Total time – Shape School (inhibition)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total time – Day-Night</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Efficiency of output:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of correct resp. – Shape School (control)</td>
<td>14**</td>
<td>14.9 (0.3)</td>
</tr>
<tr>
<td>Efficiency score – Shape School (control)</td>
<td>.41**</td>
<td>1.07 (0.28)</td>
</tr>
<tr>
<td><strong>Goal setting</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Planning and problem solving:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total score – Tower</td>
<td>5**</td>
<td>10.5 (1.7)</td>
</tr>
</tbody>
</table>

*Note. The efficiency score for the Day-Night test could not be calculated, as the total time was not measured, due to examiner’s error.

* Performance differs at least one standard deviation compared to the mean of the normative sample

** Performance differs at least two standard deviations compared to the mean of the normative sample
Table 4.10 and Table 4.11 show the BASC results for both cases.

Table 4.10  
**BASC Results for Case BR**

<table>
<thead>
<tr>
<th></th>
<th>T score</th>
<th>90% confidence interval</th>
<th>Percentile</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Clinical scales</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hyperactivity</td>
<td>53</td>
<td>46 – 60</td>
<td>67</td>
<td>ns</td>
</tr>
<tr>
<td>Aggression</td>
<td>39</td>
<td>32 – 46</td>
<td>12</td>
<td>ns</td>
</tr>
<tr>
<td>Anxiety</td>
<td>37</td>
<td>28 – 46</td>
<td>8</td>
<td>ns</td>
</tr>
<tr>
<td>Depression</td>
<td>42</td>
<td>34 – 50</td>
<td>21</td>
<td>ns</td>
</tr>
<tr>
<td>Somatization</td>
<td>60</td>
<td>52 – 68</td>
<td>83</td>
<td>ns</td>
</tr>
<tr>
<td>Atypicality</td>
<td>44</td>
<td>35 – 53</td>
<td>33</td>
<td>ns</td>
</tr>
<tr>
<td>Withdrawal</td>
<td>68</td>
<td>61 – 75</td>
<td>95</td>
<td>.05</td>
</tr>
<tr>
<td>Attention problems</td>
<td>58</td>
<td>49 – 67</td>
<td>78</td>
<td>ns</td>
</tr>
<tr>
<td><strong>Adaptive scales</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adaptability</td>
<td>44</td>
<td>35 – 53</td>
<td>28</td>
<td>ns</td>
</tr>
<tr>
<td>Social skills</td>
<td>46</td>
<td>40 – 52</td>
<td>34</td>
<td>ns</td>
</tr>
<tr>
<td><strong>Composites</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Externalizing Problems</td>
<td>46</td>
<td>41 – 51</td>
<td>37</td>
<td>ns</td>
</tr>
<tr>
<td>Internalizing Problems</td>
<td>45</td>
<td>39 – 51</td>
<td>35</td>
<td>ns</td>
</tr>
<tr>
<td>Behavioral Symptoms Index</td>
<td>44</td>
<td>39 – 49</td>
<td>28</td>
<td>ns</td>
</tr>
<tr>
<td>Adaptive Skills</td>
<td>45</td>
<td>39 – 51</td>
<td>30</td>
<td>ns</td>
</tr>
</tbody>
</table>
Table 4.11

*BASC Results for Case ZM*

<table>
<thead>
<tr>
<th></th>
<th>T score</th>
<th>90 % confidence interval</th>
<th>Percentile</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Clinical scales</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hyperactivity</td>
<td>38</td>
<td>31 – 45</td>
<td>9</td>
<td>ns</td>
</tr>
<tr>
<td>Aggression</td>
<td>43</td>
<td>36 – 50</td>
<td>26</td>
<td>ns</td>
</tr>
<tr>
<td>Anxiety</td>
<td>50</td>
<td>41 – 59</td>
<td>53</td>
<td>ns</td>
</tr>
<tr>
<td>Depression</td>
<td>42</td>
<td>34 – 50</td>
<td>21</td>
<td>ns</td>
</tr>
<tr>
<td>Somatization</td>
<td>51</td>
<td>43 – 59</td>
<td>57</td>
<td>ns</td>
</tr>
<tr>
<td>Atypicality</td>
<td>44</td>
<td>35 – 53</td>
<td>33</td>
<td>ns</td>
</tr>
<tr>
<td>Withdrawal</td>
<td>42</td>
<td>35 – 49</td>
<td>21</td>
<td>ns</td>
</tr>
<tr>
<td>Attention problems</td>
<td>61</td>
<td>52 – 70</td>
<td>87</td>
<td>.05</td>
</tr>
<tr>
<td><strong>Adaptive scales</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adaptability</td>
<td>44</td>
<td>35 – 53</td>
<td>28</td>
<td>ns</td>
</tr>
<tr>
<td>Social skills</td>
<td>33</td>
<td>27 – 39</td>
<td>5</td>
<td>ns</td>
</tr>
<tr>
<td><strong>Composites</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Externalizing Problems</td>
<td>40</td>
<td>35 – 45</td>
<td>14</td>
<td>ns</td>
</tr>
<tr>
<td>Internalizing Problems</td>
<td>47</td>
<td>41 – 53</td>
<td>41</td>
<td>ns</td>
</tr>
<tr>
<td>Behavioral Symptoms Index</td>
<td>45</td>
<td>40 – 50</td>
<td>33</td>
<td>ns</td>
</tr>
<tr>
<td>Adaptive Skills</td>
<td>37</td>
<td>31 – 43</td>
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4.7.1 Case BR

4.7.1.1 Neuropsychological test results

Within the domain of attentional control, BR performed well below average on a number of tasks, when compared to healthy controls. In particular, BR showed impairments on tasks tapping selective attention and inhibition of motor responses. As indicated by the results of the Visual Attention task, BR did not experience difficulty detecting targets within a linear array (i.e., *bunnies*), however, when stimuli were presented in a random array (i.e., *cats* array), she performed more than two standard deviations below the age mean. Although BR performed within average range on the *bunnies* array, her performance was less efficient than normal 4-year-olds, as reflected by a lower efficiency score on this task. Her inefficient performance may be due to the extra time required to complete the task, as reflected by a higher total time score, in comparison to healthy controls.

Test results also showed marked deficits within the area of inhibition. While the majority of healthy 4-year-olds were able to ignore nontargets on the *bunnies* array of the Visual Attention task, BR’s performance was two standard deviations below the age mean. BR also performed well below average in comparison to healthy controls on the Statue task. As indicated by the results of the *inhibition* task of the Shape School, BR inhibited less efficiently, when compared to normal 4-year-olds. Although she did not make more errors on this task, her performance was quite slow. BR’s performance on the Stroop-like Day-Night test was comparable to that of her age peers.

With the exception of the Comprehension of Instructions task, BR performed within the average range on all tasks within the domain of cognitive flexibility. Thus, although BR displayed significant working memory deficits, other executive processes within this domain were not impaired.

Some impairments were also noted within the domain of information processing, with BR completing two out of four tasks slower than healthy children her age. In particular, deficits in speed of performance were observed on both conditions of the Shape School (i.e., *control and inhibition*), with BR performing at ceiling level, but required more time to complete these tasks. In contrast, while BR did not require additional time to complete both arrays of Visual Attention (i.e., *bunnies* and *cats*), she
detected less targets, resulting in an inefficient performance on these tasks. On the control condition, it was found that BR performed within the average range, however, her performance was less efficient when compared to normal controls. It must also be noted, that on this task, even 3-year-olds performed at ceiling level, and therefore, this may not be an adequate reflection of BR’s performance.

4.7.1.2 Results from the Behavior Assessment System for Children (BASC)

Significant behavioural problems were noted on the clinical scale of Withdrawal, related to having trouble making new friends, being shy with other children, and showing fear of strangers. In addition, a relatively high rating was observed on the clinical scale of Somatization, related to using medication, complaining about health, and having fevers. Similarly, an elevated rating was observed on the scale of Attention Problems, related to being easily distracted, giving up easily when learning something new, and having trouble concentrating.

4.7.2 Case ZM

4.7.2.1 Neuropsychological test results

Processes within the domain of attentional control were significantly impaired. As indicated by test results from the cats array of the Visual Attention task, it was found that although ZM was able to detect target information in a random array, his performance was less efficient, when compared to healthy children his age. On a more difficult selective attention task (i.e., the faces array), which required ZM to be vigilant to specific stimulus features, he performed more than two standard deviations below average. This was reflected by less correct responses, a longer completion time, and an inefficient search strategy. Performance on the Auditory Attention task could not be measured, due to ZM’s unwillingness to engage in the task.

The findings from the inhibition measures suggest that ZM had difficulty inhibiting both motor and verbal responses. In particular, on the Statue test, ZM opened his eyes within the first 10 seconds, and had to be reminded to close his eyes in several subsequent time blocks. At 36 seconds, ZM told the examiner that the game was “boring” and started wobbling until the end of the Statue time limit. On the Stroop-like Day-Night test, ZM started out performing well on the initial trials, but was not capable of sustaining a high level of performance over the subsequent trials, saying
“day” to all remaining cards. Performance on the inhibition task of the Shape School could not be measured, due to his unwillingness to complete the task.

Overall, executive processes within the domain of cognitive flexibility were significantly impaired. In particular, on the OCTC, it was found that although ZM was able to group six toys independently, when asked to sort the objects again, according to a different feature, he needed explicit instructions, suggesting that he had difficulty switching between concepts. In contrast, most healthy 5-year-olds were able to group the six toys for a second time without any additional structure. When required to sort the toys for a third time, ZM also required explicit instructions to do so. His performance in this condition, however, fell within average range, with the majority of 5-year-olds requiring additional structure to do so.

Within the domain of information processing, ZM showed impairments on all tasks. On both arrays of the Visual Attention task (i.e., cats and faces), he required the maximum time allowed to complete the task. On the faces array, it was found that even when provided extra time, when compared to healthy controls, ZM had difficulty detecting all targets, reflecting his impairment in selective attention processing. As indicated by the control condition of the Shape School, ZM also showed deficits within the area of efficiency of output. Not only did he give less correct responses, he also completed the task slower.

Within the domain of goal setting, it was found that ZM showed impairments in the ability to plan and problem solve, as indicated by a poorer performance on the Tower task, when compared to healthy controls.

4.7.2.2 Results of the Behavior Assessment System for Children (BASC)

Results from the BASC showed a significant impairment on the clinical scale of Attention Problems and an “at-risk” rating on the adaptive scale of Social Skills, which is related to helping other children, complimenting, and responding when spoken to.
CHAPTER FIVE
Discussion

The purpose of the present study was to investigate the development of a wide range of cognitive processes within the domain of executive function during early childhood, and to examine how early frontal lobe damage may impact the maturation of these skills. In this study, the construct of executive function refers to a functional system that is necessary for goal-oriented and adaptive behaviour. Although a number of studies have investigated the development of executive processes during middle childhood and adolescence (e.g., V. Anderson et al., 2001a; Becker et al., 1987; Kelly, 2000; Levin et al., 1991; Passler et al., 1985), relatively little is known about how these skills develop in children younger than 7 years. While there are a handful of studies examining the maturation of executive function in young children, these investigations are often restricted to only one or two cognitive processes, and therefore, these studies have been unable to map developmental trajectories across a wide range of executive skills. In particular, investigations of executive function in young children have primarily focused on the development of inhibition and working memory (e.g., Diamond & Taylor, 1996; Espy et al., 1999; Gerstadt et al., 1994).

The present study sought to redress the balance of early childhood research in the area of executive function, by investigating the development of several executive processes in a sample of children between 3 and 7 years. The development of these skills was investigated within four executive function domains: attentional control, cognitive flexibility, information processing, and goal setting. To examine how damage to the anterior regions of the brain may affect the development of these domains, two case studies of patients with early frontal lobe damage were also conducted.

The study commenced by recruiting a sample of children between the ages of 3 and 7 years. Over a period of 1½ years, data from a wide range of executive function tasks were collected from this sample. The results of this study showed a considerable development of executive processes through early childhood, with clear differentiation across specific domains. While some cognitive skills were partly functional in the
youngest children, improving rapidly between the ages of 3 and 7 years, other executive processes did not appear to emerge until the age of 5 years.

In this chapter, the findings of the present study, and the theoretical and practical implications, will be discussed in four sections. In order to pinpoint at what age specific executive processes come on-line, and to identify the rate at which different skills develop, developmental changes between successive age groups will be discussed. Part two considers the different developmental trajectories of specific executive processes, and maps these across the entire age range of the sample. The third section aims to discuss the development of the four executive function domains, and to analyse the factor structure that was found using principal components analysis. Gender differences will be discussed in part four, and the last section of this chapter aims to discuss the effects of early frontal lobe damage.

5.1 Developmental changes in executive processes

In order to investigate when executive processes emerge, and at what rate these skills develop, it is important to isolate significant changes in these processes within a relatively narrow age range. This section aims to discuss the significant changes in executive processes that were found in this study between

(a) the 3- and 4-year-old groups,
(b) the 4- and 5-year-old groups, and
(c) the 5-, 6-, and 7-year-old groups.

Although a number of significant differences were observed between the 5- and 6-year-olds, and also between the 5- and 7-year-olds, no significant changes were documented between the 6- and 7-year-old groups, on any of the variables. Therefore, the older age groups were merged into a 5 – 7 year age range. A possible reason for why the results of this study did not show any significant differences between the older age groups may lie in the nature of the samples. In particular, there were only 17 children in the 7-year-old group, a relatively small sample size, which may not have been an adequate representation of the larger population.
Another possible reason may be that 6-year-olds reached ceiling effect on the measures used to examine executive processes in this study. This pattern of performance was found on some variables, such as the number of targets on the cats array of the Visual Attention task, the efficiency score of the Stroop-like Day-Night test, and the total score on Statue. However, since ceiling effect was not reached on all tasks, this interpretation may only partly explain the absence of significant differences between the older age groups.

A third possible reason for why there were no significant differences between the 6- and 7-year-old groups may be that there are relatively little developmental changes in this age period. Perhaps children reach a stage of skill integration and maturation, as suggested by Welsh et al. (1991). In the developmental literature, the age of 7 years is often used as a cut-off point when describing developmental changes in cognitive processes. For example, Piaget described the period between 2 and 7 years as the preoperational period, suggesting that children by the age of 7 years have become capable of representational skills, and that at roughly 7 years of age, children begin to apply logical reasoning to concrete objects (Piaget, 1963). Thus, it appears that the age of 7 years demarcates a transitional period, in which basic skills reach adult levels, while more complex skills emerge. It may be that between 6 and 7 years of age, executive processes reach an area of stability, which may be a necessary step before children become able to mentally combine, sequence, re-order, and separate more complex cognitive actions. This period of “functional stability” may be related to the transitional phase in CNS development, which has been suggested by neurophysiological research. For example, Thatcher (1991) suggested a transitional phase in cortical reorganisation around the age of 6 years, during which rapid growth of cerebral processes appears to reach a plateau level. The explanation of such a transitional period in executive functioning between the ages of 6 and 7 years, however, requires verification in future developmental studies.

5.1.1 From 3 to 4 years

The results of this study revealed a number of age-related changes in performance between the 3- and 4-year-old age groups on a number of executive function tasks, suggesting developmental changes in several executive processes. In particular, significant improvements were observed within the domains of attentional
control (i.e., selective attention and inhibition processes) and cognitive flexibility (i.e., working memory and concept generation).

5.1.1.1 Attentional control

The results of this study provided evidence for the notion that, between the ages of 3 and 4 years, the ability to selectively attend to stimuli improves steadily. As indicated by the Visual Attention task, 4-year-olds showed a better vigilance for targets in comparison to 3-year-old children. In combination with less impulsivity in choosing nontargets, it was found that 4-year-olds performed this task more efficiently than 3-year-olds. Since children as young as 3 years were able to perform this task, albeit less efficiently than older children, it is suggested that elements of attentional control emerge before the age of 3 years. Ample evidence exists in the literature to support this notion (e.g., Nagata & Dannemiller, 1996; Peterzell, 1993; Ruff, Capozzoli, & Saltarelli, 1996). Thus, it appears that the ability to selectively attend to visual stimuli comes on-line before the age of 3 years, and develops rapidly thereafter.

As indicated by results on the Statue test, 3-year-old children were more impaired in inhibiting impulsive movements, when compared to 4-year-olds. Not only were they less willing to engage in this task, as indicated by the relatively large number of children in the 3-year-old group who failed to stand still even before timing of the task began, they also achieved significantly lower overall scores. This finding is consistent with the results of a recent study by Klenberg et al. (2001), who investigated the number of correct 5-second intervals on the Statue test, and found that 4-year-olds were able to stand still, while keeping eyes closed and staying silent, for a longer period of time than 3-year-olds. Evidence for more adequate inhibitory control in 4-year-olds has also been provided by Diamond and Taylor (1996), who reported a significant improvement in performance on a tapping task between the ages of 3½ and 4 years. However, on this task, children were not only required to inhibit motor responses, but also to keep two rules in mind, thereby increasing cognitive demand.

Improved inhibition of motor responses was also evident on the Visual Attention task, with 4-year-olds making less perseverative errors when compared to the 3-year-old group. This finding is consistent with evidence from a study by Espy et al. (1999), who reported a significant decrease in perseverative errors on the A-not-B task
between 3- and 4-year-old children. Thus, findings from the present study support the notion that between the ages of 3 and 4 years, children appear to become more capable of exercising inhibitory control over their movements.

In addition to measuring inhibition of motor responses, this study also aimed to assess children’s ability to inhibit prepotent verbal responses. The inhibition task of the Shape School was one of the measures used to assess this capacity. Consistent with findings reported by Espy et al. (1999), it was found that while 4-year-olds did not identify significantly more targets than 3-year-olds, they did complete the task faster, suggesting that older children experience less difficulty with the inhibition task of the Shape School than younger ones. Presence of a ceiling effect on this measure may explain why 4-year-olds did not detect more targets than 3-year-olds, with even the youngest children identifying almost all stimuli. Although Espy et al. (1999) found that 4-year-olds achieved a significantly higher efficiency score, the results from this study showed that performance of both age groups on this index was comparable. However, in the present project, a more efficient performance by 4-year-olds was indicated by the significantly larger number of children in this age group that passed the practice trial of this task, when compared to 3-year-olds.

A possible explanation for why the findings of this study did not show any significant differences in efficiency scores between 3- and 4-year-olds may lie in the nature of the efficiency score calculation, which was different from the technique used by Espy and colleagues. While the efficiency score calculated in the present study only considered the number of correctly identified targets, Espy et al. also included the number of errors made. It is likely that 4-year-olds made fewer errors than 3-year-olds, thereby increasing efficiency on the task.

Further support for a similar pattern for 3- and 4-year-olds in the attentional control domain comes from the Stroop-like Day-Night test. Findings from the present study show that 4-year-olds performed better on this task, as reflected by the significantly larger number of children in this age group that passed the practice trials, when compared to 3-year-olds. In addition, 4-year-olds performed the task significantly faster than 3-year-olds, suggesting that older preschool children experience less difficulty on the Day-Night test. These findings are consistent with the
study conducted by Gerstadt et al. (1994). Using 6-month age group segments, and thus allowing for a more detailed analysis, Gerstadt and colleagues found that the Day-Night task was too difficult for children younger than 3 years, 4 months. Furthermore, they reported that even one-third of the 3½-year-old group (range = 3.4 – 3.9 years) was unable to perform this task. The results of the present study agree with those of Gerstadt et al., in that 3-year-old children experienced more difficulty on the Day-Night test when compared to 4-year-olds. On this test, children are not only required to inhibit a prepotent verbal response, but successful performance on this task is also dependent on the ability to keep two rules in mind (working memory). Gerstadt and colleagues suggest that the specific conjunction of inhibiting a prepotent response and keeping two things in mind may go beyond young children’s ability. To rule out the interpretation that younger children may not be able to remember two rules, Gerstadt et al. included a control condition, in which children were required to remembering two rules, without having to inhibit a prepotent response. It was found that even children as young as 3 years were able to do this, indicating that they are able to maintain information in working memory. Therefore, according to Gerstadt et al., it may be the combination of attentional control and working memory, which makes the Day-Night test so difficult for young children. But why is it that 3-year-olds find this so difficult? According to Zelazo and Frye’s Cognitive Complexity and Control Theory (CCC theory: Zelazo & Frye, 1998), 3-year-olds are able to represent relevant rules, but fail to employ them, because they cannot represent a higher order rule that allows them to select which rule to use. This theory suggests that, as children grow older, they acquire increasingly complex rule systems, resulting in increased control over thought and action.

5.1.1.2 Cognitive flexibility

In addition to measuring inhibition, the present study also aimed to investigate the development of conceptual reasoning skills. On the Object Classification Task for Children (OCTC), which was used to assess these processes, it was found that 3-year-olds experienced difficulty sorting a group of nonidentical toys according to a certain feature, suggesting an inability to abstract a common dimension. Findings from the OCTC showed that none of the 3-year-olds experienced difficulty categorising a group of identical toys, as reflected by their performance on the practice trials, suggesting that children as young as 3 years are able to sort multiple objects according
to overall appearance. Similar findings were reported by Jacques and Zelazo (2001),
who used the Flexible Item Selection Task (FIST) to investigate abstraction and
cognitive flexibility in preschoolers. Jacques and Zelazo showed that, despite good
performance on the criterial trials, where children were required to match identical
cards, 3-year-olds performed poorly when required to identify a common dimension in
two nonidentical cards. Jacques and Zelazo reported that, in contrast to 3-year-olds,
most 4-year-olds experienced no difficulty recognising how two nonidentical cards
could match according to a particular feature. Thus, between the ages of 3 and 4 years,
there appears to be a developmental change in the ability to abstract information from
nonidentical items. This finding is consistent with the notion that young children
primarily use concrete information as the basis for categorisation (e.g., Flavell, 1985;
Inhelder & Piaget, 1964). It is believed that it is not until later in life that categorisation
occurs on the basis of more abstract, conceptual-lexical information (e.g., Bruner,
Olver, & Greenfield, 1966).

An increase in the use of more abstract information between the ages of 3 and
4 years may also account for improvements in performance on the Comprehension of
Instructions test, which was used in this study to assess children’s ability to process
linguistic information of increasing length. Results from this task showed that
4-year-olds were able to process more complex linguistic cues, when compared to
3-year-olds. This finding suggests that, along with an increase in linguistic abilities
between the ages of 3 and 4 years, there appears to be a developmental change in
working memory capacity. This finding is consistent with Espy et al. (1999), who
reported significant improvements in this age range on the A-not-B task, suggesting
that between the ages of 3 and 4 years, children become capable of keeping
information in mind for a longer period of time.

The period of functional improvement between the ages of 3 and 4 years is
likely to be related to the rapid growth of cerebral processes that has been reported
during this age period. For example, Thatcher (1991) suggested that the first growth
spurt in cerebral development (i.e., between the ages of 3 and 5 years) is marked by
so-called micro-cycles. One of these micro-cycles was observed between the ages of
3 and 4 years, suggesting a reorganisation in cortical connections during this age
period. Further neuroanatomical evidence for dynamic maturational changes that take
place between 3 and 4 years comes from Chugani et al. (1987). Using PET scanning techniques, Chugani and colleagues showed that, during this age period, there appears to be a significant increase in the rate of glucose metabolism, reflecting an increased energy demand by the developing brain.

In summary, the results from this study suggest that the period between 3 and 4 years of age is important for the acquisition and maturation of several executive skills. During this age period, children appear to undergo major developmental changes within the domains of attentional control and cognitive flexibility. Specifically, they become more capable of selectively attending to information, exercising inhibitory control over their behaviour, and using abstract information to guide action. These functional improvements are likely to be related to underlying structural changes within the brain that appear to coincide in this age period.

5.1.2 From 4 to 5 years

The findings from this study suggest that the period between 4 and 5 years of age is one of developmental gains in a wide range of executive processes. The findings from the present study suggest that, while cognitive abilities that emerged before the age of 4 years will be “fine-tuned” during this age period, other executive competencies will begin to develop. In particular, in this study, significant improvements were documented within the domains of attentional control (i.e., selective attention and inhibition), cognitive flexibility (working memory and conceptual reasoning), and information processing (speed of processing and efficiency of output).

5.1.2.1 Attentional control

The results from this study showed that performance on the Statue test was comparable between 4- and 5-year-olds, suggesting that, during this age period, there are no developmental improvements in the ability to exercise inhibitory control over bodily movements. In contrast to the findings of the Statue test, several significant changes in performance were observed on tasks measuring the capacity to inhibit verbal responses. For instance, on the inhibition task of the Shape School, it was found that 5-year-olds inhibited more efficiently than 4-year-olds, with older children not only giving more correct responses, but also completing the task faster. These results
were largely consistent with those reported by Espy (1997) and Espy et al. (1999), despite different age ranges used in the present study to define the 4- and 5-year-old groups. Similar findings were found for the Stroop-like Day-Night test, which showed that 5-year-olds experienced considerably less difficulty with this task when compared to 4-year-olds. Consistent with the study conducted by Gerstadt and colleagues (1994), results from the present study showed that 5-year-olds were more efficient than 4-year-olds, with older children giving more correct responses. Thus, findings from the present study suggest that while some elements within the domain of attentional control reach plateau levels between the ages of 4 and 5 years, other aspects appear to undergo considerable development during this age period.

5.1.2.2 Cognitive flexibility

Results from the OCTC also showed a clear picture of developmental changes between the ages of 4 and 5 years. Although most 4-year-olds were able to group six toys according to one of three predetermined features, they experienced considerable difficulty sorting the objects for a second time, according to a different aspect. While most 5-year-olds were able to do this independently, most 4-year-old children relied on the examiner to tell them explicitly how to group the objects. Thus, it appears that although 4-year-olds are able to generate a concept according to which different objects can be grouped, they have difficulty sorting on the basis of a different dimension. These findings converge well with those from the FIST (Jacques & Zelazo, 2001). Jacques and Zelazo found that although most 4-year-olds were able to identify a common dimension in two nonidentical cards, they experienced considerable difficulty selecting a card according to two different dimensions. According to the CCC theory (Zelazo & Frye, 1998), switching between dimensions requires a higher order rule, in order to select the perspective from which to reason. In other words, in order to be able to shift between concepts in the OCTC, children need to understand that there are more than one rule according to which the objects can be sorted (i.e., the colour-rule, the shape-rule, and the function-rule). To shift between two rules, children are dependent on a higher-order rule that allows them to determine which rule to use. Thus, between the ages of 4 and 5 years, there appears to be a developmental change in the ability to employ a higher-order rule that is necessary to shift between concepts. Although most 5-year-olds were able to shift flexibly between two features, when they
were required to group the toys for a third time, they were largely dependent on structure provided by the examiner, suggesting that a second mental shift may be beyond their ability. In terms of the CCC theory, it may be that the rule structure that allows these children to select between two rules is not sufficient when a higher level of complexity is required.

5.1.2.3 Information processing

Findings from this study support the notion that as children grow older, cognitive capacity increases. In particular, it was found that 5-year-olds were able to process more complex verbal information, were more efficient, and completed tasks faster, when compared to 4-year-olds. Findings from the Comprehension of Instructions task showed that 5-year-olds performed significantly better than 4-year-olds, with older children being able to understand and carry out more complex verbal instructions than younger children. It was also found that, on several tasks, 5-year-olds were significantly faster than 4-year-olds. Thus, there appears to be an increase in speeded performance between the ages of 4 and 5 years. These findings converge well with other studies that have investigated speed of processing in early childhood (e.g., Kail, 1991a; L.T. Miller & Vernon, 1997), and suggested that 5-year-old children process information more quickly than 4-year-old children.

Neurophysiological research has indicated that between the ages of 4 and 5 years, cerebral development undergoes a number of structural changes, which may be related to the functional improvements in executive processes observed during this age period. Examining total volume of cortex and synaptic density in children, Huttenlocher and colleagues (Huttenlocher, de Courten, Garey, & Van der Loos, 1982; Huttenlocher & de Courten, 1987) showed that during this age period, both synaptic density and total number of synapses increased. Mrzlijak, Uylings, van Eden, & Judas (1990) noted that, during the same period, dendritic trees of layer III pyramidal cells expand markedly. Another cerebral change that occurs between 4 and 5 years of age involves a cyclic micro-cycle of cortical reorganisation within the larger cycle 1 of CNS development (Thatcher, 1991). Thus, it appears that, between the ages of 4 and 5 years, several significant maturational processes occur within the brain.
In summary, the results from this study suggest that between the ages of 4 and 5 years, children undergo major developmental changes within the domains of attentional control, cognitive flexibility, and information processing. In particular, across specific executive competencies, three qualitatively different developmental patterns were observed in this age range: (1) skills that reach plateau levels, (2) executive processes that show ongoing development, and (3) cognitive skills that begin to emerge. Executive skills that reached plateau levels between the ages of 4 and 5 years include the ability to inhibit motor responses and the capacity to generate concepts. Thus, it appears that by the age of 5 years, adult levels are reached on a subset of processes within the domains of attentional control and cognitive flexibility. However, results from this study suggest that, between the ages of 4 and 5 years, other processes within these domains show ongoing development. These processes include the ability to selectively attend to stimuli, inhibition of verbal responses, and working memory. Thus, it appears that these skills have come on-line before the age of 4 years and continue to develop beyond the age of 5 years. The results from this study showed that between the ages of 4 and 5, children become capable of shifting between concepts, while information is processed faster and more efficiently, suggesting ongoing development of abilities within the domains of cognitive flexibility and information processing beyond the age of 5 years. Several neurobiological changes that occur during this age period are likely to underpin the rapid functional development observed in children between 4 and 5 years of age.

5.1.3 From 5 to 7 years

This section aims to discuss the differences in performance on executive function tasks that were observed in the older age groups. The findings of the present study revealed a number of age-related changes across these groups, suggesting developmental improvements in several executive processes. These improvements were noted within all four domains of executive function: (1) attentional control, with older children better able to selectively attend to stimuli (both visual and auditory), (2) cognitive flexibility, with developmental gains observed in the areas of working memory, shifting (both between concepts and complex rules), and using feedback, (3) information processing, with older children showing increased speed and efficiency of output, and (4) goal setting, with developmental changes noted within the areas of planning and problem solving.
5.1.3.1 Attentional control

The findings of this study showed significant improvements in performance on the Visual Attention task. In particular, it was found that the performance of older children was more efficient on this task, with these children marking significantly more targets, when compared to younger children. These findings are consistent with Klenberg et al. (2001), who showed that efficient performance on the Visual Attention task increased as a function of increasing age in this age period.

Findings from the three experimental conditions of the Shape School (i.e., inhibition, switch, and both) showed similar patterns for 5- and 6-year-olds. On all of these tasks, 6-year-olds outperformed the 5-year-olds, with older children not only completing the tasks faster, they were also more efficient, when compared to younger children. Thus, 6-year-olds inhibited more efficiently, were better able to apply two different rules in naming pictures, and experienced less difficulty when integrating these cognitive processes, in comparison to 5-year-olds. Inhibition and shifting processes were also required by the Response Set task, where children had to apply a complex set of rules involving both contrasting and matching stimuli. Consistent with the results from the Shape School in this study, findings from the Response Set task showed that 6-year-olds outperformed 5-year-olds. This pattern was also found by Klenberg et al. (2001), who investigated age-related changes in performance on the Response Set task in children between 5 and 12 years, showing that performance on this task continued to improve throughout middle childhood. In addition to inhibition and shifting processes, the Response Set task also requires the ability to selectively attend to auditory stimuli. Results from the present study showed that 6-year-olds also outperformed the 5-year-olds on the Auditory Attention task, suggesting that between the ages of 5 and 6 years, children not only become more capable in shifting cognitive set, but also become more efficient in attending to selective stimuli.

5.1.3.2 Cognitive flexibility

As indicated by the Comprehension of Instructions task, which was used to measure children’s ability to process verbal information, older children performed significantly better than younger children. Thus, it appears that verbal working memory capacity increases between the ages of 5 and 7 years. The finding that older children perform better when cognitive demand increases is also reflected by results
from the OCTC, which indicated age-related changes in shifting performance. Findings from this task showed that although there were no significant differences in performance when children were required to shift for the first time, when a second shift was required, 5-year-olds experienced considerable difficulty in grouping the toys, and were largely dependent on the highest level of additional structure available. Further, it was found that although some 6- and 7-year-old children were able to independently sort and shift, most of them managed better where additional structure was provided. Thus, although children between 5 and 7 years did not seem to have difficulty shifting once, when shifting became more complex, even most older children experienced difficulty switching between concepts independently. However, a pattern was found in which older children could perform the second shift with less additional structure than younger children, suggesting a more efficient performance. In terms of the CCC theory, it appears that, between the ages of 5 and 7 years, the cognitive rule structure that is required to shift between more than two concepts begins to develop, not becoming functional before the age of 7 years.

Thus, findings from the shifting tasks used in this study suggest that there is an age-related progression in cognitive flexibility between the ages of 5 and 7 years, which appears to continue beyond this age range. Support for the notion that conceptual reasoning skills continue to develop beyond the age of 7 years has come from a recent study conducted by Jacobs et al. (2001a). Jacobs and colleagues investigated the development of concept generation in children between the ages of 7 and 15 years, using the Concept Generation Test for Children, a similar, but more complex task than the OCTC. It was found that unstructured sorting and shifting was most difficult for children younger than 9 years, with only the oldest age group performing in line with adult expectations.

5.1.3.3 Information processing

The results of this study also suggest that between the ages of 5 and 7 years, there are developmental changes in speed of information processing. In particular, results from the Shape School showed that in this age period, speeded performance improved significantly in all conditions. Thus, it appears that older children need less time to process information than younger children. This finding is consistent with other
studies which have suggested that speed of information processing appears to increase as children get older (e.g., Kail, 1991a).

5.1.3.4 Goal setting

As indicated by the results from the Tower task, it was found that the capacity to plan and problem solve develops relatively gradually between the ages of 5 and 7 years. Research has indicated that these executive capacities develop rapidly after the age of 7 years, with specific growth spurts indicated between 7 and 9 years, and between 11 to 13 years (e.g., P. Anderson et al., 1996; Krikorian & Bartok, 1998). The results of this study support the notion that complex executive skills, which place a relatively large demand on cognitive capacity, appear to emerge during early childhood, but do not show rapid development until middle childhood.

The period between 5 and 7 years is characterised by two processes of structural development: (1) cerebral growth, and (2) asymptotic stability. In particular, neurophysiological research has indicated that until the age of 6 years, several growth processes occur within the brain, including myelination, synaptogenesis, and dendritic arborisation (e.g., Holland et al., 1986; Huttenlocher, 1990, 1994; Kinney et al., 1988; Reiss et al., 1996). However, as noted earlier, the age period between 6 and 7 years is characterised by a relatively structural stability (e.g., Hudspeth & Pribram, 1990; Thatcher, 1991). These findings support the notion that the development of functional processes may be aligned with brain maturation. Results from the current study show a clear picture of developmental changes between the ages of 5 and 6 years, but no functional improvements were observed between 6- and 7-year-olds, thereby providing evidence for the association between cerebral maturation and functional development.

Neurophysiological research has indicated that information processing may be related to the development of myelination processes during childhood (e.g., Huttenlocher & Dabholkar, 1997; Klinberg et al., 1999), as progressive myelination allows for more rapid nerve conduction, and therefore, is likely to result in more efficient information transmission. More complex executive skills, such as shifting between multiple concepts, are highly dependent on efficient information transmission, and therefore, require myelinated pathways in order for these cognitive processes to be executed effectively. The results from this study suggest that more
complex executive skills do not appear to become functional until after the age of 5 years, and appear to continue developing throughout middle and late childhood. This developmental pattern corresponds with the ongoing myelination processes occurring during this period, with pathways connecting specific and associative cortical regions still developing during this period (e.g., Klinberg et al., 1999; Yakovlev & Lecours, 1967).

In summary, it appears that between the ages of 5 and 7 years, executive function development follows a pattern that is characterised by an ongoing maturation of a wide range of skills. The results from this study suggest that in this age range, most executive processes within the attentional control domain reach adult levels, while cognitive flexibility skills develop rapidly. Further, it appears that between the ages of 5 and 7 years, children become capable of processing information relatively quickly, indicating rapid development of processes within the domain of information processing. In addition, during this age period, children undergo developmental changes in more complex cognitive processes within the executive function domain of goal setting. While the age period between 5 and 6 years is characterised by relatively major developmental changes in executive processes, between the ages of 6 and 7 years, no functional improvements were noted within any of the executive function domains, suggesting that during this age period, cognitive development reaches a plateau level. Similarly, during this age period, neurophysiological research has indicated that growth processes within the brain are characterised by a phase of stability, which may be associated with the pattern observed in cognitive development.

5.2 Mapping developmental trajectories of executive processes in early childhood

It is clear that the results from this study confirm different developmental profiles for specific executive processes, with some skills becoming functional earlier in life, and developing at different rates, than others. Based on the findings from the present study, an attempt was made to map developmental trajectories of executive processes in early childhood (see Figure 5.1).
**Executive processes**

<table>
<thead>
<tr>
<th>Age (in years)</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
</table>

**Attentional control:**
- Selective attention
- Inhibition of motor responses
- Inhibition of verbal responses

**Cognitive flexibility:**
- Working memory
- Concept generation
- Shifting between concepts
- Shifting between complex rules
- Utilisation of feedback

**Information processing:**
- Speed of output
- Efficiency of output

**Goal setting:**
- Planning and problem-solving

---

Not yet functional → Ongoing development → Attainment of adult level

*Figure 5.1*  Developmental trajectories of executive processes in early childhood
5.2.1 Developmental trajectories within the attentional control domain

As shown in Figure 5.1, processes within the attentional control domain appear to develop rapidly during early childhood, with some processes reaching mature levels even before the age of 7 years. While the ability to inhibit motor responses appears to be relatively mature by the age of 5 years, the capacity to inhibit verbal responses tends to reach its developmental peak around the age of 6 years. The ability to selectively attend to stimuli, however, is believed not to reach adult levels until after the age of 7 years. Thus, it appears that attentional control processes emerge before the age of 3 years, and develop rapidly during early childhood, with relatively major developmental gains occurring between 3 and 5 years. Although in the present study, the capacity to selectively attend to auditory stimuli was only assessed in older children, research has indicated that this ability also emerges before the age of 3 years (e.g., Cheour, Leppaenen, & Kraus, 2000; Pescara-Kovach, Fulkerson, & Haaf, 2000).

The ability to selectively attend to information and to exercise inhibitory control over behaviour are important basic executive processes that are required in a number of complex cognitive activities, such as considering alternatives or planning ahead. Therefore, the development of these basic executive skills are likely to precede the development of more complex cognitive processes. The findings from this study suggest that executive capacities within the attentional control domain tend to be cognitive underpinnings for processes within the domains of cognitive flexibility, information processing, and goal setting.

5.2.2 Developmental trajectories within the cognitive flexibility domain

Processes within the domain of cognitive flexibility appear to undergo considerable development during the early childhood years, with relatively rapid developmental gains between the ages of 4 and 5 years. Findings from this study suggest that working memory capacity continues to increase throughout early childhood. This is not surprising, as more complex cognitive activities, such as shifting between complex rules, are highly dependent on the capacity to manipulate on-line information to guide action. Further, it appears that, by the age of 5 years, children are able to abstract information from nonidentical items, suggesting that by this age, children have acquired basic concept generation skills. However, the ability to combine
abstraction with more complex cognitive activities, such as shifting, does not seem to emerge until the age of 6 years.

Processes within the domain of cognitive flexibility are important in cognitive activities that involve multiple steps, procedures, response modes, or sources of information. Thus, these executive processes play an important role when an individual is required to consider alternatives when solving problems or making decisions. As children grow older, and are required to function more independently, these processes become increasingly activated. Therefore, it is not surprising that the executive skills within the domain of cognitive flexibility continue to develop beyond early childhood.

5.2.3 Developmental trajectories within the information processing domain

As older children become more capable shifting flexibly between concepts and complex rules, they also tend to show improvements in the ability to process information, resulting in faster and more efficient behavioural output. In particular, the results from this study showed a significant increase in naming speed between the ages of 5 and 7 years, suggesting a rapid development of information processing in this age range. It is believed that speed of information processing continues to develop beyond the age of 7 years, which is consistent with findings from other studies which have suggested that speed of information processing appears to increase as children grow older (e.g., Kail, 1991a).

5.2.4 Developmental trajectories within the goal setting domain

Although simple planning and problem solving skills have been observed in young children (e.g., Welsh et al., 1991; Espy et al., 2001), research has indicated that the most significant development of these skills takes place after the age of 7 years (e.g., P. Anderson et al., 1996; Krikorian & Bartok, 1998). In the present study, executive processes within the domain of goal setting were only investigated in the older age groups. It appears that planning and problem solving skills develop relatively gradually between the ages of 5 and 7 years, with no evidence of a developmental spurt in these skills, suggesting that planning and problem solving continue to develop beyond the age of 7 years.
In summary, the findings of this study suggest that the developmental trajectories of executive processes are hierarchical in nature, with more basic executive processes within the domain of attentional control, such as the ability to inhibit prepotent responses, developing first, followed by the development of more complex cognitive skills within the domains of cognitive flexibility, information processing, and goal setting, such as the ability to shift between multiple concepts. Interestingly, the most significant development was identified between the ages of 4 and 5 years, with basic executive processes just about fully matured at the age of 5, while more complex skills merely begin to develop at this age. This finding is consistent with neurophysiological research, which has indicated that during this age period, the brain undergoes a number of structural changes (e.g., Huttenlocher et al., 1982; Mrzljak et al., 1990; Thatcher, 1991).

5.3 Mapping developmental profiles of executive function domains

Based on the individual developmental trajectories of executive processes described above, it is now possible to map developmental profiles of executive function domains in early childhood. Figure 5.2 displays the developmental trajectories for the domains of attentional control, cognitive flexibility, information processing, and goal setting.
Figure 5.2 Developmental trajectories of executive function domains in early childhood

As shown in Figure 5.2, there is a clear hierarchical developmental pattern, in that the four domains of executive function emerge at different times, with the development of processes within the domain of attentional control preceding the development of the other three domains. While attentional control processes appear to plateau near the end of early childhood, processes within the domains of information processing and goal setting merely begin to develop. Cognitive flexibility processes appear to develop rapidly between 4 and 5 years, and also tend to continue developing beyond the age of 7 years. Although these developmental trajectories seem to be supported by other developmental studies, future research is necessary to confirm these profiles.
The proposed developmental trajectories tend to be supported by the principal components analysis of the data of this study, which revealed two independent factors. While the first factor is believed to tap cognitive skills that are essential for efficiency and complexity of information processing, the second factor included skills that are essential for attentional control. This factor structure supports the argument that the attentional control domain can be separated from other elements of executive function, perhaps reflecting its earlier development and maturation during early childhood, as shown in Figure 5.1 and Figure 5.2. It is likely that the first factor reflects the domains of cognitive flexibility and information processing, as the developing executive capacities within these domains all contribute to increased processing of complex information.

This two factor model has much in common with the factor structures suggested by Levin et al. (1991), Kelly (2000), and Welsh et al. (1991). Although Levin et al. reported both three and four factor models, the three factor solution identified most clearly the distinct cognitive domains thought to be subserved by the prefrontal cortex. These three factors included semantic association/concept formation, perseveration/disinhibition, and planning/strategy. Kelly produced a four factor model that included fluency/speeded response, verbal concept formation, motor organisation, and planning/strategy. Only the first factor in this model produced an eigenvalue greater than 1, and therefore, a single factor solution was the most acceptable. However, according to Kelly, a four factor model may be more representative of specialised executive modules. Welsh et al. documented a three factor model, suggesting the following factors: fluid/speeded response, hypothesis testing/impulse control, and planning. There appears to be considerable overlap in these factors, with all three studies documenting a planning factor, two studies reporting a fluency/speeded performance factor, and two studies identifying an inhibition factor. It must be noted, however, that in these investigations, factor analysis was performed on data from children between 7 and 15 years, and therefore, these factors may only apply to middle childhood. Nevertheless, the factors produced from data in the present study may reflect similar cognitive processes as the factor structures described above. In particular, similar skills appear to be tapped by the first factor (efficiency/complexity of information processing) and the fluency/speeded performance factor found by Kelly
and Welsh et al., with both factors including tasks tapping processing speed. The second factor found in this study (attentional control) appears to be related to the impulse control factor produced by Levin et al. and Welsh et al., with both factors including tasks tapping the ability to inhibit prepotent responses. Unlike the studies by Levin et al., Kelly, and Welsh et al., the tasks included in the factor analysis of the present study did not measure any planning or strategy behaviour, and therefore, no such factor was found in our model.

The model obtained from the data in this study provides some evidence for differential development in the factors. The skills tapped by variables included in the first factor (efficiency/complexity of information processing) appear to develop rapidly between the ages of 3 and 7 years, with a developmental spurt observed between the ages of 4 and 5 years. The variables included in the attentional control factor also show similar developmental patterns, characterised by a nonlinear trend, in which performance plateaus around the age of 6 years. Thus, it appears that there are different developmental trajectories for the factors found in the present study. Similar findings were reported by Kelly (2000), who reported that the four factors in his model developed at different rates, with specific periods of rapid development identified for each factor.

Although in the present study, principal components analysis was used as an exploratory technique for investigating the relationships between variables, it provides evidence to support distinct executive function domains. While the first factor is likely to reflect attentional control processes, the second factor may represent the domains of both cognitive flexibility and information processing, with executive processes within these domains playing an important role when cognitive demand increases. A possible reason for why factor analysis did not reveal specific factors for each of these domains may simply be that the number of variables from these domains was too small to identify distinct underlying processes. Another possible reason may be that, in contrast to middle childhood and adolescence, in early childhood, a distinction between the domains of cognitive flexibility and information processing has not yet developed to a level that can be tapped via standardised test measures, as the processes within both domains may depend on the same underlying cognitive module – increased processing of information, both quantitatively and qualitatively. However, since there is no
published data on which to compare this interpretation, future developmental research is necessary to further investigate this issue.

5.4 Gender differences

The results from this study did not reveal any cognitive differences between males and females within the domains of attentional control, cognitive flexibility, information processing, or goal setting. Thus, it appears that, in early childhood, there is no difference in executive functioning between males and females.

In contrast to the findings of the present study, Klenberg et al. (2001) reported gender differences on the Statue task for children between 3 and 5 years, with girls outperforming boys. However, no such difference was found for children older than 5 years. The reason why no gender differences were found in the present study may be that the sample size simply was not large enough to detect significant differences. Alternatively, cognitive differences may not be observed in young children, due to relatively undifferentiated cortical growth processes. During early childhood, the brain undergoes major structural changes, with several developmental processes occurring, such as myelination, dendritic arborisation, and synaptogenesis (e.g., Huttenlocher, 1990, 1994; Kinney et al., 1988; Klinberg et al., 1999). Due to the relatively rapid structural maturation of the brain in young children, cortical developmental pathways may not begin to differentiate before a basic neuroanatomical and neurophysiological framework has been established. In line with the association between structure and function of the brain, it may be that cognitive differences may not be observed in young children.

On the Visual Attention and Response Set tasks, Klenberg and colleagues (2001) reported cognitive differences between males and females in the 5 – 12 year age range, with girls outperforming boys. This finding suggest that girls are better able to selectively attend to stimuli. Such a gender difference has not been found in the present study, indicating that although cognitive differences between males and females with regards to selective attention processes can be observed in older children, this may not be the case for younger children. This notion supports the idea that the magnitude of gender differences is inconsistent throughout childhood (Kraft & Nickel, 1995).
Further research is necessary to investigate the role of gender in the development of cognitive processes within the domain of executive function.

5.5 The effects of early frontal lobe damage on the development of executive processes: two case studies

The functional improvements within executive function domains, which were observed in this study, are likely to be related to the ongoing maturation of the brain during early childhood. In this period, several genetically specified anatomical and biochemical growth processes are occurring, following a phase-like development, with different developmental mechanisms for specific cerebral systems (e.g., Thatcher, 1991, 1992; Hudspeth & Pribram, 1990; Huttenlocher, 1990, 1994). The frontal lobes of the brain are believed to play an important role in coordinating information from all other brain regions, and in regulating goal-directed and adaptive behaviour (e.g., Alexander & Stuss, 2000; Lezak, 1995; Luria, 1963; Shallice, 1990). Clearly, brain maturation is a complex process, and frontal brain damage sustained early in life may interfere with the development of executive processes.

The impact of early frontal brain damage on the development of executive processes was examined in two patients with damage to anterior regions of the brain. While patient BR sustained damage to the frontal lobes at the age of 2½ years, the neurological disorder in ZM was congenital. While the impairments exhibited by BR were primarily observed within the domain of attentional control, patient ZM experienced executive difficulties within all four domains of executive function: attentional control, cognitive flexibility, information processing, and goal setting. The results from these case studies provide support for the model proposed by Dennis (1989), in that brain damage may disrupt the development of cognitive skills, with consequent problems interfering with the child’s capacity to develop normally.

As discussed earlier, processes within the domains of cognitive flexibility, information processing, and goal setting do not appear to emerge before the age of 4 years, with the exception of working memory and concept generation. Therefore, based on these developmental trajectories, executive deficits within these domains are likely to become apparent later in life, as in the case of BR. Although BR displayed
significant working memory deficits, other executive processes within the domain of cognitive flexibility were not impaired. This pattern suggests that the onset of impairments within the domain of cognitive flexibility may be delayed, supporting the notion that brain lesions sustained early in life may interfere with the development of cognitive skills. The findings of this case study are consistent with other case studies in the literature (e.g., Ackerly & Benton, 1947; Eslinger et al., 1992; Grattan & Eslinger, 1992; Price, Daffner, Stowe, & Mesulam, 1990), suggesting that early frontal lobe damage may result in late-developing executive deficits, due to the immaturity of skills at the time of insult. Based on the developmental trajectories proposed in this thesis, by the age of 5 years, most executive processes have come on-line. Therefore, deficits within the more complex domains of executive function may be evident already in children as young as 5 years, as illustrated by the case of ZM.

As BR was the only patient in the clinical sample with acquired brain damage, it was not possible to investigate the effects of frontal lobe lesions that were sustained later in early childhood, for example around the age of 6 years. Based on the developmental profiles suggested in Figure 5.1., it is likely that such lesions will have a different impact on the development of executive processes, with primary deficits within the domains of cognitive flexibility, information processing, and goal setting. Clearly, there is a need for study of larger subject samples to investigate these effects.

In addition to the cognitive impairments noted above, the results from the case studies also indicated behavioural problems, suggesting that cognitive and behavioural aspects of executive processes are closely related. In line with the theory proposed by Damasio (1994, 1995, 1998), findings from the case studies of BR and ZM support the notion that social functioning may be related to underlying neuroanatomical and neurophysiological mechanisms. Specifically, early frontal lobe damage may not only disrupt the maturation of cognitive skills, but may also interfere with social-emotional development, or “hot” aspects of executive function. Social deficits may manifest in reduced self-regulation, poor monitoring of actions, and limited empathy. These findings support observations from other case studies of patients with early frontal brain damage, such as those reported by Eslinger and colleagues (1997). According to Eslinger et al., early damage to the prefrontal cortex may have significant effects on what they called “social executors”. These executors are regulated by the prefrontal
cortex, and may represent some of the essential components of social functioning. Therefore, damage to the prefrontal cortex may disrupt the functioning of these executors, resulting in specific social deficits, which are characterised by disruption of social self-regulation, social self-awareness, social sensitivity, and social salience (p. 329).

5.6 Summary
The results from this study indicate different developmental trajectories of specific executive processes during early childhood. Processes within the area of attentional control appear to become on-line before the age of 3 years, developing rapidly thereafter. The development of these processes seems to precede the development of processes within the domains of cognitive flexibility, information processing, and goal setting. Executive skills within the domain of cognitive flexibility appear to emerge around the age of 3 years, with basic conceptual reasoning skills becoming functional around the age of 4 years. However, cognitive processes within this domain do not appear to reach mature levels before the age of 7 years. More complex executive processes within the areas of information processing and goal setting do not appear to become functional before the age of 5 years, and are believed to undergo considerable development after the age of 7 years. In the present study, a relatively large functional increment was observed between the ages of 4 and 5 years, across a wide range of executive processes. While basic cognitive skills within the domain of attentional control start to reach plateau levels in this age period, more complex executive processes appear to emerge. The functional improvements in executive skills that were observed in this study are likely to be related to structural changes that occur within the brain during early childhood, including increased myelination, dendritic arborisation, synaptogenesis, and increased uptake of glucose.
CHAPTER SIX
General conclusions

6.1 Summary

In this study, the development of executive processes was investigated in a sample of 99 Australian children between the ages of 3 and 7 years. Further, the impact of early frontal brain damage on the ongoing development of these processes was examined in two case studies of children with lesions to anterior brain regions. Executive skills were measured within four domains of executive function: attentional control, cognitive flexibility, information processing, and goal setting. It was hypothesised that specific executive processes emerge at different times, and develop at different rates, with skills within domains exhibiting similar developmental profiles. It was also hypothesised that children with frontal brain damage would perform more poorly on executive function tasks, when compared to healthy children their own age, due to interruption to development during a critical stage of neurological and cognitive maturation.

To map the development of executive skills, a normative sample was divided into five age groups (i.e., 3-, 4-, 5-, 6-, and 7-year-olds), and children were assessed with several measures, tapping executive skills within four functional domains. Due to a paucity of standardised neuropsychological tests available to measure skills within the domain of cognitive flexibility, a pilot study was conducted to develop a new test for use with young children. Findings from the pilot study showed that this new test, the Object Classification Task for Children (OCTC), was a useful tool for assessing conceptual reasoning skills in children between 3 and 7 years, and therefore, it was included in the protocol for the larger study.

The effects of early frontal lobe damage on the development of executive processes during early childhood were also investigated, using a clinical sample of seven children with focal frontal lobe damage. From this sample, two cases were selected for detailed analysis. These case studies enabled interpretation of the association between specific patterns of cognitive and behavioural impairments within different executive function domains and age-related factors of frontal brain damage.
Findings from the normative study revealed a clear picture of developmental change in executive processes, with different developmental trajectories established for the domains of attentional control, cognitive flexibility, information processing, and goal setting. The developmental profiles document differences in the age at which executive processes come on-line, the rate of skill maturation, and the point at which adult skill levels are achieved.

It appears that attentional control processes emerge early in life, and develop rapidly during early childhood, with greatest improvement occurring between the ages of 3 and 5 years, and some subprocesses reaching adult levels before the age of 7 years. Processes within the domain of cognitive flexibility appear to emerge later in life, developing rapidly between the ages of 4 and 7 years, not reaching mature levels during the early childhood years. Findings also suggest that after the age of 5 years, children become more efficient and process information more rapidly, however, it is believed that the cognitive capacities within the domain of information processing do not reach their developmental peak before the age of 7 years. Similarly, executive processes important for planning ahead and solving problems appear to emerge during early childhood, with a rapid development of these skills during middle childhood and early adolescence. Results from this study also suggest that between the ages of 6 and 7 years, there may be a period of functional stability, with no improvements in performance on executive function tests observed during this age period.

Given the established links between cognitive development within the area of executive function and CNS maturation during early childhood, we investigated whether early brain damage may interfere with functional development. Results from the case studies show a clear picture of impairments in executive processes. In particular, these findings suggest that while executive deficits within the domain of attentional control may be observed in children as young as 4 years, impairments within the more complex domains of cognitive flexibility, information processing, and goal setting may not become apparent until later in life.
6.2 Limitations of study and directions for future research

While the findings of the present study have been interpreted in relation to a clinical context and previous theory, there are a number of aspects that need to be taken into account in interpreting the results.

The sample size for this study was 99, with cell sizes relatively low. It would have been desirable to have had a larger number of subjects, however, it is important to note that no other developmental studies have investigated executive skills across the 3 – 7 year age range, and thus, this project served as a pioneer study that needs further replication with larger samples. Another limitation of the study involves the cross-sectional nature of the sample, comprising five different age groups. A longitudinal design is superior for tapping developmental change more accurately, however, this is beyond the scope of the present project.

The data were limited to children from Melbourne, Australia, and it may be argued that they can not be generalised confidently to children in other countries. However, based on the many parallels between the findings of this study and the results reported by other developmental studies, the children included in the present project appeared to be a fairly representative sample. In support of this statement, recent cross-cultural research using measures such as the Wechsler tests has found no differences in results across North American and Australian children (Wechsler, 1991).

Overall, the findings from the normative study were largely consistent with those reported in the pilot study, contributing to increased reliability of the OCTC. However, differences between the two studies were noted in the number of 4-year-olds across the two settings of the task. In particular, while results from the pilot study revealed that about half of the 4-year-olds performed the task with 4 toys, and the other half with 6 toys, findings from the normative study showed that the majority of 4-year-olds completed the task with 6 objects. These inconsistent findings may be due to the nature of the samples. In particular, children in the pilot study were somewhat younger than children in the larger study. Further, the level of SES in the pilot study was lower when compared to the SES level in the larger study, which was more representative of the general population. These sample characteristics may account for
the differences observed in the number of 4-year-olds across the two settings of the OCTC. Alternatively, the different results may be due to the nature of the task. For example, it may be that the use of two settings is not sensitive enough to identify impairments in concept generation. Or, it may be that the difference in level of difficulty between the practice trials and the first test trial is too large to detect subtle developmental changes. The psychometric properties of the OCTC, including test-retest reliability, remain to be investigated.

In order to investigate cognitive skills within the domain of executive function, it is important to analyse separate underlying executive processes. In this study, an attempt was made to use microanalysis by extracting individual variables from different executive function measures, and combining them into four functionally distinct domains. The results from this study showed clear differences in developmental change across these domains, indicating distinct developmental profiles for individual variables within each test. However, as the microanalysis in this study was applied to different variables within each task, it is questionable to what extent executive processes are fractionated, and therefore, replication with other, more specific variables, is clearly required. Furthermore, as a relatively limited number of measures was employed in the current study, it is important for future research to include variables from additional executive function measures.

In this study, several developmental trajectories of executive processes were proposed. These profiles were based on children’s performance on a number of executive function tasks. It is important to note, however, that this pattern of executive function trajectories may be restricted to the research design of the present study. It may well be that the use of other measures will show different profiles. For example, in this study, the different levels of task complexity was not investigated. Relatively more complex tests of executive function will result in a performance pattern in which younger children are unable to complete tasks, while these children will most likely succeed on relatively easy tasks that are believed to tap the same underlying executive skills.
6.3 Theoretical and practical implications of study

The results from the present study suggest that the construct of executive function may be divided into several functional domains, thereby supporting the view of a distinct functional system. Findings from this study, indicating different developmental trajectories for specific executive function domains, are particularly important, as these results provide evidence for the notion that these domains have different cognitive underpinnings. It is likely that the functional improvements within each of the executive function domains are aligned with the developmental growth periods of neurobiological systems within the frontal lobes. From a clinical perspective, this notion is particularly important, as it provides a supporting framework for explaining the range of executive deficits observed in brain damaged children. Further development of the proposed model of executive function may identify even more functional domains.

Evidence from this study supports the notion that certain executive processes are separable and assessable in children as young as 3 years. Previously, it has not been clear that specific aspects of executive function can be differentiated at such a young age. Investigating these skills in such young children, however, presented a set of challenges, due to the participants’ limited social-emotional and cognitive repertoire. This raises two important issues relating to the developmental evaluation of executive processes in young children: (1) whether, in fact, executive function assessments in children as young as 3 years should be attempted; and (2) the issue of what is a “good” way of measuring executive competencies in young children. As pointed out by Espy et al. (2001), assessing developmental changes during the preschool period is essential, since major developmental processes occur in the prefrontal cortex, and, in light of a clinical context, many common disorders emerge during this period. Thus, preschool assessment of executive processes is useful and desirable.

The second issue is more complicated, since it raises the questions of how executive competencies are defined and which abilities can be measured in young children. Despite these controversies, there are a number of important aspects that need to be taken into account when assessing executive processes in young children, such as the development of aspects in other cognitive systems (e.g., perception,
memory, language), psychometric issues, and the nature of the child. In order to delineate the different aspects of performance on executive function tasks, it is important to fractionate underlying processes. Therefore, in devising new tasks, it should be attempted to include multiple steps, conditions, or levels, which tap an increasing complexity of executive processes.

Results suggest further that the mapping of normal developmental trajectories of executive processes in the larger study may assist clinicians in explaining the range of executive impairments in young children following early brain damage. As the four functional domains appear to develop at different times and distinct rates, impairments within executive domains may be difficult to differentiate in young children, resulting in a more global pattern of deficits.

While some deficits may become apparent early in life, other executive impairments may not be observed until the child is older, or may go unnoticed for a period of time. Understanding the specific developmental profiles within the area of executive function is essential for (1) identifying developmental deviations, (2) developing/improving management techniques and treatment interventions, and (3) helping clinicians and families to provide an environment in which the child is able to reach his or her potential, and to improve quality of life.
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