Prospective Memory: Early Developmental Trajectory and Effects of Paediatric Traumatic Brain Injury on its Functioning

By

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Abstract

Very little is known about the effects of paediatric traumatic brain injury (TBI) on prospective memory, the memory for future intentions such as remembering to post a letter in the morning or do homework. The main aim of this thesis was to redress that shortcoming in the literature. To investigate the effects of paediatric TBI on prospective memory as reliably and fully as possible, the study of children and adolescents with brain injuries was preceded by a developmental study. Given that the process of recovery from brain injury is imposed on the ongoing process of development, it is important to understand more about the normal developmental trajectory of prospective memory first of all. Study 1 compared the prospective-memory performance of 88 normally developing children, adolescents and young adults. The main task was computerised, and its design was influenced by a prefrontal-lobe model because prospective memory is believed to be mediated by the prefrontal regions of the brain. Variables associated with prefrontal-lobe capacity were manipulated: the cognitive demand of an ongoing task, and the importance of the prospective task. Results of Study 1 found that children remembered to respond to fewer prospective cues than adolescents or adults, but that adolescents and adults remembered similarly. Further, the differences between the children’s performance and the adolescents’ and adults’ widened as the cognitive demand of the ongoing task increased. However, the effects of increasing the cognitive demand did not vary between the adolescents and adults. It made no difference to anyone’s performance whether the importance of remembering the prospective cues was stressed or not. On the other hand, performance on executive functions, as measured by the Self-Ordered Pointing Task (SOPT), the Stroop Colour Word Interference Test (Stroop), and the Tower of London
(TOL), which are also believed to be affected by prefrontal capacity, produced the same age effects as were produced on the computerised prospective-memory task. Further, performance on the SOPT and Stroop predicted performance on the high-demand level of the prospective-memory task. Study 2 compared 34 children and adolescents with TBI with the non-injured children and adolescents from Study 1 on the same tasks. Results revealed that overall those with TBI had poorer prospective-memory performance than their non-injured peers. However, a different pattern of impairment was evident in the children than in the adolescents. Specifically, the children with TBI performed similarly to their non-injured peers, but the adolescents with TBI were significantly worse than the non-injured adolescents. This trend was most noticeable as the cognitive demand of the ongoing task increased. Further, the age and injury effects were reflected in the performances on the executive-function tests, and the TOL predicted performance on the high-demand, prospective-memory task in those with TBI. Study 3 aimed to examine the ecological validity of Study 2, by investigating whether the impairments in prospective memory in young people with TBI measured quantitatively, were matched with qualitative data. Twelve parents of children and adolescents with mild to severe TBI were interviewed about whether or not their children’s injuries impacted on their memory (retrospective and prospective) in everyday life. Results showed that in general most children suffered memory losses as a result of their brain injuries, and that prospective-memory loss caused particular hardships for the children and their families. Taken together, the results of the current research revealed that the development of prospective memory reaches a peak of maturity in adolescence, and
that adolescents with TBI show greater decrements in prospective memory than adolescents
without TBI, but that this pattern is not evident in children, where those with TBI were not
significantly different from those without. These findings give support to the prefrontal-
lobe model of prospective memory by showing that prefrontal maturity, which reaches a
peak during adolescence, reflects the prospective-memory performance of healthy
adolescents, and prefrontal injury, which is very common with TBI, shows the effects of
deficits more during adolescence than in earlier years when the prefrontal regions are not
yet fully developed. Study 3 showed that impairments in prospective memory that result
from TBI translate into disabilities in the real world. As a follow up it is recommended
that rehabilitation strategies be designed to assist young people with prospective-memory
impairments adjust better to school and the demands of everyday living. The prefrontal-
lobe model should guide the design of such strategies.
Statement of Originality

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

Signed ............................................ Date.................................................

Heather Jean Ward
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CHAPTER ONE
Paediatric Traumatic Brain Injury

Traumatic brain injury (TBI) \(^1\) is a major public health problem. It results in many deaths and serious long-term neurobehavioural morbidity in those who survive. There is a large body of research on the effects of TBI on outcomes in adults, and in general, the outcomes tend to be relatively predictable and stable. The literature on TBI in children, despite growing rapidly over the past 20 years or so, is still smaller by comparison with the adult literature. And, evidence from studies of children tend to show that there is more variance in postinjury outcomes among children than among adults, suggesting that there are developmental factors that interact with severity and nature of injury. A goal of this thesis, therefore, was to compare children with TBI at different stages of development by examining the effects of injury on one particularly type of memory, namely, prospective memory.

Although the current thesis concentrates on the effects of paediatric TBI on prospective memory, it is important first of all to understand how this particular type of memory develops throughout normal childhood, because to date, little research has been conducted on the early development of prospective memory. Further, the research that does exist tends to have produced inconsistent and ambiguous results, largely because there has not been a systematic approach to the subject.

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\(^1\) TBI includes both closed (non-penetrating) and open (penetrating) head injuries. However, in this thesis the emphasis will be on closed head injury.
This thesis consists of six chapters. Chapter 1 reviews the literature on paediatric TBI and Chapter 2 overviews the literature on memory, and in particular, prospective memory. Chapter 3 describes the first study, which used an experimental paradigm to explore the normal developmental trajectory of prospective memory from middle childhood, through adolescents to early adulthood. Chapter 4 describes the second study, which used the same paradigm, to compare groups of children and adolescents with TBI with each other, and with their non-injured age peers assessed in the first study. Chapter 5 follows up on the topic of the effects of paediatric TBI on prospective remembering by investigating children’s memory functioning in everyday, real-world contexts using qualitative interviews. Not only does that study assess the ecological validity of the quantitative, laboratory-based study, it provides a rich source of data not only on the everyday effects of paediatric TBI on prospective memory, but on other types of memory as well. Chapter 6, the final chapter, integrates and discusses the empirical findings and presents final conclusions and recommendations for future follow ups.

The remaining part of the current chapter first defines paediatric TBI, then discusses its epidemiology and neuropathology, describes clinical indices used to measure severity, and explores developmental issues that impact on the sequelae of TBI. The focus then shifts to memory, and the effects of paediatric TBI on its functioning. It will be concluded from the review that the existing body of knowledge on the effects of paediatric TBI on memory is incomplete. In particular, to date, there
has been only one peer-reviewed study reported in the literature specifically on the impact of paediatric TBI on prospective memory (McCauley & Levin, 2004).  

Description and Causes

TBI is an acquired brain injury that results from a direct blow to the head or from the impact of the external forces exerted on the head by sudden acceleration-deceleration, such as occur in motor-vehicle accidents and falls. Transportation-related TBIs (e.g., motor-vehicle accidents) and falls account for between 75% and 80% of all TBI in published studies (Kraus, 1995). The causes of injury tend to vary depending on the children’s ages. Infants and young children are frequently injured in falls (Yeates, 2000). However, in children less than 4 years of age, child abuse may be the major cause of serious brain injury because compared with motor vehicle or sports injuries, which generally result from a single collision, child abuse injuries tend to be multiple. To compound the seriousness of “shaken baby syndrome”, young sufferers often have secondary injuries such as hypoxia that may result from delays in reporting the injuries (Adelson & Kochanek, 1998; Duhaime et al., 1992). Among older children, sporting accidents, and pedestrian or bicycle collisions with motor vehicles account for a large proportion of TBIs. Adolescents are particularly likely to be injured in motor vehicle accidents (Yeates, 2000).

Epidemiology

The estimated worldwide incidence of paediatric TBI is 180-220 per 100,000 children (Ewing-Cobbs, Levin, & Fletcher, 1998; Michaud, Duhaime, & Jaffe, 1999). The incidence rate in Australia appears to be consistent with the world rate. For

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2 Note, however, that other studies may have assessed the impact of paediatric TBI on prospective memory less specifically. For instance, Anderson, Catroppa, Morse, & Haritou (1999) used the Rivermead Behavioural Memory Test for Children, which comprises some prospective memory items, to compare long-term outcomes of children with mild and severe TBI.
instance, during the year 1996-97, the hospital-admission rate across Australia for children aged 0 – 14 years was 221 per 100,000 (Fortune & Wen, 1999). Overall, the male to female ratio was about 2:1. This too is in line with international data, as reported by Goldstein and Levin (1987). Kraus (1995) partly attributes the higher incidence of TBI among boys to their tendency to engage in more risky behaviours.

Mortality and Morbidity

TBI is said to be the leading cause of death and disability among children and adolescents in Western societies. It accounts for more than twice the number of deaths of young people as leukaemia, the second most common cause of childhood mortality (Lehr, 1990). Most children (82%) admitted to hospitals with TBI in the United States (and presumably the figures are similar in other industrialized countries), suffer mild brain injuries. By comparison, only 14% suffer moderate to severe injuries, and 5% are fatal (Michaud et al., 1999). Not surprisingly, the mortality rate is highest among children with severe injuries, and negligible (< 1%) among those with mild injuries (Yeates, 2000). Clearly, survival rates of 95% are extremely high, and are in fact significantly higher among children than among adults (Adelson, 1999; Goldstein & Levin, 1987). This may be partly attributable to the “plastic” nature of a child’s developing brain that allows better physical recovery, and partly to the advances in acute medical treatment technologies (Mateer, Kerns, & Eso, 1997). However, as the number of survivors of paediatric TBI increases, there is a concomitant increase in the number of young people at risk of suffering long-term, injury-related disability. Michaud and colleagues (1999, p. 345) highlight the seriousness of this by pointing out that the: “incidence of significant disability is approximately 20 percent among survivors (and that) traumatic brain injury is the

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3 See the section on Developmental Issues and Sequelae in this chapter for a discussion of plasticity.
most common cause of acquired disability in pediatrics”. As more young people
survive once-fatal head injuries, and the incidence of acquired disability increases,
there is undoubtedly much greater hardship imposed for much longer periods on
sufferers and their families. After all, children have an entire lifetime ahead of them
(Bigler, Clark, & Farmer, 1997).

Neuropathology

Observable injuries resulting from TBI can be classified into two broad
categories: primary and secondary. Primary injuries result directly from the trauma
itself. They include skull fractures, contusions and haemorrhage, and shear-injuries to
axons and blood vessels. These injuries occur when the skull is stopped by the
impact, but the brain continues to move and “collide” with the skull. The injuries
appear to be most prominent in specific areas, regardless of the site of impact. For
instance, according to Snow and Hooper (1994), and Yeates (2000), the resulting
focal contusions are particularly likely to occur in the frontal and temporal regions,
because of their proximity to the bony prominences in the anterior and middle areas of
the skull. The hippocampal region (medial-temporal lobe) seems to be particularly
affected (Bigler, 1990). For instance, studies investigating the breakdown of the
blood-brain barrier after TBI have demonstrated the selective vulnerability of the
hippocampus to trauma (Hicks, Smith, Lowenstein, Saint Marie, & McIntosh, 1993;
Schmidt & Grady, 1995). And, the diffuse axonal injuries, which result from twisting
and stretching of the axon fibres at the time of impact, appear to be most common in
the frontal and temporal regions of the brain and at the boundaries between gray and
white matter (Bigler; Yeates). In fact, neuroimaging consistently reveals that focal
lesions are generally larger and occur more frequently in frontal and anterior temporal
regions than in posterior temporal, parietal, or occipital regions (Levin et al., 1989).
In addition to primary injuries, an array of secondary medical complications can result. These include: (a) hypoxia; (b) ischemia; (c) oedema; (d) extradural haemorrhage or haemotoma; (e) subdural haemorrhage or haematoma; (f) cerebral atrophy (cell death at the site of contusion, often more evidenced in the frontal and temporal regions); and (g) posttraumatic seizures (Snow & Hooper, 1994). Other complications can also occur. These are less visible but nevertheless potentially very serious. They are neurochemical events that include the overproduction of free radicals and excitatory amino acids, which can disturb cell functioning and result in cell death, particularly in receptors in the hippocampus (Yeates, 2000).

As indicated, the impact of extreme forces exerted on the brain can trigger a complex array of physiological and neurochemical mechanisms. The complexity and “invisibility” of some of these mechanisms, in turn, can make the measurement of injury severity extremely problematical. Outlined below are descriptions of the various clinical indices that are used to estimate the severity of injury.

Measuring Injury Severity

The most frequently used index of severity for TBI is the Glasgow Coma Scale (GCS), which is a measure of the degree of impaired consciousness (Jennett & Teasdale, 1981). The GCS is obtained by assessing the child’s level of eye opening, verbal performance, and motor response. The total score ranges from 3, most severe, which indicates no response to stimuli, to 15, which indicates no abnormalities in the three areas of functioning. Typical classifications are shown in Table 1 (Bigler, 1990; Kraus, 1995).

The length of posttraumatic amnesia (PTA) may also determine severity. Posttraumatic amnesia is the initial stage of recovery after emergence from coma and is characterised by amnesia, disorientation and rapid forgetting (Ewert, Levin, Watson, & Kalisky, 1989). This period is deemed to be resolved when the child
recovers episodic memory (memory for previous, personal events) and returns to full consciousness (Fletcher, Ewing-Cobbs, Francis, & Levin, 1995). Typically, those with PTA of more than one week have the greatest cognitive impairment (Jennett, 1986; Kraus, 1995). Refer to Table 1 for mild, moderate, and severe comparisons of length of PTA.

Table 1

Typical Classifications of Injury Severity Using GCS and Length of PTA

<table>
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<th>Diagnostic Measure</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
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<td>GCS</td>
<td>13 – 15</td>
<td>9 - 12</td>
<td>≤ 8</td>
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<tr>
<td>Length of PTA</td>
<td>&lt; 1 hr</td>
<td>1 - 24 hrs</td>
<td>&gt; 24 hrs</td>
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Last, evaluation of severity of TBI can also be determined by imaging procedures. Computerized tomography (CT) and magnetic resonance imaging (MRI), in addition to the traditional electroencephalogram (EEG), can be used to assess the anatomical (CT and/or MRI) or electrophysiological (EEG) basis of TBI (Jennett, 1986). CT and MRI demonstrate the presence of cerebral contusion, haemorrhage, oedema and other structural lesions. Note, however, that Bruce (1995) reports that there is not a good correlation between anatomic injury, as revealed by CT and MRI, and cognitive dysfunction. And Johnson (1992) says that this particularly applies in the case of children and CT scans, even though changes in postmorbid functioning clearly indicate brain damage. This absence of demonstrable evidence on brain scans may possibly be explained by some of the non-structural, neurochemical damage that can occur. Bruce suggests that positron emission tomography (PET), which measures

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4 Note that Fletcher et al. (1990) place those with GCSs of ] 13 in the moderate category if complicated by skull fracture.
brain activity rather than structure may help clinicians improve diagnoses and predictions of outcome.

In summary, there is not a single measure that adequately assesses brain injury severity. Obviously, the reliability of the diagnosis and outcomes of TBI increase where a number of different clinical indices are employed. These indices should include any combination of the following: (a) alteration in the level of consciousness as indicated by GCS; (b) length of PTA; (c) physiological evidence (e.g., EEG); (d) radiological evidence (e.g., CT, MRI, PET); and (e) objective physical or neuropsychological findings (e.g., aphasia, sensory or cognitive deficit; Jennett, 1986).

Developmental Issues and Sequelae

Trauma to the fully-developed adult brain tends to produce deficits that are not only fairly predictable but also that remain generally static in the long term. Trauma to the evolving young brain, however, results in deficits that may change in nature and severity over time (Mateer et al., 1997). Put simply, TBI affects adults and children differently. And, due to the brain’s ongoing development throughout childhood and adolescence, TBI also affects children of different ages differently. A TBI in an infant or preschooler will not necessarily result in the same outcomes as a similar injury in an older child or adolescent. In fact, age at the time of injury is a factor well known to contribute greatly to variability in outcomes after TBI (Adelson, 1999; Ewing-Cobbs et al., 1998; Ylvisaker, 1998). As suggested, age variability in outcome may occur because children’s brains, in not being fully mature at birth, or even at mid-childhood or adolescence in the case of some functions, are continually developing and changing. Further, the lack of maturity of the young brain and its propensity for rapid morphological change and synaptic connectivity are believed to make the child’s brain more plastic at early stages of development, and therefore more
able to recover from TBI at those stages. This belief that brain injury sustained early in life results in less functional impairment than later trauma is referred to as the “Kennard Principle” (Hart & Faust, 1988). Certainly, children recover physically at a faster rate than adults. And, there is some evidence that early-onset amnesia due to hippocampal damage results in closer-to-normal recognition memory performance than late-onset amnesia (Baddeley, Vargha-Khadem, & Mishkin, 2001). This enhanced recognition among those with early-onset amnesia may be explained by compensatory factors that occur during the process of development that may in turn be due to functional reorganisation (Broadbent, Clark, Zola, & Squire, 2002).

However, clinical evidence often suggests that plasticity is not enough to protect the young brain from subtle cognitive deficits (Mateer et al., 1997). In fact, functionally, children are sometimes more adversely affected by TBI than are adults because stages of development, which occur only within a short time window, may be disrupted by injury (Adelson, 1999). Given that the effects of TBI are frequently more ambiguous in children and adolescents, and that these ambiguities are related to the complexities of neurological development, it is important to explore some of these developmental issues further.

Unlike the brain of other vertebrates, the human brain is relatively underdeveloped at birth. For instance, from birth the human brain trebles its weight by 3 years of age (Kiernan, 1998), and the skull bone is thinner during infancy and early childhood than in later years (Bruce, 1995). Further, the myelination of axons and the full electrophysiological development of neurons take several years. To support these developments, glucose uptake and metabolic activity of the brain are very high relative to adult levels. For instance, Chugani, Phelps, and Mazziotta (1987) found that 3- to 8-year olds had mean local cerebral metabolic rates for glucose at 190 to 226% of levels reported for adults. And, studies of cerebral blood
flow (CBF) revealed that global CBF at birth was lower than adult levels, rose to 70% higher than adult levels at 5 to 7 years of age, and tapered off again to adult levels in adolescence. (Chiron et al., 1992; Lou, Henriksen, Greisen, & Schneider, 1990).

Paradoxically, the very young unmyelinated brain, which is underdeveloped in terms of speed of synaptic connectivity, may potentially recover better from trauma than the fully-myelinated, and more sophisticated adult brain because certain proteins present in myelin are known to inhibit axonal regeneration in the central nervous systems (CNSs) of higher vertebrates (Fields, Schwab, & Silver, 1999; Huber & Schwab, 2000; McClellan, 1998).

After the process of myelination begins, synaptogenesis is another major anatomical process to occur in the child’s brain. This involves rapid synaptic connectivity and dendritic branching that takes place in response to external stimuli. It is during the stage of most rapid synaptogenesis, at approximately 7 to 8 years of age, that the brain is believed by some to have its best potential for recovery from injury (e.g., Adelson, 1999), another possible explanation for the phenomenon of neuroplasticity.

At the cellular level, neuroscientists also describe the presence of particular growth factors, called neurotrophins, present in the very young brain but not in the mature one, that appear to be able to repair denervated synaptic connections. Sherrard and Bower (2001), for example, found that two neurotrophins, brain derived neurotrophic factor (BDNF), and neurotrophin-3 (NT-3), induced spontaneous reinnervation of deafferented neurons in the cerebellum of newborn rats that was not replicated in more mature animals. However, they report that when BDNF from the young rats was injected into the denervated cerebellar region of the older rats, the same regenerative processes resulted. Berardi, Lodovichi, Caleo, Pizzorusso, and
Maffei (1999) report a similar phenomenon, that the exogenous supply of a neurotrophin called *nerve growth factor* (NGF), which only appears naturally during a short critical period postnatally, was able to turn around the effects of visual deprivation on the visual cortex of adult rats.

Most evidence for the neuroplasticity of the young brain contributing to a high degree of functional recovery after trauma is based on animal models, especially those using rodents and felines (Adelson, 1999; Bigler, 1990). However, in clinical practice, children who suffer a moderate to severe TBI often have a poor prognosis (Arroyos-Jurado, Paulsen, Merrell, Lindgren, & Max, 2000). According to Adelson, these apparently contradictory findings may in part be due to differences between models of injury used to mimic TBI in the laboratory and “real life” clinical injuries. It would seem that trauma to the child’s brain is more complex than can be simulated in animal models – despite new models that are more accurate in approximating high-velocity-acceleration-deceleration injuries (see for example, Dixon, Lyeth, & Povlishock’s 1987 “fluid percussion model”). Indeed, clinical trauma may create an anatomical, physiological and chemical environment within the child’s brain that can interfere with its normal maturation (Adelson, 1999).

Another important difference between animal models of brain injury and clinical cases of children with TBI is the length of the recovery period, which may be only a few weeks in animals but is much longer in children. Maximum recovery from trauma can take years in the human brain. Therefore when a TBI occurs in childhood, the recovery period could conceivably coincide with critical periods of development. During early phases of cerebral development, the acquisition of advanced functions is very period specific and dependent on the successful completion of the preceding maturational stage. By disrupting the attainment of foundational functions at critical periods, TBI and the ensuing recovery period impair the brain’s ability to acquire
higher, complex functions (Adelson, 1999; Anderson, Damasio, Tranel, & Damasio, 2000). For example, a TBI in a very young child who has not yet reached a particular language-development milestone, can be much more serious than a similar injury in a child who has successfully completed this stage of development (Fletcher et al., 1995). If the neurological processes involved in language learning are not yet activated in a young child, and her brain is injured before this can occur, it is possible that the processes may never develop normally. At the same time, in an older child where these processes are firmly established at the time of injury, even a serious injury may be unable to “undo” those processes. This is demonstrated in a study by Ewing-Cobbs, Miner, Fletcher, and Levin (1989), which showed a significant difference in receptive language function between infants (less than 3 months old) and toddlers. Those injured during infancy had greater difficulty developing receptive and expressive language, whereas those injured as toddlers showed a better improvement rate in receptive language.

Ylvisaker (1998) also expresses some skepticism about the belief that being young confers an advantage in outcome after TBI, particularly in relation to functions associated with the prefrontal and limbic areas of the brain. He points out that a brain trauma involving those regions, which occurs in early childhood, may have unseen consequences at the time of injury and for years afterwards. But, problems often emerge later in the child’s life when those functions associated with the prefrontal regions are expected to mature. In fact, Ylvisaker (p. 7) stated that: “it is possible that as younger children mature, they will ‘grow into’ neuropsychological deficits”. Evidence for this is found in a study by Anderson and colleagues (2000). They investigated a young woman with seriously impaired decision making, social skills, and behaviour, who had been diagnosed variously from childhood with Attention Deficit Hyperactivity Disorder (ADHD) and Conduct Disorder. Parents and teachers
had reported having difficulty with managing the child’s behaviour, and all psychological and pharmacological interventions employed over many years failed to have any impact. After interviewing her parents, examining medical records, and conducting extensive neurological and neuropsychological tests, they found that the young woman had suffered a brain insult during infancy, with damage to the prefrontal cortex. She had sustained a TBI at 15 months, experienced only momentary loss of consciousness, and on admission to hospital had a normal GCS. She was discharged from hospital soon after and at follow-up 2 months later was reported neurologically and behaviourally normal. A normal pattern of development and behaviour ensued until the child was around 3 years of age (i.e., approximately 1½ years after her injury). Anderson et al. (p. 283) pointed out that her TBI: “was largely forgotten or ignored in subsequent years, even as numerous mental health professionals attempted to diagnose and treat her emerging behaviour problems”. This case demonstrates how children can grow into neurological impairments even after an apparently mild injury.

Clearly, because children’s brains change continually as they mature, it is very difficult to predict long-term, functional outcomes. On the one hand, there are suggestions that the plasticity of the developing brain gives it more resilience and that therefore, a child could suffer less-adverse consequences after TBI than an adult. On the other hand, however, there is evidence that children may be more rather than less vulnerable because certain critical areas of functioning are not established yet. Given all of the complexities and uncertainties about the developmental consequences of paediatric TBI, it is clearly unwise to automatically assume that what applies to adults will also apply to children and adolescents, or similarly, that what applies to adolescents will apply to younger children.
One thing concerning children and adolescents who have suffered TBI appears to be certain, however. Among those who survive, memory impairment is commonly reported and observed (Ewing-Cobbs et al., 1998). This phenomenon of memory loss is briefly overviewed below.

Memory Impairment in Broad Terms

Sequelae of TBI can occur over a number of domains: neurocognitive, behavioural, emotional, and social (for a detailed discussion of these see Ewing-Cobbs et al., 1998; Snow & Hooper, 1994). The focus of this research, however, is on one particular area of neurocognition: memory. Memory is important to study for at least two reasons. First, memory deficits occur with high frequency after TBI. For example, Levin and Eisenberg (1979) noted after conducting an analysis of composite scores obtained from children with TBI on measures of memory, language, motor and somatosensory functioning, and visuospatial ability that memory was the most frequently disrupted domain. Second, memory impairments are likely to be a major obstacle for young TBI sufferers in both everyday functioning and school performance (Ylvisaker & Szekeres, 1998). For example, with memory impairments, children may be unable to: remember instructions, keep track of conversations, recall names, keep appointments, or remember to do homework. Given that the ability to learn and remember is dependent on effective memory processing, and that children have so much more to learn than do adults, it is not surprising that memory impairment represents a major obstacle for young people with TBI.

The bulk of the research on the effects of paediatric TBI has focused on explicit memory, the conscious memory for past facts and events, which is frequently reported to be impaired, especially after moderate to severe injuries (see for example,
Basset & Slater, 1990; Jaffe et al., 1992; Roman et al., 1998; Yeates, Blumenstein, Patterson, & Delis, 1995). Note that none of the studies cited assessed implicit memory, which mediates processes such as conditioning, priming and procedural memory, and which requires no consciousness about the prior learning experience. In fact, to this author’s knowledge only two published studies have investigated implicit memory in children with TBI (viz., Shum, Jamieson, Bahr, & Wallace, 1999; Ward, Shum, Wallace & Boon, 2002). Further, research on the effects of paediatric TBI on prospective memory, the memory for future intentions such as remembering to go for a doctor’s appointment at 2 o’clock tomorrow, is also minimal with only one study specifically targeting prospective memory so far reported in the literature (McCauley & Levin, 2004).

Note that Chapter 2 will follow up on the topic of paediatric TBI and its effects on memory. Detailed descriptions will be given of each of the main three memory types noted above: explicit, implicit, and prospective. Chapter 2 will also reveal the current “state of play” by reviewing the relevant literature. A particularly close examination will be made of prospective memory, as it is the main topic of focus in this research.

Summary

The current chapter reported that: (a) the effects of paediatric TBI are serious in terms of the numbers of children and adolescents affected, and in terms of the many years of disability and handicap that are often endured by young people after TBI; (b) the outcomes for children are less predictable or stable than they are for adults, and that children’s situations can worsen with time; and (c) that despite memory being
essential for everyday cognitive and emotional functioning, knowledge about the
effects of paediatric TBI on memory is limited.

As noted, the topic of paediatric TBI and its effects on memory functioning,
particularly prospective memory functioning, will be explored in more detail in the
chapter that follows.
CHAPTER TWO

Memory, With a Special Emphasis on Prospective Memory

"Life is all memory except for the present moment that flies by so quickly we can hardly catch it going by" (Tennessee Williams).

The main focus of this chapter is prospective (future) memory. However, to provide a context for the discussion of prospective memory, a brief outline is firstly given of the construct, memory, in broader terms. This introduction is followed by descriptions of the two retrospective (past) memory subtypes: explicit and implicit, which provide a basis for comparison for prospective memory, and which provide background for the third study that is outlined in Chapter 5.

The construct, memory, is difficult to define. In general terms it may be thought of as a group of processes "by which experience shapes us, changing our brains and our behavior" (Banich, 2004, p. 324). In behavioural terms, memory enables individuals to: learn; remember facts and events experienced in the past; remember to switch off the stove, turn up on time for appointments, or take the correct dose of medication at the correct time; and recognise and name people met previously. The use of the singular term, memory, tends to imply that it is a unitary system. However, memory appears to comprise various systems or processes that are specialised in terms of storage time and capacity; modality; level of consciousness involved; and whether what is to be remembered happened in the past (retrospective), or is something to be done in the future (prospective; Baddeley, 1997; Cohen, 1997; Squire, 1992; Tulving, 2002). It is often only through neuropsychological studies
involving patients with brain insult that the distinct role of the various systems becomes clear. Occasionally, brain-impaired patients fail to remember certain things, but remember others very well. They do so in such a consistent manner that a clear pattern of memory performance emerges, with a neuroanatomical basis, suggesting that different memory systems control different memory tasks (Cohen, 1997).

Explicit Memory

Explicit memory, a type of retrospective memory, is the conscious, intentional recollection of past experiences, and is usually assessed by tests of free recall, cued recall and recognition. Examples of explicit remembering are: being able to describe what you ate for breakfast this morning and where you took your holiday last year, and recognising a person you met at a party a month ago. As indicated in Figure 1, explicit memory is generally understood to comprise two subtypes: semantic and episodic (Tulving, 2002). Semantic memory represents an individual's knowledge about the world, for example, historical events, facts learned at school and the names of people and places. Episodic memory, on the other hand, is the memory for personal events, and has been described as autobiographical memory (Kolb & Whishaw, 2003). Episodic memory allows humans to remember their own unique experiences in the world, for example, where they went to school and who they were with last Christmas. Figure 1 shows in diagrammatic form a hierarchical representation of each of the three memory systems, and their respective subsystems, of interest in this research.
Figure 1. Retrospective (explicit and implicit) and prospective components of memory.

* Note that the explicit and implicit components, sometimes referred to as "declarative" and "nondeclarative" respectively, are based on distinctions proposed by Squire (1992) and represented diagrammatically by Baddeley (1997).
Despite the distinctions between episodic and semantic memory outlined, the majority of studies that investigate explicit memory describe it in a non-differentiated manner, simply as the conscious recollection of the past, whether the recollection involves personal or general information, or whether it is visual or auditory, et cetera. This tendency to assume a global understanding of memory extends further. For instance, in general, when clinicians or experimental psychologists refer to memory deficits, they are most often referring to deficits in explicit memory only. One need go no further than to look at the memory tests typically used with clinical populations to realise that the majority are restricted to subtests of immediate and delayed recall, and recognition of verbal and nonverbal stimuli (e.g., Wechsler's, 1987, Memory Scale - Revised; Warrington's, 1984, Recognition Memory Test; and Rey's, 1964, Complex Figure). There are, however, a few exceptions to this general trend, for example, digit span subtests that assess short-term working memory, and the Rivermead Behavioural Memory Test (Wilson, Cockburn, & Baddeley, 1985), that incorporates prospective-memory items. Nevertheless, it is the subtests of long-term recall and recognition that dominate.

**Explicit Memory and Paediatric TBI**

Reported below is a review of a recent sample of studies that investigated paediatric TBI and explicit memory. Combined they covered injury severity from mild to severe, and were conducted from one month to twelve months post resolution of PTA.

Basset and Slater (1990) reported deficits in immediate and delayed recall in a group of adolescents with TBI. The researchers compared 10 patients with severe
TBI, 19 with mild, and 29 controls. When asked to recall details from stories, those with mild TBI performed at the same level as the controls, while those with severe TBI recalled significantly less. This pattern applied to both immediate and delayed (30 min) recall. Similarly, in a study of immediate recall, delayed recall, and recognition of word lists, Roman and colleagues (1998) compared three groups of paediatric patients: one with severe TBI (n = 17); one with mild to moderate TBI (n = 27); and a third group of traumatically injured children without TBI (n = 18). Both groups with TBI were tested within one month of the resolution of PTA, and again three months later. Those in the non-TBI group were tested at the same time as those with TBI with whom they were age and gender matched. Differences between each group’s performance and those of a 920-strong normative group’s were compared. Those with mild to moderate TBI and those without TBI were found to perform at a similar level to the normative group on free recall. By contrast, those with severe TBI showed impaired performance. Similar patterns occurred with recognition memory. Note that studies by Jaffe and associates (1992), and Yeates and associates (1995), which used paradigms similar to the ones just described, reported almost identical findings. That is, children with moderate to severe TBI performed significantly worse on various tests of explicit memory than children with minor TBI or those without brain injuries. However, it is interesting that in Jaffe and colleagues' study, those with severe TBI were worse than controls on recall but not on recognition, possibly because testing did not occur until 12 months after the resolution of PTA. With recovery over time, encoding capacity might have improved relative to retrieval.
Although the studies cited represent only a small sample from the literature, further evidence of impaired explicit memory is explained in the section on the Implicit-Explicit Memory Dissociation, which follows shortly.

**Implicit Memory**

Implicit memory, the second type of retrospective memory, involves the recollection of recent experiences in which memory for those experiences affects behaviour in the absence of conscious recollection of the original experiences themselves (Masson & Graf, 1993). Using the diagram in Figure 1 as a guide to the classification of implicit memory, each of the main sub-categories named there will now be described.

The first category of implicit memory referred to in Figure 1 is called *priming*. Priming describes a phenomenon whereby an item that has just been perceived or processed, is perceived more easily the next time, a temporary facilitation that is similar to a warm-up effect (Baddeley, 1999). Priming can occur over a wide range of sensory systems and at either a perceptual or conceptual level. In an example of verbal priming called *word stem completion*, participants are presented with a series of target words (e.g., CABINET). After an interval, they are given a series of incomplete words stems (e.g., CAB___?) and asked to say the first word they think of beginning with that stem. If priming has occurred, respondents will say the word *cabinet*, rather than any other word beginning with *cab* such as *cabin*, *cable*, or *cabbage* even though the latter words might occur more frequently in the English language (Parkin & Leng, 1993).
Procedural learning is the second category of implicit memory referred to in Figure 1 and involves the acquisition of skills, including learning a new tune on the piano, riding a bicycle, solving puzzles, and learning the route to a new location. In clinical or experimental assessment of procedural memory, motor skills are frequently measured by a pursuit-tracking task that requires subjects to keep a pointer in contact with a rotating target. With practice, subjects should increase the amount of time the pointer stays in direct contact with the target (Corkin, 1968). Conceptual, higher-level skills are frequently measured by a mirror-reading task that requires subjects to read words that are written backwards. With practice, subjects learn how each of the letters appear when written backwards, and become faster at deciphering the words (Ewert et al., 1989).

Conditioning is the third category of implicit memory that appears in Figure 1. As Pavlov demonstrated in his experiments on salivation in dogs, if a bell is always associated with the presentation of food, eventually the bell alone will cause salivation. Pavlov's experiments represent an example of classical conditioning or associative learning (Baddeley, 1999; Lieberman, 1993). Evidence suggests that classical conditioning can occur without any recollection of the original pairing of the associated events. For instance, the Swiss neuropsychiatrist Claparède described how he secreted a pin in his hand when he shook hands with a patient with amnesia. The next day the patient refused to shake hands, despite having no recollection of the actual incident (Baddeley). Operant or instrumental conditioning is also a form of implicit memory, whereby learning is facilitated by responses to stimuli either being reinforced (positively or negatively) or punished (Lieberman).
Explicit-Implicit Memory Dissociation

Evidence for a distinction or dissociation between the two retrospective memory subtypes, explicit and implicit, derives from two sources: developmental and neuropathological studies. Following is a brief outline of these two sources of evidence.

Developmental Evidence

A study by Greenbaum and Graf (1989) compared 3-, 4-, and 5-year olds on priming and recall. The 3-year olds showed similar levels of priming to the 4-, and 5-year olds, but significantly lower levels of recall. Similarly, Parkin and Streite (1988) compared 3-, 5-, and 7-year olds and adults on explicit memory (viz., recognition) and visual priming (viz., fragmented pictures). Results showed that although overall ability to identify pictures from fragments increased with age, improvement rates in identification over trials were equivalent among the four age groups. Recognition scores, on the other hand, showed a distinct improvement with age. And, Naito (1990) tested children in grades 1, 3, 6, and college students with word fragment completion, free recall and recognition. Priming was unaffected by either age or level of processing (perceptual or conceptual), and was also stable across 7-min and 6-day delays despite significant declines in recognition and recall from older to younger children.

Similar explicit-implicit distinctions have been noted at the opposite end of the developmental spectrum. Graf (1990), for instance, reported that among ageing adults, individual’s explicit memory performance decreased by as much as 50%, but
implicit memory performance (viz., priming) remained constant. Further, Jelicic, Craik, and Moscovitch (1996) found that older adults in their sixties, seventies and eighties were significantly worse at perceptual and conceptual explicit-memory tasks than young adults in their twenties and thirties. However, there were no age differences on perceptual implicit-memory tasks (word-fragment completion), and only small differences on conceptual implicit tasks (category production). Taken together, the consistency of developmental trends support the notion of implicit and explicit memories being distinct systems.

Neuropathological Evidence

In 1980, Cohen and Squire reported impaired explicit and retained implicit memory (procedural) in eight patients with amnesia: one with a penetrating brain injury, four with Korsakoff’s syndrome, and three tested 6 to 9 days after receiving bilateral electroconvulsive therapy (ECT) for the relief of depressive illness. Specifically, when presented with words consisting of letters written backwards, the brain-impaired patients, compared with controls (n = 5), learned to read the mirror-reversed words normally, even after a 13-week delay, but could not remember the words they had read, nor recollect the experience itself. This study became a landmark because it reported that the class of preserved implicit learning in those with amnesia extended beyond the perceptual-motor realm into the more abstract, higher levels of cognitive functioning.

Specialised studies of adults with TBI have also compared explicit and implicit memory functioning (e.g., Schmitter-Edgecombe, 1996; Shum, Sweeper, & Murray, 1996; Vakil, Jaffe, Eluz, Groswasser & Aberbuch, 1996). Between them,
these studies compared over 60 adults with severe TBI with the same number of non-
injured controls using similar adaptations of verbal priming tasks, and either
recognition or recall tests of the same items used for the priming. These studies
revealed a consistent pattern: that those with TBI, compared with controls, showed
impaired recognition and recall but preserved priming.

The studies noted so far demonstrate decrements in explicit memory and no
decrements in implicit memory. However, the following studies provide evidence of
the reverse: impaired implicit and preserved explicit memory. One by Gabrieli,
Fleischman, Kearne, and Reminger (1995) examined implicit and explicit memory in
one patient with a right occipital lobe lesion, five non-neurologically impaired
individuals, two patients with amnesia, and seven patients with focal cortical lesions
outside the right occipital cortex. Results showed that the patient with the right
occipital lesion, when compared with the others, had intact explicit but impaired
implicit memory for words, with the deficit specific to visual priming. Similarly,
Yamadori, Yoshida, Mori, and Yamashita (1996) reported that patients with
Parkinson’s Disease (n = 10), and those with spinocerebellar degeneration (n = 9),
demonstrated deficiencies in acquiring mirror-reading skills, but normal performance
on word recognition tests compared with a control group (n = 10).

The evidence clearly demonstrates a double dissociation between explicit and
implicit memory, which in turn suggests that different cortical areas mediate the two
memory systems. Indeed, the hippocampal area, and the prefrontal and temporal
cortices have been shown to mediate explicit memory, while a number of different
cortical and sub-cortical areas have been shown to mediate implicit memory (Nissen,
For instance, PET scans reveal that the basal nuclei play an important role in perceptual-motor learning (Saint-Cyr & Taylor) and in mirror reading (Yamadori, et al., 1996). On other cognitive-procedural tasks such as the Tower of Hanoi, however, PET scans reveal that the motor cortex, parieto-occipital cortex, and some prefrontal regions were all involved (Grafton, Hazeltine, & Ivry, 1995; Moscovitch, 1992). In contrast, on visual priming tasks, Gabrieli and colleagues (1995) showed that the right occipital cortex is the area of the brain associated with that function.

Implicit Memory in Children with TBI

Undoubtedly, adults with TBI show evidence of retained implicit and impaired explicit memory. However, as discussed in Chapter 1, it is more difficult to predict outcomes in children and adolescents with TBI than in adults. Therefore, it cannot be assumed that implicit memory is preserved in young people as it is in adults. To test the effects of TBI on children’s implicit (and explicit) memory, Shum et al. (1999) utilized a fragmented picture-completion procedure (priming) and a related cued recall test on 12 children with severe TBI and 12 controls. Results showed that the children with TBI performed as well as the controls on the visual priming, but performed significantly more poorly than the controls on the cued recall. A second children's study assessed procedural memory using rotary-pursuit and mirror-reading tasks in 15 children and adolescents with moderate to severe TBI, and 15 age-matched controls (Ward et al., 2002). Explicit memory tasks were recall and recognition tests of previously learned items associated with the rotary pursuit and mirror reading. Again, results showed that children with TBI learned at the same rate as a group of
non-injured peers on the rotary-pursuit and mirror-reading tasks, but were less able than their peers to recognise or recall information, even when specifically reminded to remember.

Taken together, the two children’s studies suggest that the situation for children is the same as it is for adults, namely, that explicit memory is impaired and implicit memory is preserved. However, further investigation is required in controlled experimental conditions, and particularly in everyday contexts because of the implications of preserved implicit memory for paediatric TBI rehabilitation.

Prospective Memory

The remainder of this chapter focuses on prospective memory: its definition, a brief outline of the prefrontal-lobe model of prospective memory, an examination of some methodological issues involved in the measurement of prospective memory performance, and studies that explore its functioning in different populations.

Prospective memory is defined as: "remembering to do something at a particular moment in the future, or as the timely execution of a previously formed intention" (Kvavilashvili & Ellis, 1996, p. 25). Prospective memory mediates such functions as remembering to take lunch to school, and pass on a message to someone intended to receive it. It requires the ability to integrate complex goal-directed behavioural sequences that enable individuals to fulfil their intentions in a meaningful order and at the appropriate time (Burgess, Quayle, & Frith, 2001). Brandimonte (cited in Passolunghi, Brandimonte, & Cornoldi, 1995) proposed that there are six phases in the process of prospective recall: (1) formation of an intention; (2) remembering the intention (i.e., remembering what to do); (3) remembering when to
do it; (4) remembering to perform the action; (5) actually performing the action in the
time, place, and manner prescribed; and (6) remembering that the action was
performed after it has been completed.

Retrospective/Prospective Differences

Several differences between retrospective (the past) and prospective (the
future) remembering have been reported. First, while retrospective remembering
usually involves committing to memory several pieces of information at one time
(e.g., 6 items to buy from the store), prospective remembering more often involves
minimal information (e.g., 1 phone call, Kvavilashvili, 1998). Moreover, in
retrospective remembering people are usually prompted by external cues (e.g.,
someone’s question) to initiate a controlled search of memory (Winograd, 1988). In
contrast, prospective remembering involves no reminders and is often spontaneous,
whereby an intention “pops into mind” without conscious effort while involved in
another activity (Einstein & McDaniel, 1996). In addition, whereas retrospective
memory relates to what is to be remembered (e.g., a friend's telephone number),
prospective memory is concerned with whether an intended action is performed at the
appropriate time (e.g., the friend is phoned on her birthday not two days after,

Prospective Memory and Person Attributes

Another quality of prospective memory, which Einstein and McDaniel (1996)
believe distinguishes it from retrospective memory, is that prospective memory

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5 There is still some controversy about whether differences actually exist between prospective and
retrospective memory (see for example, Baddeley & Wilkins, 1984; Burgess & Shallice, 1997; Dalla
Barba, 1993; Ellis, 1996; Kvavilashvili, 1987; Roediger, 1996). However, no discussion of this
controversy is provided here as it is beyond the scope of this thesis.
overlaps with other cognitive processes such as planning and monitoring, and with noncognitive ones such as personality attributes. Winograd (1988) had earlier agreed with this position, claiming that psychological variables such as personality, motivation, and compliance interacted with the ability to recall prospectively. For instance, persons who are compulsive and conscientious are more likely than their opposites to initiate thoughts about to-be-performed tasks (Einstein & McDaniel). This implies that it is not only the strength of a person's memory that determines whether he will remember, but also how motivated he is, what importance he places on fulfilling plans, how able he is to plan, or how willing he is to comply with others' requests. However, not everybody believes these non-memory features interact exclusively with prospective memory. For example, Graf and Uttl (2001) believe this interaction is just as likely to occur with retrospective memory as it is with prospective. This debate is followed up later in the Discussion section of Chapter 5, the chapter that investigates qualitatively, the effects of paediatric TBI on everyday memory.

**Components of Prospective Memory**

Paradoxically, despite the supposition noted previously that prospective and retrospective remembering involve distinctive cognitive processes, it is agreed among prospective memory researchers that in order to successfully perform an intended action, one must remember both *when* to act and *what* the action should be (Einstein & McDaniel, 1996; Ellis, 1996; Graf & Uttl, 2001). This means that prospective remembering comprises both prospective (when) and retrospective (what) components. For example, if as you dress for work in the morning, you form the
intention to stop at the corner store on your way home from work to buy bread and milk, you must remember at least two things: to stop at the shop as you approach it (prospective component); and that it is bread and milk you need to buy (retrospective component). When approaching the store, there is nothing to alert you to pay attention to this cue. You must appreciate its relevance without anyone to remind you (Meir & Graf, 2000).

**Dual-Task Paradigm**

Research into prospective memory is relatively recent compared with research into explicit and implicit memory, with the first book devoted entirely to prospective memory (i.e., Brandimonte, Einstein, & McDaniel) not appearing until as recently as 1996. And, the early research involved such tasks as having subjects telephone the experimenter from home at set times (West, 1988), or return postcards (Meacham & Leiman, 1982; Meacham & Singer, 1977). Although these paradigms contributed much descriptive data on prospective memory, they lacked control and the ability to assess behaviours and strategies used by the subjects. To overcome these shortcomings, Einstein and McDaniel (1990) developed a laboratory-based research paradigm that remains the gold standard in assessing prospective memory performance. The paradigm comprises dual tasks, one, referred to in the current research as the *ongoing* task, is an activity designed to occupy the attention of the subjects. Often, though not always, the ongoing task is incidental, and performance on that task is not of paramount interest to the experimenter. The other task, the *prospective* task, is designed to be executed at specifically designated times (time based), and in response to specific cues while the ongoing task is being performed.
(event based), or after an ongoing task is finished (activity based). Performance on the prospective component is of paramount interest to the experimenter.

Core Features of Laboratory Simulations of Prospective Memory

In the real world, because the intention to act is formed prior to the action being carried out, the intention has to be held in mind for varying lengths of time. Further, as indicated, the appropriate time to act frequently coincides with times when other activities or tasks are being performed. And, as also stated, there are often no explicit reminders to act. Given these natural characteristics of prospective memory, Ellis and Kvavilashvili (2000), advise that laboratory simulations, to be valid, must mimic these core characteristics. They therefore recommended that: (a) there be a delay between encoding and retrieval of the prospective memory task; (b) no explicit prompt be provided when the occasion to act arises (i.e., not saying, "do it now"); and (c) participants be engaged in a separate activity that has to be interrupted in order to perform the prospective task. The latter directive, of course, reflects the dual-task paradigm that was developed by Einstein and McDaniel (1990).

Different Types of Prospective Memory Tasks

Not all prospective memory tasks are the same. Listed here are examples of how tasks can vary in characteristics of the: (a) prospective task itself; (b) the retrieval context of the prospective task; and (c) ongoing task. First, the retrospective component (the what) of the prospective task can be simple, for example, ring a friend, or it can comprise a complex chain, for example, check the bank balance, buy a gift, then post the gift (Ellis, 1996). Second, prospective tasks can be habitual (e.g., taking medication with breakfast each morning) or episodic and infrequent (e.g.,
wishing someone a happy birthday tomorrow; Harris, 1983). Third, the intention to act can vary in its attraction or desirability, and therefore, as stated previously, incorporate motivational forces. For instance, if the "to-do" event involves visiting a distant relative, the intention may be relatively weak. If however, the event is to have dinner and see a movie with a friend, the intention will probably be stronger (Ellis). Fourth, the importance of performing a future action may be stressed, for example, the boss says the cash must be deposited at 4.30 pm, or it may be unstressed, for example, a parent says reheating the quiche may make it taste better. Research (e.g., Kliegel, Martin, McDaniel, & Einstein, 2001; Kvavilashvili, 1998) has found that prospective memory tends to be more successful when the to-do task is emphasised, possibly because more cognitive resources are allocated to remembering the intention. Fifth, some intentions have to be kept in mind for a long time (hours, days), whereas the retention interval for other tasks is very short (seconds, minutes; Einstein & McDaniel; Kvavilashvili, 1987). Finally, some prospective tasks can be done after all other tasks have been completed (e.g., buy bread and milk after work). Others have to interrupt other activities (e.g., go to the meeting at 10.00 while busy trying to meet a deadline). Research (Kvavilashvili, Messer, & Ebdon, 2001) has found that prospective remembering is more effective when another task (ongoing) does not have to be interrupted than when it does have to be interrupted. The difference is probably explained by the availability of cognitive resources. Specifically, in the interrupt condition, the available resources have to be shared between the two tasks, whereas no sharing is required in the non-interrupt condition.
The retrieval context can also vary. This means that the circumstances or characteristics of a future occasion that prompt the retrieval of a previously planned intention can be different. First, remembering to act can be prompted by an event (e.g., an unrelated phone call, a colleague entering the room), a time (e.g., at 6.00 pm, after work), or nothing at all, where the intention spontaneously pops into mind (Einstein & McDaniel, 1990; Ellis, 1996). Second, the retrieval prompt or cue can vary in familiarity and distinctiveness. For example, McDaniel and Einstein (1993) found that if a cue is familiar, it can fail to prompt an earlier planned action because it becomes part of the background. An unfamiliar cue, however, is more likely to be effective in triggering the action because it stands out. Similarly, if a cue is relatively indistinguishable from other items or tasks at hand (e.g., a particular invoice in a batch of 100 other invoices), then it will be less likely to prompt an action than if it were distinctive (e.g., a purple document in the midst of yellow ones).

Finally, ongoing activities that need to be interrupted to perform the prospective task can be simple, requiring few cognitive resources (e.g., photocopying). By contrast, ongoing activities can be complex, taking up large cognitive resources (e.g., solving a mathematical problem; Einstein & McDaniel, 1996). Taken together, the above examples of prospective-task differences illustrate the complexities of prospective remembering and suggest that varying tasks require varying degrees of cognitive resources to execute.

*The Prefrontal Model of Prospective Memory*

The effects of ageing on prospective memory functioning are interesting to report because they give an indication of the anatomical substrates that mediate
prospective memory. In fact, West (1996) proposed a frontal-lobe model of prospective memory based initially on two converging facts: (a) that aged adults show deterioration in the prefrontal cortex, and (b) that aged adults under-perform on tests of prospective memory compared with young adults when involved in ongoing tasks that place a large demand on frontal-lobe capacity. In particular, West contended that prospective memory failures are explained in terms of a reduction in efficiency of executive functions (viz., working memory, planning, monitoring, and allocation of cognitive resources) that are known to be mediated by the prefrontal cortex.

West’s frontal-lobe model appears to have found empirical support from others who have studied cognitive ageing. For example, a study by Park, Hertzog, Kidder, Morrell, and Mayhorn (1997), which incorporated two experiments, reported diminished prospective memory performance in older participants. Experiment One was event-based, where participants responded to external cues (visual or auditory). The sample comprised 48 young adults aged in their late teens to early twenties, and 48 older adults aged in their mid to late seventies. Experiment Two was time-based, where participants responded at particular time intervals. The sample for the second experiment comprised 56 young-adult-aged college students and an equal number of older adults aged in their seventies. Participants performed an ongoing working-memory task with relatively high cognitive resource requirements. Specifically, they had to read and remember an ever-changing series of words that appeared on a computer screen. At random intervals, when the word RECALL appeared on the screen, they were prompted to try to recall and say aloud the last three words that had
appeared. The prospective component of the task in Experiment One was to press a key in response to a particular target background pattern. The prospective memory task in Experiment Two was to pull a lever at designated time intervals. Results in both experiments showed reduced prospective memory performance in the older groups relative to the younger, and a trend, which did not reach significance in the event-based experiment, for the older adults to perform worse than the younger as the demand of the ongoing task increased.

Evidence of the influence of the prefrontal region is possibly more apparent in a second study conducted by Kidder, Park, Hertzog, and Morrell (1997). Again, a dual-task paradigm was used, where prospective tasks were embedded in ongoing, working memory tasks. The working memory task was similar to the semantic recall task used in Park and associates' (1997) studies, except this time there were two versions, one with a low-cognitive load and the other with a high load. The amount of attention required to perform the working-memory task was manipulated by increasing the number of words to be recalled. The prospective task was event based. Again, a response was required to a specific background pattern. Results revealed that older adults compared with younger adults were less effective in responding to the prospective cues in the high-load condition, but performed on a par with the younger group in the low-load condition. These results suggest that when ongoing cognitive tasks are demanding, and there are limited cognitive resources available, performances on an additional task (viz., the prospective memory task) will be adversely affected. Taken together, the two studies described sustain the idea that
poorer prospective memory in ageing adults is due to a decrease in functioning of the prefrontal cortex, which plays a marshalling role in allocating cognitive resources.

Further evidence of a prefrontal link with prospective remembering comes from a clinical neuropsychological observation noted by Burgess, Veitch, de Lacy Costello, and Shallice (2000), who studied five neurological patients whose everyday life impairments included marked failures in prospective remembering. Burgess and colleagues found after comparing the patients' medical charts that all had sustained damage to at least one of the prefrontal regions of their brains. The same pattern of prefrontal damage was not apparent in patients with preserved prospective memory.

**Prospective Memory in Adults with TBI**

Research on the effects of TBI on prospective memory in adults began as interviews and self-reports, as a means of surveying this new field. For instance, in a questionnaire study involving over 100 people with TBI, which probed six different components of memory including prospective memory, Mateer, Sohlberg, and Crinean (1987), found that respondents reported prospective memory as their most frequent memory problem. Factor analysis isolated a factor that they termed *Attention-Prospective Memory*. Items loading on this factor were associated with immediate memory, working memory, mental control, and carrying out intended actions. Mateer and her colleagues argued that this grouping of items indicated that the ability to perform prospective memory tasks relied on attention to temporal and situational cues.

When more was known about the incidence and context of prospective forgetting in adults with TBI, researchers moved beyond the descriptive into more
analytic studies. These analytic studies tended to aim to isolate the cognitive processes that underpin this type of memory. One such experimental study by Shum, Valentine, and Cutmore (1999) investigated time-, event-, and activity-based prospective memory in adults with TBI. In this study, the time- and event-based tasks were embedded within two ongoing tasks that required participants, 12 with TBI, and 12 age-matched control, to answer general-knowledge questions from a computer screen. Throughout the process, the computer showed the participants' percentages correct on the questions. In the time-based condition, participants were told to report their percentage score to the experimenter every 5 minutes. In the event-based condition, participants were told to report their score when they saw a particular cue. In the activity-based condition, participants were told at the beginning of the session that when they had finished the computer tasks (i.e., no interruption required) they should write their score on a whiteboard, switch off the computer monitor, and turn off a light. The results demonstrated impairment in those with TBI across the range of prospective memory tasks. These findings suggested that adults with TBI find it difficult to switch attention from one task to another, or alternatively, that they do not have enough cognitive resources to simultaneously focus on one task and to keep an intention to act in conscious awareness. And, as demonstrated by their poorer performance on the activity-based task, those with TBI also had difficulty holding an intention in mind for a prolonged period.

Later, attempts to isolate cognitive processes involved in prospective memory became more overt. For instance, a recent study by Maujean, Shum, and McQueen (2003) expressly set out to test the prefrontal-lobe model of prospective memory. The
researchers used a dual-task paradigm similar to the one used by Kidder and colleagues (1997) in their ageing study, whereby the amount of cognitive load on the ongoing tasks was manipulated. Maujean and colleagues hypothesised that it would be harder for those with TBI than those without, to successfully perform prospective memory tasks when the ongoing task took up more cognitive resources. Specifically, participants performed two versions of a lexical-decision task, one with a low-, and the other with a high-cognitive demand. In the low-demand condition, participants were presented with four letters that appeared simultaneously on a computer screen and were asked to indicate by pressing a key whether the stimulus was a word or a non-word. In the high-demand condition, the same decision about whether the stimulus was a word or non-word also had to be made, but this time the four letters were presented one at a time, which required more mental effort, specifically a greater working-memory load. The prospective memory tasks involved asking the participants to press a specific key whenever one of the words was an animal word (e.g., frog or lion). Results supported the hypotheses, that individuals with TBI performed more poorly on prospective memory tasks when the cognitive demand of the ongoing task was increased and that the difference was greater between the TBI and control groups in the high than the low cognitive-demand condition (i.e., there was a significant Group x Demand interaction).

There is apparent convergence between the findings in the normal ageing, and clinical neuropsychological - especially the adult TBI literature - that implicates the prefrontal regions of the brain in prospective memory. However, the evidence reported so far is strictly behavioural. Other sources of evidence for a prefrontal...
explanation of prospective memory need to be explored. Outlined below is a summary of other types of research that support the prefrontal-lobe model of prospective memory.

**Radiological Evidence for Prefrontal Involvement in Prospective Memory**

A study by Yamadori et al. (1997), which employed PET scans to measure regional cerebral blood flow, found that when participants performed a task involving the realization of a delayed intention (viz., a prospective-memory task), very specific regions of the brain were activated. In particular, increased blood flow in lateral and medial prefrontal areas was observed during the execution of the tasks. Similarly, Burgess and associates (2001) found, using PET, that compared with a baseline measure, regional cerebral blood flow increased in the general area of the prefrontal cortex when healthy participants were required to maintain an intention to act (i.e., expecting a prospective-memory stimulus). And a third study, using event-related potentials (Leynes, Marsh, Hicks, Allen, & Mayhorn, 2003), found evidence that the right frontal area plays a role in the formation of prospective actions, and that those intentions are kept active in memory by processing mediated by the left frontal pole.

**Relationships Between Prospective Memory and Executive Functions**

Indirect evidence of a relationship between prospective memory and the prefrontal lobes comes from studies that demonstrate a relationship between executive functions and prospective memory. This relationship is important to discuss because executive functions are broadly associated with the prefrontal areas of the brain and are believed to be involved in setting goals, and in planning and organising behaviour in pursuit of those goals (Lezak, 1982).
There is no unitary executive function construct (Stuss & Alexander, 2000). Rather, executive functions comprise distinct processes including: attentional flexibility and planning (Grattan & Eslinger, 1992); self-awareness, self-initiation and self-regulation (Craik, 1986; Stuss & Alexander); response inhibition (Barkley, 2000; Hanten, Bartha & Levin, 2001); attention and working memory (Hanten, et al.); and synthesis of multiple pieces of information across time and space (Grattan & Eslinger). Because prospective memory comprises several processes similar to executive functions, namely: forming and initiating intentions, and planning (Shimamura, Janowsky, & Squire, 1991); and inhibition of interference (Busch, 2001), which seem to be dependent on working memory capacity for the allocation of resources (Mateer, et al., 1997), researchers have considered it important to assess the relationship between these two cognitive processes. They believe that the relationship is due to their both being mediated by the prefrontal lobes.

In fact, Shimamura and colleagues (1991) state that prefrontal insult may lead not only to dysexecutive syndrome (Baddeley, 1986) but also to impairments in prospective memory. Indeed, Maujean and colleagues (2003), in their study of adults with TBI, found a positive relationship between two measures of executive function and prospective memory performance. They used the Tower of London (TOL), Controlled Oral Word Association Test (COWAT), and the Letter-Number Sequencing Sub-Test (LNST) of the WAIS-III as their measures of executive function, which assess planning, cognitive flexibility and working memory respectively. Positive correlations were found between the COWAT and prospective memory performance, and the LNST and prospective memory performance. And, in
a study involving normally-developing children aged 7 to 12 years, Kerns (2000) found positive correlations between a measure of prospective-memory performance and the Self-Ordered Pointing Task (SOPT), a test of visual working memory, the Stroop Colour Word Interference task (Stroop), a test of focused attention, and on the nonalternating version of the Delayed Alternation-Nonalternation task, also a test of attention.

Clearly, there is mounting support for the prefrontal-lobe model of prospective memory from studies of ageing, clinical neuropsychology, radiology, and of relationships between prospective memory and executive functions. However, surprisingly few researchers have explicitly tested this model in children. Given that the prefrontal regions are understood to reach a peak of maturity that corresponds with puberty (Lehr, 1990; Marlowe, 2000; Yakovlev & Lecours, 1967), there is much that can be understood about the role of the prefrontal areas in prospective remembering by comparing the prospective memory performance of normally developing younger children and adolescents. Further, as already indicated, only one published study (i.e., McCauley & Levin, 2004) has investigated experimentally, prospective memory in paediatric TBI. Such studies have great potential too in contributing to our understanding of the role of the prefrontal regions in mediating prospective memory because the prefrontal lobes are the most common site of focal lesions and diffuse axonal injury in TBI (Adams, Graham, Scott, Parker, & Doyle, 1980; Holbourn, 1943; Levin, Goldstein, Williams, & Eisenberg, 1991).

Given the potential of studies of prospective-memory performance in normally developing children and adolescents to contribute to a greater understanding of the
processes involved in prospective remembering, it is important now to examine a
tsample of the early developmental studies.

*Prospective Memory and Children - Developmental Perspective*

In modern society, the need for prospective memory starts early in life (Beal, 1988), with young school-aged children expected to remember such things as doing homework and giving school notices to parents. Researchers have wondered about the age at which these capacities develop and how their development proceeds through childhood into adolescence. To find some answers, scholars have compared younger and older children on a variety of prospective memory tasks. One of the first studies, by Somerville, Wellman, & Cultice (1983), compared 2-, 3-, and 4-year-olds on naturalistic tasks that required them to remind their caregivers of things to do over a 2-week period. The results were unexpected. Even after delays of several hours, some 2-year-olds were able to remember tasks that were of high interest to them (e.g., remind the caregiver to buy candy when at the shop tomorrow). And, there was no effect of age. Two-year-olds performed as well as 4-year-olds. Another early study by Ceci and Bronfenbrenner (1985) compared 10-year-olds and 14-year-olds on a task that involved their checking the time periodically as cupcakes baked in an oven. The children's clock checking during the waiting period was assessed in their own homes or a university laboratory. There were no age effects in the familiar setting. However, in the laboratory setting, the older group used more effective time monitoring strategies than the younger. This trend for younger children to perform more poorly in a laboratory than older children, but to perform at a similar level in
familiar settings, suggests that again, motivational, or other non-cognitive issues may be involved (see Baddeley, 2002).

More recent children’s studies attempted to isolate variables that directly affect prospective memory. One by Passolunghi and associates (1995) attempted to gauge the effects of encoding modality on prospective memory. They compared 7- and 8-year-olds with 10- and 11-year-olds on computer-based tasks, on which the encoding modality was manipulated, visually, verbally, and motorically. In the visual condition, children were asked to press a key when they saw a picture of a boat. In the verbal condition, they pressed the key when they saw the word boat written, and in the motoric condition, they actually performed the action of pressing the key immediately after listening to the instructions. In this condition, the target word was presented auditorily. Over three varying experiments on encoding manipulation, prospective memory was generally found to improve with age. In particular, there were age effects on both the verbal and motoric encodings, but not on the visual. The authors' inferred that younger children succeeded as well as older in the visual condition because this is a well-developed means of encoding in young children, but were poorer in motor enactment and verbal encoding because these require additional cognitive resources that young children do not yet possess.

A study by Kerns (2000) aimed to test prospective memory in younger and older children and to correlate scores on prospective tasks with scores on tests of executive functions. Kerns used a purpose-designed computer game called CyberCruiser with children aged 7 to 12 years. The ongoing task involved driving a vehicle as fast as possible. Points were accumulated for speed and accuracy of “driving”. The
prospective-memory task was to monitor the level of available fuel. If respondents failed to press a button when the fuel got low, they would run out of fuel and lose all of their points. Results showed that older children ran out of fuel less frequently than younger, suggesting improved prospective memory ability with increasing age. Also, the prospective memory measure was correlated significantly with three out of six executive function measures, that is, the SOPT, Stroop Colour Word Interference, and the Delayed alternation-nonalternation tasks.

The children’s studies cited all investigated different dynamics of prospective memory, and used different age groups and research paradigms. Although the combined results indicated some maturational trends in prospective remembering, no distinctive patterns emerged. For instance, Somerville and associates (1983) found no age effects with 2-, 3-, and 4-year-olds, possibly because of a strong interaction between the prospective task and motivational forces. In older groups, Ceci and Bronfenbrenner (1985) found differences on a long-term monitoring task between 10- and 14-year-olds in a laboratory but not in a familiar setting. Passolunghi and associates (1995) found differences in prospective encoding between 7- and 8-year-olds, and 10- and 11-year-olds, but only in particular modalities. And Kerns (2000) reported consistent incremental improvements from 7 through to 12 years of age on a task that probably involved monitoring long-term memory and interrupting a complex ongoing task. In fact, Kvavilashvili and associates (2001, p. 418) stated that prospective memory studies in children have:

been conducted over considerable time intervals by various researchers who explored different variables with different tasks, and as a result, there is no coherent picture of the development of prospective memory skills in children.
Kvavilashvili and colleagues attempted to redress this shortcoming by investigating the effects of variables that have been identified by theoretical models (e.g., Kvavilashvili & Ellis, 1996) as crucial for successful prospective recall. Thus, they used interruption of an ongoing task to compare, over three different experiments, 4-, 5-, and 7-year-olds. The ongoing task required the children to remove cards one at a time from four different packs and to name the item that was pictured on each card. When they saw a picture of an animal, the children were asked to take the card and place it in a box. In the interrupt condition, one animal card was inserted in the middle of each of the four packs, so the naming (ongoing) task had to be interrupted to perform the prospective-memory task. In the non-interrupt condition, an animal card was placed at the bottom of each pack, so that the prospective-memory task could be performed after the completion of the ongoing task. This meant that the children had more time to think about the prospective component because their cognitive resources were not divided between the two tasks. Interestingly, Kvavilashvili and colleagues' prediction that there would be no age effects on these prospective memory tasks - based on what had been reported in earlier studies across this age range - was generally realized. Although 7-year-olds performed better on prospective memory tasks than 4- and 5-year-olds, the researchers report that the effects of age explained only 7-10% of the variability in prospective memory across the three experiments. On the other hand, task interruption explained a considerable amount of variability in performance (10-24%), but there was no interaction between age and interruption. Note however that the absence of an interaction may have been
attributable to the younger children having lower baselines than the older children, which can often result in interactions being misinterpreted (Snodgrass, 1989).

Despite Kvavilashvili and colleagues' (2001) attempts to clarify the picture regarding the development of prospective memory in children by using a more systematic, theory-based approach, many ambiguities still exist. Therefore, it is clearly time for well-conceived early developmental studies to be conducted.

**Prospective Memory in Children with TBI**

In a recently published study by McCauley and Levin (2004), results showed similar impairments in prospective remembering in children and adolescents with TBI as were found in adults with TBI (e.g., Maujean et al., 2003; Shum, Valentine, & Cutmore, 1999). McCauley and Levin compared 10- to 19-year-olds in three groups: those with serious orthopaedic injuries not involving the head, mild TBI, and severe TBI. In the ongoing task, participants were presented with words printed in different colours and were told to indicate as quickly as possible to which category (e.g., fruits and furniture) the words belonged. The prospective task involved reporting words printed in blue. After completing trials on which all words were presented in black letters, individuals performed the prospective trials. The authors reported that a large proportion of participants with mild or severe TBI failed to indicate any blue words when they appeared without prior reminding to look out for them. However, after a reminder to perform the prospective task was given to all at the same point in the task (i.e., at the beginning of the 4th block of trials), prospective performance improved in the orthopaedic and mild TBI groups, but remained comparatively impaired in the severe TBI group. Reaction time (RT) data indicated that mean RT was slower as
TBI severity increased. Moreover, there was a response cost for all groups in RT when performing the prospective task concurrently with the ongoing task, and the cost in terms of slowed RT increased with greater TBI severity.

Although McCauley and Levin (2004) did not indicate the sites of the brain injuries in their TBI samples, their results may nevertheless give further support to the prefrontal model of prospective memory. Firstly, as stated previously, TBI frequently results in damage to the prefrontal cortex (Adams et al., 1980; Holbourn, 1943; Levin et al., 1991). Therefore, it is possible that those with TBI, especially those with severe injuries, were failing to remember prospectively because of focal lesions and/or diffuse axonal damage in the prefrontal regions of their brains.

Secondly, McCauley and Levin’s study showed that where the prospective task was required to compete for resources (i.e., probably working memory and attention) with the ongoing task, there was a response cost in terms of RT on the prospective task, suggesting that the two tasks were initiated from the same region of the brain, again very likely, the prefrontal regions.

Previous research on the effects of TBI on prospective memory had focused on adults, and found that those with severe injuries had poor prospective memory. McCauley and Levin’s (2004) study is important because it showed, possibly for the first time, that severe TBI adversely affects prospective remembering in children as well. However, a limitation of McCauley and Levin’s research is that it demonstrated what occurs to prospective memory after severe paediatric TBI, but not why it occurs. There was no direct testing of factors that might have helped identify the neuroanatomical underpinning of prospective memory.
Summary

The current chapter described quite briefly, two types of retrospective memory: explicit and implicit, and more fully, prospective memory. It was noted that most research on the effects of TBI on memory functioning has focused on explicit memory, and that very little by comparison has focused on implicit or prospective memory. Based on evidence from ageing studies, those involving adults and children with TBI, those employing radiological techniques, and from positive relationships noted with executive functions, prospective memory is thought to be mediated by the prefrontal cortex. To date, studies of the early, normal development of prospective memory have yielded inconsistent results. Further, only one known published study has investigated prospective memory in children with TBI, and that study did not attempt to directly test the prefrontal model of prospective memory.

Follow On

Although the principal aim of this thesis was to investigate further the effects of paediatric TBI on prospective memory, it is imperative to the understanding of those brain-injury effects to understand more clearly what "normal" children of different ages are able to remember prospectively. Without a better understanding of whether average 7- and 13-year-olds differ in prospective remembering, it is difficult to know whether brain-injured 7- and 13-year-olds are functioning within their developmental ranges. And, therefore, it is also difficult for investigators be certain whether any apparent deficits are attributable to the brain injury or to developmental factors. In fact, Lehr (1990) pointed out the importance of preceding or integrating developmental studies with those of brain injury in children, and expressed regret that
this integration generally did not occur in paediatric TBI, and that there has been too much reliance on research on brain injury in adults. Lehr (1990, p. 41) stated:

Head injury in children can actually be conceptualized as one process imposed on another process. That is, the process of recovery or improvement is imposed on the ongoing process of development (yet) surprisingly little research and even clinical work with head-injured children and adolescents proceeds from a developmental base….this is understandable in that the information from developmental and clinical child psychology has not been integrated with the effect of acquired neurological injury.

To redress this lack of integration of developmental studies with the effect of paediatric TBI on prospective memory, the current program of research begins with an investigation of the normal developmental trajectory of prospective memory from middle childhood, through adolescence to early adulthood. And, to attempt to approach the developmental research more systematically than has been done previously, the investigation is guided by a theoretical model: that is, the prefrontal-lobe model. Chapter 3, which follows, outlines in detail a quantitative, developmental study of prospective memory.
CHAPTER THREE

Study 1: The Development of Prospective Memory

As implied in the last chapter, previous studies of the early development of prospective memory have been somewhat introspective, focusing mainly on varying features of prospective memory tasks themselves, without looking much towards a wider literature. The current study, however, in attempting to be more systematic in its approach to assessing developmental features of prospective memory, has integrated findings from clinical and experimental neuropsychology, and applied the prefrontal-lobe model to the examination of prospective memory across age ranges. Therefore, in this study, two variables closely linked with prefrontal capacity were manipulated: the cognitive demand (high and low) of the ongoing task, and the importance (stressed and unstressed) of the prospective component.

The cognitive-demand manipulation was an adaptation of the paradigm used by Maujean and colleagues (2003) in their study of adults with TBI. The adaptation was made because a pilot study found the original ongoing tasks were not sensitive to the variations in reading abilities of the age ranges (i.e., children through to young adults) being assessed in the current study. However, as in the Maujean et al. study, the cognitive demand of the ongoing task was varied from low to high in an attempt to manipulate prefrontal demand. These low-high manipulations had been found to be sensitive to injury effects in adults with TBI (Maujean et al.), and to age effects in

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adults (Kidder et al., 1997). Specifically, young adults with TBI, and healthy ageing groups performed worse than healthy young adults overall, and the margin of difference between the groups increased as the level of demand increased.

The importance manipulation was based on paradigms used by Kvavilashvili (1998), and Kliegel et al. (2001). This manipulation assumes that if one aspect of a task is stressed over another, then cognitive resources are directed away from the less important to the more important task. In general, Kvavilashvili, and Kliegel et al. found that when participants were told to pay particular attention to performing the prospective task (importance stressed condition), they did better than when the importance of attending to the prospective component was not stressed. These results suggest that the tasks allocated the most cognitive resources were the ones most successfully performed.

Given that the prefrontal model of prospective memory has veracity, and there is also evidence that the development (e.g., myelination) of the prefrontal region of the brain is more protracted than other brain regions and appears to reach a peak of maturity around puberty (Lehr, 1990; Marlowe, 2000; Yakovlev & Lecours, 1967), this study aimed to provide further converging evidence for the prefrontal model. It was hypothesised that pre-pubescent children would be poorer at prospective memory than adolescents, but that adolescents would be on a par with young adults. Further, as the cognitive demand of the ongoing task increased, and the importance of the prospective component was not stressed, children's performance would decrease more than either adolescents' or young adults', but that the adolescents’ would not decrease
more than the adults’. It was also hypothesised that there would be significant relationships between scores on executive-function and prospective-memory tasks because the prefrontal cortex is also understood to be the anatomical correlate of executive functioning (Shimamura et al., 1991).

To assess the ecological validity of the experimental prospective-memory task, scores on this task were correlated with scores on a self- (or parent-rated) questionnaire about everyday prospective memory. It was hypothesised that scores on the questionnaire would be lower for children than adolescents or adults, but that adolescents’ and adults’ scores would be similar. It was also hypothesised that there would be a significant positive relationship between the two measures of prospective memory. Finally, to help establish convergent validity, and compare the cognitive processes involved in two prospective memory tasks, the main experimental task was correlated with a secondary prospective-memory task based on one developed by Ksavilashvili (1998). It was hypothesised that the children would respond to fewer prospective cues on the secondary task than adolescents or adults, but that the adolescents would be on a par with the adults. It was also hypothesised that there would be a significant positive relationship between scores on the two prospective memory tasks.

Method

Participants

The sample comprised 90 individuals: 43 males and 47 females, who made up three groups. There were thirty 7- to 10-year-olds in Group 1; thirty 13- to 16-year-olds in Group 2; and thirty 18- to 21-year-olds in Group 3. Table 2 shows mean ages
and standard deviations by gender, and estimated IQ scores for each of the groups.

Estimated IQ was assessed using two subtests: Vocabulary (verbal) and Matrix Reasoning (nonverbal) of the Wechsler Abbreviated Scale of Intelligence (WASI, Psychological Corporation, 1999). A one-way ANOVA revealed there were no group differences in estimated IQ ($F[87] = 1.98, p > .05$).

Table 2

**Mean Ages and Standard Deviations by Gender, and Estimated IQ Scores for Each of the 3 Groups**

<table>
<thead>
<tr>
<th>Age Group</th>
<th>7 - 10 years</th>
<th>13 - 16 years</th>
<th>18 - 21 years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males</td>
<td>Females</td>
<td>Males</td>
</tr>
<tr>
<td>n</td>
<td>13</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Mean age</td>
<td>8.31</td>
<td>8.82</td>
<td>14.53</td>
</tr>
<tr>
<td>SD (age)</td>
<td>1.25</td>
<td>1.13</td>
<td>1.23</td>
</tr>
<tr>
<td>Estimated IQ</td>
<td>114.80 (9.55)</td>
<td>112.03 (10.61)</td>
<td>109.67 (9.83)</td>
</tr>
</tbody>
</table>

Participants in Group 1 were recruited through the community and two primary schools: one State and the other Catholic. Participants in Group 2 were recruited through the general community and a Lutheran secondary school. And participants in Group 3 were recruited through the general community and a technical college. All participants came from inner and outer suburban, and regional towns in the south-eastern area of Queensland, Australia, and all were from either upper-
working or middle-class families. All participants were competent English language
speakers and readers, including four children in Group 1 from non-English speaking
backgrounds (2 Japanese, and 2 Vietnamese).

Design

The main part of the study comprised a mixed-factorial, 3 x 2 x 2 design, with
Demand (low and high) of the ongoing task a within-subjects variable, and Group (1,
2 & 3), and Importance (stressed and unstressed) of the prospective task between-
subjects variables.

Materials and Tasks

Experimental Prospective Memory Tasks

Two prospective memory tasks were used in this study: one computerised, and
one manual. Both were event based. The computerised task was the primary one. It
incorporated manipulations to specifically test the prefrontal-lobe hypothesis. The
manual task was the secondary one used to compare the cognitive processes involved
in different prospective memory tasks.

Computerised task (general). This task used Einstein and McDaniel's (1990)
standard dual-task paradigm, where prospective memory cues are embedded in an
ongoing task. Here, two levels of the ongoing task (counterbalanced low- and high-
demand), which each ran for 9 min, required participants to make lexical decisions:
to decide if a series of letters, presented one at a time, made words or non-words. The
low-demand level used short letter strings. The high demand used longer letter
strings. If respondents thought the letters made proper words, they pressed a green
key (1st key) on a 6-key RB-600 Series response box (Cedrus Corporation, 1996)
attached to the computer. If they thought the letters did not make proper words, they
pressed a red key (2\textsuperscript{nd} key) on the response box. Further, participants were told that while making their word/non-word decisions, they would see randomly presented italic letters within some of the words and non-words. These italic letters, 12 in total, represented the prospective memory cues. The importance of remembering the prospective cues was stressed for half the participants and not stressed for the other half. On seeing the cues, participants were told to press the 6\textsuperscript{th} key, one of four grey keys (3\textsuperscript{rd} to 6\textsuperscript{th}), on the response box.

The task was presented on a Toshiba 1800-Series, portable computer. The letters were presented on the computer screen via a software package: SuperLab Pro (Cedrus Corporation, 1996). The letters were black on white, appeared in the centre of the screen, and were in lower case Arial font, size 120. Responses were recorded by the computer, which showed a "C" for Correct if the right key was pressed at the right time; an "E" for Error if the wrong key was pressed; and a "NR" for No Response.

The total number of correct prospective responses was tallied from the computer data. Figure 2 shows the computer and response box.

\textit{Pilot Study}. Task features (ongoing & prospective) were determined after monitoring the performances of 35 individuals aged 7 to 50 years in a pilot study. Four aspects of the task were resolved in the pilot: (a) the number of prospective cues to use; (b) the overall running time of the tasks; (c) the words to use for the low- and high- demand lexical decisions; and (d) the interstimulus intervals in the low- and high-demand conditions.

Twelve prospective cues were found to reliably measure prospective-memory performance with no floor or ceiling effects. And, the 9-min running time was found
to reliably monitor prospective remembering, without taxing the attentional resources of the youngest children, or resulting in loss of motivation. Ideally, all groups would have been presented with identical letter strings. However, the pilot indicated that developmental differences in reading ability precluded that possibility. Given the wide age range and associated developmental differences, it was apparent that the same tasks for all created unequal cognitive demands, whereas carefully designed unequal tasks were more likely to create equal demands. Note that unequal tasks are commonly used when comparing children of different ages (see for example; Hitch,
Halliday, Schaafstal, & Schraagen, 1988; Hitch, Woodin, & Baker, 1989). In fact, Diamond (1991, p. 352) stated that: “sometimes a task must be modified in order for it to measure the same ability in a different population.”

After extensive piloting, 3- and 4-letter words were chosen for low- and high-demands respectively for the 7- to 10-year-olds. Four- and 6- or 7-letter words were chosen for low- and high-demands respectively for the 13- to 16- and 18- to 21-year-olds. Lexical-decision error rates in the pilot showed that the 3- (low) and 4-letter (high) differential for Group 1 appeared roughly equivalent to the 4- (low) and 6- or 7-letter (high) differential for Groups 2 and 3. These between-group similarities in lexical-decision accuracies tend to indicate that the cognitive demands of the respective ongoing tasks were the same for each of the groups. The words were selected from a list of frequently occurring English words (Leech, Rayson & Wilson, 2001). The children's words matched Years 1 and 2 Australian schools' spelling lists, while the older groups' words matched Years 2 to 5 spelling lists (Clutterbuck, 1990).

Interstimulus intervals, which are indicated in the Cognitive Demand Manipulation section, were longer in the low- than in the high-demand conditions, but were consistent for all age groups. The pilot found that the low-demand intervals, despite the different sized letter-strings for the children’s, and adolescents’ and adults’ tasks, produced consistently high accuracy rates (i.e., approx. 95%) on lexical decisions across the ages, and appeared a comfortable working speed for all participants. The shorter, high-demand intervals, again with different between-group letter-strings, also produced consistent, though lower accuracy rates (i.e., approx. 86%) on lexical decisions across the ages, and appeared a less comfortable working
speed, without, however, causing frustration or loss of motivation. Therefore, the interstimulus intervals appeared on the one hand to place different cognitive demands on the low and high conditions as planned, and on the other hand, to be consistent across the ages.

*Computerised task (cognitive-demand manipulation).* Based on Maujean and colleagues' (2003) design, the non-words were identical to the words, except that the last letter was altered. For example if a proper word was "both", its non-word equivalent was "bota". Altering only the last letter ensured that lexical decisions could not be made until the last letter appeared, which meant that attention had to be maintained from the first to the last letter on every set of letters presented. See Table 3 for a more expansive list of words and non-words used.

In the low-demand condition, the 3- (Group 1) and 4-letter strings (Groups 2 & 3) were presented at 850 ms intervals. The between word/non-word intervals were 1600 ms. During those intervals punctuation marks ("?" and "!") appeared to: (a) indicate that the letter string was now complete, and (b) allow response time.

In the high-demand condition, the 4-letter (Group 1) and 6- and 7-letter strings (Groups 2 & 3) were presented faster, at 600 ms intervals. The between word/non-word intervals were 1300 ms, with punctuation marks again filling the intervals. Figure 3 shows how the letters and punctuation marks appeared on the computer screen, one character at a time, for both words and non-words in the low- (Group 1) and high-demand conditions (Groups 2 & 3) of the ongoing task. The low- and high-demand levels of the task were presented in counterbalanced order to control for order
effects. Half the participants completed the low-demand condition first, and the other half completed the high-demand condition first.

Table 3

Samples of Words and Non-Words in Low- and High-Demand Conditions Across Groups

<table>
<thead>
<tr>
<th>Words</th>
<th>Non-Words</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low-demand</strong></td>
<td><strong>High-demand</strong></td>
</tr>
<tr>
<td>7-10 years</td>
<td>13-16, &amp; 18-21 years</td>
</tr>
<tr>
<td>two</td>
<td>lost</td>
</tr>
<tr>
<td>job</td>
<td>came</td>
</tr>
<tr>
<td>his</td>
<td>sent</td>
</tr>
<tr>
<td>most</td>
<td>nothing</td>
</tr>
<tr>
<td>nothing</td>
<td>always</td>
</tr>
</tbody>
</table>

Computerised task (importance manipulation). Half the participants in each group were assigned to an importance-stressed condition, and the other half to an importance-unstressed condition. Those in the importance-stressed condition were told: *As well as pressing the green key or the red key quickly and accurately, I would like you to press the end key (Pointed to the 6th key on the response box) whenever you see any letters in italics. It is important to do both these things.*

Those in the importance-unstressed condition were told: *It is important to press the green key or red key as quickly and accurately as possible, and if you remember, would you do me a favour. All the letters were formerly in italics, but were changed to standard letters. I may have missed changing some, so if you happen*
Figure 3. Examples of letter-by-letter presentations of a: 3-letter word used in low-demand condition for Group 1 (above); and 6-letter non-word used in the high-demand condition for Groups 2 and 3 (below).
to see any that are still in italics, would you press this key for me, please (Pointed to the 6th key).

**Computerised task (prospective component).** As indicated, the 12 italic letters (prospective cues) were presented randomly. However, to ensure that the cues were spread reasonably throughout the 9 min, and did not, for example, all appear within the first 1 min, the task was programmed as 3 blocks. Each of the 3 blocks contained four cues. Note, however, that there were no breaks between blocks. The 9 min-task ran continuously.

In each condition of the ongoing task, six italic letters appeared within words and six appeared within non-words. Half the italics were vowels, and half were consonants. Approximately one-third of the letters appeared at the beginning, one-third in the middle, and one-third at the end of the words and non-words. A sample of words containing italics letters was shown to participants prior to testing to make sure they could distinguish the italics from normally-oriented letters. Figure 4 shows examples of how the target italic letters appeared in words and non-words.

**Computerised task (manipulation checks).** After completing both the low- and high-demand conditions of the computerised prospective memory task, participants were asked a series of questions to: (a) ensure that any failures to respond to prospective memory cues were not the result of retrospective memory failures, that is, a failure to recall the instructions (Ellis & Kvavilashvili, 2000); (b) obtain some understanding of the mental processes involved in remembering prospectively; and (c) ascertain whether the prospective-memory task importance manipulation was working.
Figure 4. Varying locations of italic letters (prospective-memory cues) within low- and high-demand words and non-words for Groups 1, 2, and 3.

The questions asked were:

1) What were you asked to do if you thought the word was a proper one?
2) What were you asked to do if you thought the word was not a proper one?
3) There was something else you were asked to do. What was that, and when did you have to do it?
4) Did you only remember to press the last key when you saw an italic letter, or were you looking out for italics all the time?
5) Which task did you think was the most important, pressing the Green or Red keys quickly and accurately, pressing the last key when you saw an italic, or did you think both were equally important?

Further, to ensure as much as possible that prospective memory performance was reduced as a result of the cognitive-demand manipulations, and not as a result of artifacts such as perceptual difficulties (e.g., an inability to see the targets), a group of
39 individuals comprising 21 males and 18 females, aged 6 to 61 years, was tested separately on the prospective-only component. Individuals in this single-task group were given the high-demand version of the computer-based task appropriate for their ages, and asked only to press the 6th key on the response box when they saw an italic letter. They were not required to make any lexical decisions. Again, the number of italic letters out of 12 was the dependent measure.

Finally, to check whether the different ongoing tasks (i.e., different letter strings for the children) were equated in terms of cognitive demand as much as possible, between-group, lexical-decision accuracy rates were compared.

*Manual prospective-memory task.* This task was adapted from one devised for university undergraduates by Kvavilashvili (1998), which involved reading aloud a piece of text (ongoing task) and substituting a target word in the text with another word (prospective task). The current ongoing task comprised an age-appropriate narrative. The prospective task, as in Kvavilashvili's, comprised specific word substitutions. To ensure respondents engaged fully in the reading, they were told they would be asked questions about the story when they had finished reading. After piloting with 20 individuals aged 7 to 25 years, an easier version of the narrative was developed for 7- to 10-year-olds than for 13- to 16-, and 18- to 21-year-olds because of the younger children's relative inexperience as readers. The children's narrative had an approximate reading age of Year 1. The adolescents' and young adults' narrative had an approximate reading age of Year 5 (Flesch-Kincaid formula incorporated in Microsoft Word). Both narratives were seven pages long and both had two prospective targets per page.
The children were told that their story, called *The Twig Fence*, had been written for beginning readers, and they were to read it to see if it was suitable for Grade 1 students. Attention was drawn to the name of the boy, *Henry*. Readers were told that because *Henry* might be a difficult word for children in Grade 1 to read, they should substitute that name with *Tom* whenever *Henry* appeared in the text. Figure 5 shows a sample page of text used in the story, *The Twig Fence*.

---

After breakfast on Saturday, the family went to work in the garden.

"I think the sandpit should be made first," said *Henry* (prospective memory cue). *

"No," said Kim, "I think the swing should be made first."

Mum said, "No, I think we should make the gardens and fix the fence first. If we make the sandpit first, *Henry* (prospective memory cue) *will play in the sand, and not help us make the other things. If we make the swing first, Kim will want to swing, and not help us make the other things."

"I agree with Mum," said Dad.

---

* Cues not highlighted for participants

**Figure 5.** Sample page of text from the manual prospective-memory task for 7 to 10 year olds, showing prospective-memory cues.

Participants in the adolescent and young adult groups were told that their story, called *The Fire*, had been developed for older primary-school-aged children, and they were to read it to see if it was suitable for Grades 5 and 6 students. Attention
was drawn to the name of the town, Lower Palmer. Readers were told that the word Lower was misleading because the town was in the hills, and that whenever they saw the word Lower in the text, they should substitute it with Upper Palmer. Figure 6 shows a sample page of text used in the story, The Fire.

Jane stood on the verandah and gasped as she looked towards the west. Huge clouds of smoke billowed into the sky.

"Why's the fire in the west?" she wondered, almost in disbelief.

She had only just heard a news report about the fires in the Lower (prospective memory cue) * Palmer area. The report distinctly said that the fires were all to the south. What was going on? Surely others knew about the fire on the western front. If the radio stations didn't know yet, at least the fire service must know.

She rushed quickly to the other verandah to check the south. She was horrified at what she saw. They were trapped. She had to do something. She had to act quickly.

"I mustn't alarm the children," she whispered to herself. "Stay calm, Jane. Stay calm...What will I do? Where can I take the children?"

Jane's husband, Robert, had left early that morning. He was a member of the Lower (prospective memory cue) * Palmer Bush Fire Brigade. His crew had been sent to the fire front in the south, near the neighbouring town of Hillgrove.

* Cues not highlighted for participants
The number of correct word substitutions was tallied for each page. These scores were summed to provide the total score out of a possible 14, which represented the dependent measure.

**Prospective Memory Questionnaire**

To determine if there was a relationship between performance on the experimental prospective-memory tasks and everyday prospective remembering, adult participants (Group 3) and parents of the children and adolescents (Group 1 & 2) were given an 11-item prospective memory questionnaire. The instrument was adapted for children, adolescents and young adults from the Comprehensive Assessment of Prospective Memory (CAPM, Roche, Fleming & Shum, 2002), which was developed originally to assess mental ageing. The CAPM comprised: Section A that measured the frequency of prospective memory failure; Section B that measured the perceived amount of concern about these failures; and Section C that attempted to ascertain the reasons for remembering or forgetting. In the current study, only items from the frequency scale (Section A) were included. Further, the items addressed issues relating to instrumental activities of daily living (IADL, e.g., appointments and school/college/work-related activities), but not issues relating to basic activities of daily living (BADL, e.g., dressing, eating, and hygiene maintenance), which were also incorporated in the CAPM.

Sample items in the current version of the prospective-memory questionnaire included:

1) *Forgetting to pass on a message*
2) *Forgetting appointments*
3) *Forgetting to buy an item at the shop, or from school*
Note that some of the items varied with the ages and life circumstances of the target groups. For instance, Item 8 in the young adults' version was worded: *Forgetting to take things to or from work or place of study (e.g., laptop computer, disks, textbooks, case notes, class notes)*. Item 8 in the children's and adolescents' version, which was completed by parents, was worded: *Forgetting to take things to or from school (e.g. homework, lunch, sporting gear, notes to parents/teachers)*. Respondents rated how often they (or their children) experienced memory lapses for each of the 11 items on a 5-point scale: 1 = Never; 2 = Rarely (once/month); 3 = Occasionally (2 - 3 times/month); 4 = Often (weekly); 5 = Very Often (daily); and N/A = Not Applicable.

Internal consistency of the IADL items of the CAPM have been supported by a Cronbach's alpha score of 0.92. And in tests that compared young-to-middle-aged adults (n = 327) and aged adults (n = 200), the CAPM was found to be sensitive in discriminating age groups. Similarly, Section A of the CAPM was found to be sensitive in discriminating adults with TBI from their non-injured peers when including responses from both groups of adults and their significant others (Roche et al., 2002). The dependent measure on the questionnaire was the total forgetting score.

**Executive Function Tasks**

*Self-Ordered Pointing Task (SOPT)*. A variant of the representational drawings subtask of the SOPT (Petrides & Milner, 1982) was used as a measure of visual working memory. The drawings were altered for the current study because some of the originals were "politically incorrect" (e.g., depicted a man smoking a cigarette) or dated (e.g., showed 1960s-style household objects, which may have been unrecognisable for some of the younger participants).
In accordance with the test developers' instructions, the subtask was divided into four sections, each comprising 6, 8, 10 and 12 pages of coloured pictures. The pictures were arranged in a matrix on an A4-sized page. Participants were instructed to point to one picture (any picture) on the first page, to turn the page and point to a different picture, and to turn again and point to a third different picture, and so on until all pages in that section were completed. The 6-picture section was used as a practice set. The 8-picture section was administered as the first test section, followed in turn by the 10- and 12-picture sections. A different set of pictures, selected from Microsoft Clip Gallery 5.0, was used for each of the four sections. However, the same pictures were used within each section, but appeared in different locations on each successive page. To increase the demand on working memory, each section, except the practice section, was administered three times in succession. This meant that participants had to separate in their minds each trial, or risk the possibility of confusing one trial with the next. Participants were discouraged from pointing to the same location on consecutive pages because if pictures happened to occur in different locations, participants could “safely” point to the same location and avoid pointing to the same picture, and therefore would not have to remember what the pictures were. See Figure 7 for a sample picture page.

In terms of its validity, Daigneault and Braun (1993) found the SOPT correlated with the Wisconsin Card Sorting Test \( (r = .33) \), the Porteus Mazes \( (r = .38) \), and the Stroop test \( (r = .36) \), all tests of executive functions, though ones that measure different components. The SOPT is also commonly used clinically and has been found to accurately reflect anticipated cognitive differences in patients with frontal
Figure 7. A sample picture page from the adapted version of the representational drawings subtask of the SOPT
lobe and those with temporal lobe lesions (Petrides & Milner, 1982). Similarly, Shimamura and Jurica (1994) found the SOPT to be sensitive to age differences among adults, again reflecting changes in frontal lobe functions with ageing. Further, Kerns (2000) found, after controlling for age, that a representational drawings subtask of the SOPT similar to the one used in the current study, was significantly correlated (r = .28) with time-based prospective memory performance in children.

Stroop Colour Word Interference Task (Stroop, 1935). A standardized version of the Stroop as described by Golden (1978) and Golden, Espe-Pfeifer, and Wachsler-Felder (2000) was used as a measure of focused attention. The test consists of three pages of 100 items, presented in 5 columns of 20 items each. The first page comprises the words "RED", "GREEN" and "BLUE" printed in random order in black and white (W-block). The second page comprises Xs in sets of four (i.e., "XXXX"), printed in red, green, or blue ink (C-block). The third page comprises the colour words used on page one printed in an incongruent colour (e.g., "RED" printed in green ink; CW-block). The three pages were administered in consecutive order. Participants were instructed to proceed down the columns as quickly as they could, stating the: words in W-block; colours in C-block; and ink colours in CW-block. If participants made an error, they were told, "Wrong". They self-corrected and moved on as quickly as possible. Participants were timed on each page, and after 45 seconds told to stop. After raw scores were age adjusted, interference scores were calculated by subtracting the number of items completed on the CW block from the number of items predicted to be completed using the formula: (C x W)/(C + W) (Golden; Golden, et al.). Interference scores were used as the dependent measure.
Extensive reliability and validity testing have shown the Stroop: (a) to have good test-retest reliability (.75 to .90, Uttl & Graf, 1997); (b) to be moderately related to Perceptual Organisation (r = .37) and Freedom from Distractability (r = .29) factors on the WAIS-R; and (c) to load on the same factor as serial subtraction tasks, and to reflect the ability to sustain mental processes (Shum, McFarland, & Bain, 1990). Further, the Stroop interference score is reported to be effective in distinguishing between normal controls and brain-injured patients (Hanes, Andrewes, Smith & Pantelis, 1996), and age effects have also been found in a broad sample, aged 12 to 83 years (Uttl & Graf).

Tower of London (TOL). The TOL has been used extensively as a measure of planning ability (Kartsounis & Poynton, unpublished study cited in Shallice & Burgess, 1991a; Lezak, Howieson, & Loring, 2004; Owen, Downes, Sahakian, Polkey, & Robbins, 1990; Shallice, 1982). The current study used a version of the TOL developed by Tunstall (1999) who increased the number of disks from three to four to overcome a ceiling effect commonly reported in the original version (Levin, et al., 1997). Figure 8 shows a photograph of the 4-disk TOL apparatus.

Participants were presented with four coloured disks (black, blue, white, and yellow) on a 3-peg (long, medium, and short) board. Disks were arranged in the start position (as shown in Figure 8). A stimulus booklet was faced towards participants and they were told to look at the first picture (practice problem), to rearrange the disks to match the picture, and to do so in the number of moves specified. Rules for moving the disks stipulated that: (a) a disk being lifted from one peg and placed on
Figure 8. Starting position for the 4-disk version of the TOL

another constituted a move; (b) only one disk could be moved at a time; (c) the short peg held 2 disks, the medium 3, and the long 4; (d) after solving a problem the disks were to be moved back to the start position; and (e) if required, participants were allowed three attempts per problem. After successfully completing the practice problem, participants worked through 10 problems in order of difficulty from easiest to hardest. Three points were awarded for solving each problem on the first attempt,
two points on the second, one point on the third, and zero if the problem was not solved in three attempts. Total scores were obtained by summing the scores across the 10 problems. The total scores represented the dependent measure.

The 4-disk version of the TOL has been found to have adequate test-retest reliability (.60), to load on the same factor as the Porteus Mazes (Tunstall, 1999), and to be sensitive in detecting planning impairments in children with TBI (Shum, et al., 2000).

Procedure

Participants were assessed individually in quiet locations either in their homes or in a laboratory at Griffith University. Assessments took approximately 2 hours. When necessary, additional instructions, practice, and breaks were given to participants. The order of testing was: (1) first version (low- or high-demand) of the computerised prospective memory task; (2) SOPT; (3) WASI; (4) manual prospective memory task (reading and word-substitution); (5) Stroop; (6) TOL; (7) second version (opposite of first) of the computerised prospective memory task; (8) manipulation-check questions; and (9) CAPM questionnaire.

Results

Data Screening

Prior to analysis, participants' ages and estimated IQs; number of cues detected on low- and high-demand versions of the computerised task; number of word substitutions made on the manual task; scores on the SOPT, Stroop, TOL; and
questionnaire were screened for missing values, outliers and normality of distributions. These variables were examined separately for the three groups. There were no missing values and no multivariate outliers. However, two cases in Group 2 were univariate outliers and were removed, one because of an extremely low Z score on the reading-based, word-substitution task, and one because of an extremely high Z score (i.e., a high error rate) on the SOPT. The participant with the low score on the reading-based task did not comply with the instructions, and the participant with the high error score on the SOPT appeared to lose concentration. After removing each case, distributions improved, and this left 28 cases in Group 2, and 30 each in Groups 1 and 3 for analyses.

An alpha level of .05 was used for all analyses. The Greenhouse-Geisser correction was used for analyses involving repeated measures and where the results of the Mauchly's Test indicated that sphericity assumptions were violated.

**Manipulation Checks**

To determine if prospective memory failures were due to not understanding the instructions, or a failure of retrospective memory (i.e., recall), all participants were asked, after completing the computer-based tasks, what they had to do if: (a) the letters made a word; (b) the letters made a non-word; (c) what other task they had to perform; and (d) under what circumstances they had to perform that other task. All participants (i.e., 100%) indicated total understanding and/or total recall of the instructions.

To gain some understanding of what strategies participants used to help them remember to respond to the prospective memory targets, they were asked if: (a) they
thought about the cues all the time and looked out for them; or (b) they only remembered to respond when they actually saw the cues. Table 4 shows frequencies by group of the different strategies employed in remembering. As can be seen in the table, very few participants were unable to remember their thought processes.

Overall, the majority said they remembered to respond to the prospective memory cues only when they saw them. This was particularly the case with children and adults, and moderately so with adolescents. Close to half the adolescents reported

Table 4

*Group Frequencies of Remembering Strategies*

<table>
<thead>
<tr>
<th>Strategy Used</th>
<th>Group Frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Children</td>
</tr>
<tr>
<td>Don't know/Can't remember</td>
<td>3.3%</td>
</tr>
<tr>
<td>Remembered only when saw the cues</td>
<td>73.3%</td>
</tr>
<tr>
<td>Thought about all the time/Looked out for the cues</td>
<td>23.3%</td>
</tr>
<tr>
<td>Thought about at the start, but with all the other things to think about,</td>
<td>0.0%</td>
</tr>
<tr>
<td>switched to remembering only with the cues</td>
<td></td>
</tr>
<tr>
<td>Remembered only when saw the cues at the start, but with the reminders,</td>
<td>0.0%</td>
</tr>
<tr>
<td>began to think about all the time and looked out for the cues</td>
<td></td>
</tr>
</tbody>
</table>
thinking about the cues all the time, and looking out for them, whereas approximately one-quarter of the children and adults used that strategy. Interestingly, some adolescents and adults reported changing their thinking about the tasks as they proceeded through the trials.

Participants were also asked whether they thought: (a) making the lexical decision was the most important task; (b) pressing the $6^{th}$ button in response to an italic letter was the most important task; or (c) both were important. Theoretically, those in the importance stressed condition ought to have said both tasks were important, and those in the importance not stressed condition ought to have said that the lexical-decision task was more important. In general, this trend was observed. Table 5 shows the group frequencies of congruence and non-congruence between the instructions given and the participants' indications of what they thought was most important. Note that no participants indicated thinking that responding only to italic letters was most important. All believed that either the lexical decision or both were most important. Overall there was a high level of congruence in all three groups, indicating that most participants thought the most important aspect of the task was in line with the instructions they were given. Instances of non-congruence are indicated in Table 5.

Despite the overall high level of congruence between instructions and beliefs about importance, it can be seen from Table 5 that some participants were skeptical about the instructions, and therefore did not comply. This was particularly evident among the adolescents, where around one-third showed non-congruence between
Table 5

*Group Frequencies of Congruence and Non-Congruence Between Instructions and Beliefs About What Was Most Important*

<table>
<thead>
<tr>
<th>Belief</th>
<th>Group Frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Children</td>
</tr>
<tr>
<td></td>
<td>Con</td>
</tr>
<tr>
<td>Making the lexical decision was most important</td>
<td>40.0%</td>
</tr>
<tr>
<td>Both tasks were equally important</td>
<td>43.3%</td>
</tr>
</tbody>
</table>

* Indicated that despite being told that both tasks were important, they believed the research was about reading ability so concentrated more on the lexical-decision tasks.
** Indicated that despite being told the lexical decision task was the most important, they believed it was more likely to be their ability to "juggle" both tasks that was of importance.

instructions and their own beliefs about what was important. Non-congruence was less in adults and children. However, comparisons in congruence frequencies between those in the importance-stressed and importance-unstressed groups showed that there were no significant differences (Chi square $\chi^2 [1] = .0029, p > .05$).

*Prospective-Only Version of the Computer Task*

Responses to prospective cues were compared between the group of 39 who performed the prospective-component-only task (single task) with the experimental
group that performed best on the prospective task overall, that is, the adolescents on the low-demand version of the dual task. The single-task group's mean number correct was 11.62 ($SD = 0.71$). The dual-task's group mean number correct on the low-demand version was 10.46 ($SD = 1.20$). An independent groups $t$ test, revealed that the single-task group performed significantly better than the most accurate dual-task group on the prospective task, $t (65) = 4.91, p < .001$, suggesting that: (a) failures to respond to the italics were not due to perceptual difficulties, and (b) performing the ongoing task resulted in a response cost on the prospective task.

Comprehension of Reading-Based Manual Task

To ensure participants had engaged in the reading of the narratives (the manual prospective-memory task), they were asked a series of questions about their respective stories. The children answered five and the older groups answered seven questions. Most respondents, young and older, scored 100% on the comprehension questions, with some answering slightly less accurately, though well enough to indicate a high level of engagement with the reading.

Accuracy of Lexical Decision Making

Table 6 displays the mean percentages and standard deviations of lexical-decision accuracy rates as a function of Demand, Importance and Group. It can be seen that all groups scored over 91% accuracy in the low-demand condition, and most scored between 85% and 91% in the high-demand condition. Results of a $2 \times 2 \times 3$ mixed-factorial ANOVA with a within-subjects variable Demand and between-subjects variables of Group and Importance, showed a main effect for Demand, $F (1, 82) = 67.25, p < .001$, and a main effect for Group, $F (2, 82) = 13.33, p < .001$. There
Table 6

*Mean Percentage (and Standard Deviations) of Lexical Decision Accuracy as a Function of Demand, Importance and Group*

<table>
<thead>
<tr>
<th>Group</th>
<th>Importance</th>
<th>Demand</th>
<th>Importance</th>
<th>Demand</th>
<th>Importance</th>
<th>Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td></td>
<td>High</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>Stress</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Children</td>
<td>92.33%</td>
<td>(2.97%)</td>
<td>91.00%</td>
<td>(3.59%)</td>
<td>86.33%</td>
<td>(6.10%)</td>
</tr>
<tr>
<td>Adolescents</td>
<td>95.31%</td>
<td>(2.93%)</td>
<td>94.73%</td>
<td>(2.94%)</td>
<td>88.38%</td>
<td>(7.03%)</td>
</tr>
<tr>
<td>Adults</td>
<td>95.33%</td>
<td>(3.42%)</td>
<td>95.00%</td>
<td>(4.23%)</td>
<td>92.13%</td>
<td>(6.13%)</td>
</tr>
</tbody>
</table>

was no main effect for Importance and no interactions involving Importance.

However, there was a significant Demand x Group interaction, $F(2, 82) = 4.56, p < .05$, indicating that the groups’ accuracies varied on the two levels of demand. Tests for the simple main effects of Group at the two levels of Demand showed there was a significant effect of Group in the low-demand condition, $F(2, 85) = 10.29, p < .001$, and also in the high-demand condition, $F(2, 85) = 11.22, p < .001$. Tests for comparisons showed that in the low-demand condition, the children were significantly less accurate in making lexical decisions than the adolescents, $t(85) = 3.78, p < .001$, but that the adolescents and adults were equally accurate, $t(85) = 0.19, p > .05$. In the high-demand condition the children were again less accurate than the adolescents, $t(85) = 2.60, p < .05$, but the adolescents were also less accurate than the adults, $t(85)$
81

= 2.04, \( p < .05 \). In terms of reductions in accuracy of lexical-decision making from the low- to high-demand conditions, children showed a mean of 5.93\% (\( SE = 0.96 \)) reduction, adolescents a 5.33\% (\( SE = 1.01 \)) reduction, and adults a 2.20\% (\( SE = 0.89 \)) reduction. Results of planned comparisons showed that the effect of increasing the demand resulted in a similar level of reduction in lexical-decision accuracy for the children and adolescents, \( t(85) = 0.53, p > .05 \), but in a lower level of reduction for the adults than for the adolescents, \( t(85) = 2.23, p < .05 \).

*Dual-Task Prospective Memory Tasks*

*Computerised Task*

Table 7 displays the means and standard deviations of the number of prospective-memory cues detected as a function of Demand, Group and Importance. It can be seen that the children (Group 1) responded to fewer italics letters than adolescents (Group 2) or young adults (Group 3) on either the low or high-demand conditions. The adolescents' scores on both the low- and high-loads were similar to the adults'. The table also shows that across the groups, individuals scored better on the low- than on the high-demand conditions, but that it did not seem to make a difference whether the importance of looking out for the italics letters was stressed or not. A 3 x 2 x 2 mixed-design ANOVA, with between-subjects variables of Group and Importance and a within-subjects variable of Demand showed a main effect for Demand, \( F(1, 82) = 65.59, p < .01 \), indicating that overall there was a significantly better performance on the low- than on the high-demand conditions. There was also a main effect for Group, \( F(2, 82) = 27.79, p < .01 \), indicating that overall, scores varied significantly from group to group. A post hoc analysis using Tukey's B, showed that
Table 7

*Mean Number (and Standard Deviations) of Prospective-Memory Cues Responded to as a Function of Demand, Importance and Group*

<table>
<thead>
<tr>
<th>Group</th>
<th>Importance</th>
<th>Demand</th>
<th>Mean</th>
<th>SD</th>
<th>Mean</th>
<th>SD</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stressed</td>
<td>Low</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Children</td>
<td></td>
<td></td>
<td>8.80</td>
<td>(1.70)</td>
<td>7.20</td>
<td>(2.88)</td>
<td>5.67</td>
<td>(2.09)</td>
</tr>
<tr>
<td></td>
<td>Unstressed</td>
<td></td>
<td>10.23</td>
<td>(1.54)</td>
<td>10.67</td>
<td>(0.82)</td>
<td>8.85</td>
<td>(2.23)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stressed</td>
<td></td>
<td>10.40</td>
<td>(1.40)</td>
<td>10.33</td>
<td>(1.68)</td>
<td>9.07</td>
<td>(1.87)</td>
</tr>
<tr>
<td></td>
<td>Unstressed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Maximum number of cues detected = 12

the 7- to 10-year-olds detected or responded to fewer prospective memory cues than either the 13- to 16-year-olds or 18- to 21-year-olds, but that the 13- to 16-year-olds were level with the 18- to 21-year-olds. There was no main effect for Importance, $F(1, 82) = 1.06, p > .05$; no significant two-way interactions between Group and Importance, $F(2, 82) < 1.0$, and Demand and Importance, $F(1,82) < 1.0$; and no three-way interaction between Demand, Group and Importance, $F(2, 82) = 1.29, p > .05$.

Because there was a main effect for Group, with the children’s prospective performance lower than the other groups’ overall, it is likely that the children began from a lower baseline (i.e., had lower scores in the low-demand condition). If baselines were different, interactions between Demand and Group should not be
reported because the interactions would not account for relative group differences (Snodgrass, 1989) between the two demand conditions. It was therefore important to test whether there were group differences in baselines, and if differences were found, to estimate proportional declines in performance from the low-to high-demand conditions across the three groups.

The children's baseline scores ($M = 8.0; SD = 2.46$) were lower than the adolescents' ($M = 10.46; SD = 1.20$) and adults' ($M = 10.37; SD = 1.52$), but the adolescents' and adults' were similar. A one-way ANOVA found there were indeed significant group differences in baselines, $F (2, 85) = 17.39, p < .001$. And a post hoc analysis using Tukey's B revealed that the children performed more poorly overall in the low-demand condition than either the adolescents or young adults, but that the adolescents and adults were at the same level. As a follow up, proportional differences between low- and high-demand performances across groups were calculated using the following formula (Russo, Nichelli, Gilbertoni, & Cornia, 1995; Shum, Jamieson, Bahr, & Wallace, 1999; Snodgrass, 1989; Stuss, Floden, Alexander, Levine, & Katz, 2001):

\[
\frac{\text{low-demand score} - \text{high-demand score}}{\text{low-demand score}} \times 100
\]

Mean proportional difference scores were found to be 30.91% (SE = 5.25) for the 7- to 10-year-olds, 15.90% (SE = 3.57) for the 13- to 16-year-olds, and 13.63% (SE = 3.68) for the 18- to 21-year-olds, which showed that the children's proportional decline in performance from the low- to the high-demand condition was greater than the proportional declines for either the adolescents' or adults'. By contrast, the adolescents' proportional decline was similar to the adults'. The results of a one-way
ANOVA revealed that the proportional declines were indeed significantly different among the groups, $F(2, 85) = 4.65, p < .05$, and a post hoc comparison using Tukey's B showed that the low-high proportional scores were significantly different between the children and adolescents, and the children and adults, but not between the adolescents and adults.

Given that several participants did not comply with the instructions in the importance manipulation, the mixed-factorial ANOVA was rerun with only the 70 compliant subjects included in the analysis. Results still indicated no effect of Importance on remembering the prospective-memory targets.

*Manual Prospective Task*

The mean number of correct word substitutions by group were: children ($M = 9.58, SD = 3.24$); adolescents ($M = 13.09, SD = 0.83$); and young adults ($M = 13.20, SD = 0.89$). These results showed that the children's scores were lower than the adolescents' and adults', but that the adolescents' and adults' scores were similar. A one-way ANOVA showed a significant difference among the experimental groups, $F(2, 85) = 30.87, p < .01$, and a post hoc comparison using Tukey's B showed that the children's rate of remembering to alter their target word was poorer than either the adolescents' or adults', but that the adolescents' rate of remembering was the same as the young adults'.

*Prospective Memory Questionnaire*

Questionnaires completed by the adults, and parents of those under 18 years about everyday prospective forgetting showed that mean total forgetting scores were: children ($M = 21.13, SD = 5.55$); adolescents ($M = 22.43, SD = 4.43$); and adults ($M =
21.59, \( SD = 4.74 \)). A one-way ANOVA showed no significant differences in reported everyday, prospective-memory forgetting among the groups: \( F(2, 85) = .64, p > .05 \).

**Executive Function Tests**

**SOPT**

Table 8 shows the mean number of pointing errors by group. These scores show that the children's errors were more than either the adolescents’ or adults’, but that the adolescents and adults were similar. A one-way ANOVA showed a significant difference across the groups, \( F(2,85) = 19.90, p < .01 \). Post hoc comparisons using Tukey's B showed that the children's memory for pictures was indeed worse than either the adolescents' or adults, but that the adolescents’ and adults’ memories were not significantly different.

**Stroop**

Table 8 shows the mean colour-word interference scores by group, indicating that in general, results improved with age. A one-way ANOVA showed a significant difference among the groups, \( F(2, 85) = 30.87, p < .01 \). Post hoc comparisons using Tukey's B showed that children were considerably less focused than the adults, but that the children were no worse than the adolescents. The adolescents' and adults' measures of focused attention were not significantly different.

**TOL**

Table 8 shows mean planning scores by group. Children scored lower than the adolescents and adults, but the adolescents and adults were at a similar level. A one-way ANOVA showed a significant difference among the groups, \( F(2, 85) = 14.62, p < .01 \). Post hoc comparisons using Tukey's B showed that the children were poorer at
planning than either the adolescents or the adults, but the adolescents' and adults' planning was not significantly different.

Table 8

*Mean Scores (and Standard Deviations) by Group on Tests of Executive Functions*

<table>
<thead>
<tr>
<th>Test</th>
<th>7 - 10 years</th>
<th>13 - 16 years</th>
<th>18 - 21 years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>SOPT errors</td>
<td>9.92</td>
<td>4.55</td>
<td>4.86</td>
</tr>
<tr>
<td>Stroop interference</td>
<td>3.14</td>
<td>4.46</td>
<td>5.68</td>
</tr>
<tr>
<td>TOL totals</td>
<td>19.17</td>
<td>3.62</td>
<td>22.93</td>
</tr>
</tbody>
</table>

*Relationships between Self-Report, Executive Function Tests, Manual, and Computerised Prospective Memory Tasks*

To examine the relationships between performance on the computerised prospective memory task, manual prospective task, the self-report measure, and the three components of executive functions, two hierarchical multiple regressions were conducted. The dependent variables were the low- and high-demand scores on the prospective memory tasks, and the independent variables were estimated IQ, group (dummy coded), the scores on the manual prospective memory tasks and the questionnaire, and the three executive-function measures (viz., scores on the SOPT.

---

7 For comparisons, separate multiple regressions were run with the reading-based manual prospective measure as the DV and the computer-based measures (Low and High) entered as IVs. Results were similar to the ones where the computer-based measures were the DVs.
To evaluate the unique contribution of the manual tasks and measures of executive function, estimated IQ was entered into the regression equations first, followed by group. Table 9 summarises the results of the hierarchical regression of the manual prospective memory measure, questionnaire, and measures of executive function on the low-demand prospective memory task. After step 1, with IQ in the equation, $R^2 = 0.006$, $F (1, 86) < 1.00$. Group was added to the equation in step 2. After this step, $R^2 = 0.29$, $F (3, 84) = 11.49, p < .001$, and $R^2$ change $= 0.29$, $F$ for change $(2, 84) = 16.86, p < .001$.

The scores on the manual prospective task, questionnaire, and the three measures of executive function were added to the equation in step 3. After this step, $R^2 = 0.34$, $F (8, 79) = 5.02, p < .001$. The $R^2$ change for the last step was .05 and was not statistically significant, $F$ for change $(5, 79) = 1.09, p > .05$.

Table 10 summarises the results of the hierarchical regression of the scores on the manual prospective-memory task, questionnaire, and measures of executive function on the high-demand prospective memory task. After step 1, with estimated IQ in the equation, $R^2 = 0.01$, $F (1, 86) < 1.0$. Group was added to the equation in step 2. After this step, $R^2 = .34$, $F (3, 84) = 14.65, p < .001$, and $R^2$ change $= .34$, $F$ for change $(2, 84) = 21.52, p < .001$. The manual-based prospective memory score,
Table 9

*Hierarchical Multiple Regression of Manual Prospective Scores, Questionnaire, and Measures of Executive Function on Low-Demand Prospective Memory*

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>Low-Demand</th>
<th>IQ</th>
<th>Grp 1</th>
<th>Grp 2</th>
<th>Manual</th>
<th>Q'aire</th>
<th>SOPT</th>
<th>Stroop</th>
<th>TOL</th>
<th>B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IQ</td>
<td>-.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-.02</td>
<td>-.08</td>
</tr>
<tr>
<td>2</td>
<td>Grp 1</td>
<td>-.54</td>
<td>.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-2.39</td>
<td>-.53*</td>
</tr>
<tr>
<td></td>
<td>Grp 2</td>
<td>.28</td>
<td>-.02</td>
<td>-.49</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.09</td>
<td>.02</td>
</tr>
<tr>
<td>3</td>
<td>Manual</td>
<td>.38</td>
<td>.00</td>
<td>-.65</td>
<td>.30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.05</td>
<td>.06</td>
</tr>
<tr>
<td></td>
<td>Q'aire</td>
<td>-.10</td>
<td>.08</td>
<td>-.07</td>
<td>.12</td>
<td>.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-.02</td>
<td>-.10</td>
</tr>
<tr>
<td></td>
<td>SOPT</td>
<td>-.36</td>
<td>-.12</td>
<td>.56</td>
<td>-.25</td>
<td>-.34</td>
<td>-.01</td>
<td></td>
<td></td>
<td></td>
<td>-.04</td>
<td>-.09</td>
</tr>
<tr>
<td></td>
<td>Stroop</td>
<td>.30</td>
<td>-.03</td>
<td>-.31</td>
<td>-.04</td>
<td>.29</td>
<td>-.07</td>
<td>-.27</td>
<td></td>
<td></td>
<td>.05</td>
<td>.16</td>
</tr>
<tr>
<td></td>
<td>TOL</td>
<td>.20</td>
<td>-.01</td>
<td>-.51</td>
<td>.27</td>
<td>.40</td>
<td>.36</td>
<td>-.38</td>
<td>-.26</td>
<td></td>
<td>-.09</td>
<td>-.13</td>
</tr>
</tbody>
</table>

|       | Mean     | 9.59       | 112.10 | .34  | .32   | 11.93  | 21.59  | 6.47 | 6.03   | 21.58 | R = .58 | R² = .34 |
|       | SD       | (2.14)     | (10.18) | (.48) | (.47) | (2.62) | (4.74) | (4.42)| (6.71) | (3.45) |

* p < .01
questionnaire, and the three measures of executive function were added to the equation in step 3. After this step, $R^2 = 0.46$, $F(8, 79) = 8.49$, $p < .001$. The $R^2$ change for the last step was .12 and was statistically significant, $F$ for change $(5, 79) = 3.49$, $p < .01$. From Table 10, it can be seen that the SOPT was a significant predictor of the high-demand score, $\beta = -.33$, $p < .01$, while the Stroop was also an important predictor, $\beta = .17$, $p = .076$.

Discussion

The aim of Study 1 was to obtain a clearer picture of the developmental trajectory of prospective memory than had been achieved previously. To achieve this aim, the current study employed a computerised task, which used a prefrontal-lobe model to guide the investigation. Variables linked with prefrontal capacity were manipulated. Specifically, the cognitive demand of the ongoing task was controlled so that the task placed either a low or high demand on available cognitive resources. And, the importance of remembering the prospective task was manipulated, such that the importance of remembering was either stressed or not stressed. Children, adolescents and young adults were compared on prospective-memory tasks in which the cognitive demand and importance variables were manipulated. Further, the three groups' scores on standardised measures of executive functions, which are also understood to be mediated by the prefrontal cortex, were used to predict prospective memory performance. To understand some of the underlying thought processes
Table 10

*Hierarchical Multiple Regression of Manual Prospective Scores, Questionnaire, and Measures of Executive Function on High-Demand Prospective Memory*

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>High-Demand</th>
<th>IQ</th>
<th>Grp 1</th>
<th>Grp 2</th>
<th>Manual</th>
<th>Q’airre</th>
<th>SOPT</th>
<th>Stroop</th>
<th>TOL</th>
<th>B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IQ</td>
<td>-.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>-.09</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>-3.41</td>
<td>-.59*</td>
</tr>
<tr>
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<td>Grp 2</td>
<td>.29</td>
<td>-.02</td>
<td>-.49</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.01</td>
<td>.00</td>
</tr>
<tr>
<td>3</td>
<td>Manual</td>
<td>.35</td>
<td>.00</td>
<td>-.65</td>
<td>.30</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.03</td>
<td>.03</td>
</tr>
<tr>
<td></td>
<td>Q’airre</td>
<td>-.11</td>
<td>.08</td>
<td>-.07</td>
<td>.12</td>
<td>.09</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-.02</td>
<td>-.11</td>
</tr>
<tr>
<td></td>
<td>SOPT</td>
<td>-.55</td>
<td>-.12</td>
<td>.56</td>
<td>-.25</td>
<td>-.34</td>
<td>-.01</td>
<td></td>
<td></td>
<td></td>
<td>-.20</td>
<td>-.33*</td>
</tr>
<tr>
<td></td>
<td>Stroop</td>
<td>.35</td>
<td>-.03</td>
<td>-.31</td>
<td>-.04</td>
<td>.29</td>
<td>-.07</td>
<td>-.27</td>
<td></td>
<td></td>
<td>.05</td>
<td>.17+</td>
</tr>
<tr>
<td></td>
<td>TOL</td>
<td>.25</td>
<td>-.01</td>
<td>-.51</td>
<td>.27</td>
<td>.40</td>
<td>.36</td>
<td>-.38</td>
<td>.26</td>
<td></td>
<td>-.09</td>
<td>-.07</td>
</tr>
</tbody>
</table>

| Mean  | 9.59     | 112.10       | .34  | .32   | 11.93 | 21.59  | 6.47   | 6.03  | 21.58  | R    |
| SD    | (2.14)   | (10.18)      | (.48)| (.47) | (2.62)| (4.74) | (4.42) | (6.71)| (3.45) | R²   |

* p < .01, + p = .076
involved in prospective remembering, to compare one type of prospective task with another, and to attempt to measure the ecological validity of the prospective-memory tasks, other measures were obtained. These included manipulation checks on the computerised task, a reading-based, manual prospective-memory task, and a prospective-memory questionnaire.

Before summarising the major findings, it is important to reiterate that participants understood and remembered instructions on the computerised task, and showed evidence of engaging in the reading on the manual task. Moreover, those who performed the prospective memory task as a single task achieved significantly better prospective-memory scores than the highest achievers (i.e., the adolescents in the low-demand condition) on the dual-task version. And, although there was evidence of non-compliance with respect to the ‘importance’ instructions, there were no differences in non-compliance between those in the importance-stressed and those in the importance-unstressed conditions.

As hypothesised, the children (pre-pubescent) were found not to perform as well on the computerised prospective memory task as the adolescents or adults, but that the adolescents performed as well as the adults. Further, the children's proportional decrease in prospective-memory performance from the low- to the high-cognitive-demand conditions was significantly greater than either the adolescents' or the adults’, but that the adolescents' reductions were equivalent to the adults'. There was no significant importance effect, that is, it made no difference overall whether the importance of remembering the prospective cues was stressed or not. On the manual, reading-based prospective-memory task, performance was found to differ between the
children and adolescents and children and adults, but not between the adolescents and adults. However, performance on the reading-based prospective task did not predict performance on either the low- or high-demand versions of the computer-based task. Scores on the prospective memory questionnaire did not differ among the groups, and questionnaire scores did not predict performance on either the low- or high-demand tasks.

With respect to executive functioning, the children's visual working memory as measured by the SOPT was significantly worse than either the adolescents' or adults’, but the adolescents' and adults' were of a similar standard. The TOL results showed the same pattern as the SOPT, that is, the children were poorer at planning and problem solving than the adolescents and adults, but the adolescents and adults were on a par. A different pattern of performance emerged on the Stroop where it was found that the adults' focused attention was better than either the adolescents' or children's, but that the children's and adolescents' focused attention was similar. In terms of relationships between the measures of executive function and prospective memory, it was found that visual working memory as measured by the SOPT was a significant predictor of performance on the high-cognitive demand version of the prospective-memory task. And, focused attention as measured by the Stroop, was an important predictor of performance on the high-cognitive-demand version of the task. However, none of the executive-function tasks predicted performance on the low-demand version of the prospective-memory task.

Several specific conclusions can be drawn from the results of this study. First, the computerised task was sensitive in detecting age effects in prospective
remembering from middle childhood to young adulthood, without floor or ceiling effects that are often reported in studies of prospective memory (Kvavilashvili, 1998). And, there was a high level of consistency in performance on each of the demand levels within each of the three groups.

Second, the results indicated that in accordance with findings by Passolunghi and colleagues (1995) on encoding modalities in children; Kvavilashvili and colleagues (2001) on task interruptions in children; Kidder and colleagues (1997) on ageing adults; and Maujean and colleagues (2003) on individuals with TBI, increases in the cognitive demand of an ongoing task decrease prospective remembering. This effect occurred despite the prospective task being almost habitual in nature (i.e., the cues occurring frequently), and occurring as often in the high- as in the low-demand conditions. Further, the demand effect matches results by Ellis and Nimmo-Smith (1993) where respondents in a diary study reported that thoughts of prospective memories “sprang to mind” more often when they were involved in tasks that required less concentration. Similarly, Einstein and McDaniel (1996, p. 125) reported that:

Subjects are more likely to think of or rehearse the prospective memory task during times that are less resource demanding and that such rehearsal benefits prospective memory.

It appears that as more of the finite cognitive resources are used in the execution of one task (e.g., an ongoing task), fewer resources remain for the execution of subsequent tasks (e.g., prospective-memory tasks). Superior performance by the single-task group over the best-performing, dual-task group on the prospective component adds weight to this conclusion. Further, Einstein, Smith McDaniel and Shaw (1997) have noted concurrence with this view. And, Smith (2003) showed
evidence of a cognitive resource tradeoff by demonstrating the reverse, that as
cognitive resources are channeled into a prospective-memory task, performance on an
ongoing task diminishes. Specifically, Smith found that lexical-decision reaction
times (RTs) on identical words and non-words were slower in individuals who also
responded to embedded prospective cues than in individuals who did not respond to
prospective cues. McCauley and Levin (2003) reported a similar response cost in
children with mild and severe TBI, where the concurrent performance of a prospective
memory task significantly increased RTs on an ongoing task above the RTs recorded
when the prospective task was not included. Further, there is evidence that as the
cognitive energy requirements of a task increase, the more the prefrontal regions of
the brain are likely to be involved. For instance, Gevins and colleagues (1998) found
from research using EEG measures that as mental effort or cognitive demand
increased, so too did theta band activity in the prefrontal region of the brain.

Third, the results demonstrated that in general adolescents (and young adults)
remembered significantly better than the children. However, despite indications of a
strong age effect on prospective memory, a caveat is noted in interpreting this effect.
Specifically, in attempting to make the lexical-decision tasks age appropriate, the
children were given shorter letter strings than the older groups. The pilot showed that
this group-based difference in letter strings produced the same accuracy rates on
lexical-decision making across the groups. Similarly, in the current study, although
there were statistically significant group differences in accuracy rates, there was only
a 3.50% overall difference between the children and the adults in the low-demand
condition, and a 7.24% overall difference between them in the high-demand
condition. Further, the reduction in lexical-decision accuracy from the low- to the high-demand condition was the same for the children and adolescents, but different between the adolescents and adults. Although in general both the pilot and current studies found similar lexical-decision accuracy rates on low- and high-demand strings across groups, the interpretation of the age effect is, however, subject to the accuracy of this task adjustment.

Nevertheless, there are several logical reasons for assuming some maturational effects on prospective recall. Firstly, the children’s manipulations were weaker than the adolescents’ and adults’, yet the effects on the children’s prospective remembering were strong. Specifically, the children’s letter strings were shorter than the other groups’, but rather than this give them an advantage over the older groups, the children showed poorer responding to prospective cues than either the adolescents or adults. Further, the children not only had poorer prospective remembering in the low- and high-demand conditions, they also had greater proportional reductions in performance from low to high despite there only being one letter’s difference in the two levels for the children, and a 2- or 3-letter difference for the adolescents and adults. Secondly, the adolescents performed as well as the adults on the high-demand version, despite the adolescents appearing to find the task slightly more difficult than did the adults (as indicated by the adolescents’ lower lexical-decision accuracy rates than the adults’). Thirdly, the child-adolescent differences in prospective remembering concur with findings by others. In particular, Ceci and Bronfenbrenner (1985) found that overall, 14-year-olds were better than 10-year-olds at checking on cakes baking in an oven. Similarly, Kerns (2000) found that 12-year-olds (i.e., at or
near puberty) remembered better than younger children to refuel their cars. Fourth, there were no age adjustments on the standardised tests of executive functions, yet there were consistently poorer results among the children than among the adolescents or adults on both the SOPT and the TOL.

Assuming the task adjustments were accurate, the child-adolescent differences in prospective remembering suggest more than normal developmental effects were at work. After all, in the current study there was a third group, young adults, and, the adolescents performed at the same level as those young adults, yet the adolescent-adult age differences were similar to the child-adolescent age differences. Therefore, it appears to be more than just being older and more experienced that is making the difference. Perhaps there are specific maturational processes that explain the significant differences in prospective remembering between the children and adolescents, which at the same time account for there being no significant differences between the adolescents and adults. And, it is reasonable to assume, if Lehr (1990), Marlowe (2000), and Yakovlev and Lecours (1967) are correct in stating that the prefrontal region of the brain reaches a peak of maturity around puberty, that it is prefrontal maturity in particular that accounts for the child-adolescent differences, and adolescent-adult similarities in prospective remembering.

Fourth, scores on the prospective memory questionnaire were consistent across the three age groups and did not predict performance on the computerised prospective tasks. The lack of age effects and of a relationship between the self- or parent-report and the quantitative measure of prospective memory could be explained by the psychometric properties of one or both of the measures. For example, the
questionnaire was developed originally for adults and its reliability may not be as
good when used to measure children’s performance. In fact, one or two parents of
younger children commented to the researcher when filling out the questionnaire that
their children were “pretty good for their age”. When they were asked, “but, how do
they compare with you, another adult, or their older siblings”, the parents would
usually reconsider and downgrade their responses to reflect a higher rate of forgetting.
The tendency to make allowances for younger children may have occurred more often
than observed and this could have been because parents were aware that the same
questions were later being asked of parents of children with TBI, and the parents of
uninjured children wanted to be certain their children did not appear to have any
memory deficits.

Fifth, although performance on the manual, reading-based prospective tasks
reflected the performance on the computerised tasks in terms of showing significant
age effects, performance on the reading tasks did not predict performance on the
computerised tasks. The lack of a significant relationship between the two
prospective tasks could be due to differences in task designs. Specifically, in the
computer version, the computer determined the presentation speed. In the reading
version, the individuals' reading rates determined the presentation speed. Further, on
the computer task the prospective cues, although all italic letters, were different
letters. On the reading task, the prospective cues were identical. Moreover, on the
computer task the cues were hidden most of the time and only appeared on the screen
momentarily. However, in the reading version, the cues were visible on each page at
all times. From observation, highly competent readers "read ahead" and had time to
see and process the cues. And, less competent readers frequently hesitated slightly before reading words, including the target words, which again gave them extra time to process the cues. Given that participants appeared to have greater control over the execution of the prospective component in the reading than in the computer tasks, this may mean they had greater freedom in allocating their cognitive resources in the reading than in the computer tasks.

Sixth, there were significant relationships between executive functions (i.e., working memory and focused attention) and highly resource-demanding prospective memory. These relationships have been found by others, for example Kerns (2000) in normally developing children; Maujean et al. (2003) in adults with TBI; and Shallice and Burgess (1991b) in adults with prefrontal lesions. Taken together, these results give additional weight to the prefrontal-lobe model of prospective memory because executive functions appear also to be mediated by the prefrontal cortex (Ewing-Cobbs, Levin, & Fletcher, 1998; Fletcher, Ewing-Cobbs, Miner, Levin, & Eisenberg, 1990).

Two further points regarding the prospective-memory, executive-functions relationships are important to note. Firstly, the fact that relationships were found between the high-demand prospective tasks and executive-functions tests, but not between the low-demand and executive-functions tests, suggests that the high-load activity was calling on prefrontal resources more than the low-load activity. This conclusion coincides with the physiological evidence obtained by Gevins and colleagues (1998), that as cognitive load increases, electrical activity in the prefrontal cortex increases. Secondly, relationships were found between the high-demand tasks
and two executive-functions tasks (viz., SOPT & Stroop), but not the third (viz., TOL). This finding is not surprising given that: (a) the range of skills referred to collectively as executive functions is broad (Ewing-Cobbs et al., 1998), and therefore, no two tests of executive functions may measure identical constructs; and, (b) although relationships have been indicated between executive functions tests and prospective memory tests, so far, it is unclear what the precise processes are that account for the commonality. For instance, while Cohen and O’Reilly (1996) suggested some equipotentiality in prefrontal regions with respect to inhibition control, working memory and prospective recall, Shallice (1996) suggested the opposite, that different prefrontal regions mediate inhibition, working memory and prospective recall. Interestingly, both may be correct, that while there are prefrontal subsystems responsible for specific processes, complex cognitive tasks such as the realisation of intentions may call on subsystems to integrate their functions, and it might be different subsystems called upon for different prospective tasks. In the case of the current computerised task, where participants did not initiate the intentions, planning skills, such as those measured by the TOL, were probably not required to the extent they are in self-initiated intentions. By contrast, holding the intention in mind, monitoring for the prospective cues, and having to switch attention from the ongoing to the prospective tasks, clearly required working memory capacity and focused attention such as are required to effectively execute the SOPT and Stroop respectively. Refined experimental designs, lesion studies and those involving functional imaging will no doubt improve the understanding of the apparently related processes of executive functions and prospective memory.
Seventh, the current study found that it made no difference to prospective remembering whether the importance of remembering was stressed or not. By contrast, Kvavilashvili (1998) and Kliegel and associates (2001) found that when participants were encouraged to direct their cognitive resources specifically towards executing the prospective component of a task, they remembered better than when not directed to do so. One explanation for the lack of importance effects here may be that many participants believed the lexical-decision task was the most important, despite being told that it was the prospective component that was most important. This skepticism may have been due to the instructions participants received during the recruiting process. As part of the cover story, to disguise the intention to measure prospective memory, participants were told that the study sought to measure aspects of concentration and reading ability. Possibly, in attempting to conceal the true intention, the reading aspect was inadvertently over-emphasised. A second explanation for the lack of an importance effect may be attributable to the experimental design. Because importance was a between-subjects manipulation, there may have been insufficient power to detect its influence on prospective-memory functioning.

Eighth, in terms of the thought processes involved in remembering the prospective cues, overall, most participants reported remembering only when they saw the cues, though almost half the adolescents reported keeping the intention in mind and looking out for them. Interestingly, keeping the intention active could conceivably reflect greater potential for prospective remembering, as the adolescents performed better than the children, who did not report looking out for the cues nearly
as often. However, the adolescents' strategies did not improve their remembering over the young adults’, who also did not report looking out for the cues as often. Furthermore, keeping the “to do” task in conscious awareness does not always result in acting on the intention at the right time. For instance, despite rehearsing over and over, “turn on the radio at 7.30 to hear an interview”, if just before 7.30 you become distracted by other events, the intention to act may be forgotten long enough for you to miss the interview. Nevertheless, despite some inconsistencies in the success of the remembering strategies, further investigation of the thought processes involved in prospective memory is warranted. For instance, a closer examination of the thought processes involved during performance in low- and high-demand conditions may help confirm whether Einstein and McDaniel’s (1996) belief is true that rehearsal of the cues is dependent on how able subjects are to look out for them, which in turn varies with cognitive load.

Overall, the current study has been more systematic, and has clarified some of the ambiguities that previously existed in research on the development of prospective memory. Specifically, this study has shown that it is not cognitive maturity per se that contributes to improvements in prospective remembering, but possibly to a particular type of cognitive maturity, that of the prefrontal lobes. In isolating the relationship between prospective memory and prefrontal capacity, the findings of this study have also contributed further to the understanding of the theory of prospective memory. For example, it is now clear that cognitive demand is an important variable in prospective remembering and that it is as important in children as it is in adults. In fact, the amount of cognitive demand required by a task may not only affect the
amount of resources left over to execute a second task, but may also affect the amount
of rehearsal time available to process prospective cues. Further, there are mental
processes associated with executive functions that overlap with prospective memory,
and these processes may vary with the type of prospective task. Note that there are
other contributions that this study has made to the understanding of prospective
memory, but given that Studies 2 and 3 add weight to these contributions, they are
discussed more fully in subsequent chapters including Chapter 6, the General
Discussion.

Study 1 also had limitations. First, as previously noted, despite the indications
of a strong age effect, this effect was subject to the accuracy of the task adjustment
made for the children. Second, as described previously, there were shortcomings
associated with the importance manipulation, such that the general task instructions
probably undermined the effectiveness of the manipulations, and the between-subjects
design limited the power. Third, the tasks, conducted in a laboratory-type setting may
not tell us a great deal about how prospective memory functions in the real world,
where as noted in Chapter 2, prospective tasks vary considerably. Therefore, as
follow ups, it is recommended that identical ongoing tasks be given to all age groups,
possibly using visuo-spatial stimuli. Or, to verify the argument that the same does not
necessarily mean equal, different age-based tasks may be used again, but next time be
cross validated more explicitly by using data not only on lexical-decision accuracy,
but also on reaction-time, self-ratings, and possibly functional imaging. Further, it is
suggested that importance be reexamined as a within-subjects variable.
Of greatest importance to the current program of research, however, is to follow up further on the prefrontal model of prospective memory by assessing children and adolescents with TBI on tasks similar to the ones employed in this study. Given that insult to the prefrontal region of the brain is common after TBI (Adams et al., 1980; Holbourn, 1943; Levin et al., 1991), it would be informative to compare those injured with those not injured. Even more clarity might be obtained if among adolescents with TBI, those injured prior to the onset of puberty could be compared with those injured after the onset of puberty. In fact, Study 2, which is described in the next chapter, compares the performances of the non-injured child and adolescent cohorts tested in the current study with age-matched cohorts with TBI. And as a means of assessing the ecological validity of the experimental paradigms in measuring prospective-memory performance, Study 3, which is described in Chapter 5, examines the effects of paediatric TBI on prospective remembering in natural, everyday settings.
CHAPTER FOUR

Study 2: Prospective Memory in Children and Adolescents with TBI

To date, very little is known about the effects of paediatric TBI on prospective memory, with only one study (McCauley & Levin, 2004) focusing directly on this type of memory reported in the literature so far. In attempting to redress this shortcoming, and to further test the prefrontal-lobe model of prospective memory, Study 2 assessed children and adolescents with TBI on prospective-memory and executive-function tasks. The same cognitive-demand manipulations: low and high, as were used in Study 1 were applied in the current study. However, unlike Study 1, the current study did not involve the importance manipulation. This exclusion occurred because there were no significant importance effects found in the non-injured sample, possibly due to insufficient power. Given that the sample with TBI in Study 2 was smaller, the power to detect any importance effects would be even less.

Study 1 found significantly better prospective remembering in adolescents than in younger children, and increases in the age differences as the cognitive demand of the ongoing task increased. These findings concurred with evidence that prefrontal maturity reaches a peak around puberty (Lehr, 1990; Marlowe, 2000; Yakovlev & Lecours, 1967), and that prefrontal capacity decreases with increases in cognitive load (Gevins et al., 1998). Evidence also indicates that the prefrontal cortex is particularly vulnerable to injury with TBI (Adams et al., 1980; Holbourn, 1943; Levin et al., 1991), which is borne out by evidence of impaired prospective memory in adults with moderate to severe TBI (e.g., Maujean et al., 2003; Shum, Valentine & Cutmore,
1999), and children with severe TBI (McCauley & Levin, 2004). There is also evidence of significant positive correlations between executive functions, known to be mediated by the prefrontal cortex, and prospective memory from Study 2 and others (e.g., Kerns, 2000; Maujean et al.).

Based on this combined evidence, Study 2 hypothesised that on prospective-memory tasks, children and adolescents with TBI would remember to respond to fewer prospective cues overall than those without injuries. However, given the role of the prefrontal lobes in prospective memory, and that these regions mature at puberty, it was hypothesised that adolescents with TBI would show greater prospective memory impairments than non-injured adolescents, but that children with TBI would not be worse than non-injured children. Further, it was hypothesized that as the cognitive demand of the ongoing task increased, performances of the injured groups would decrease more than those in the control groups, and that the effects of demand would be greater between the two adolescent groups than between the two children’s groups. In addition, it was hypothesized that those with TBI would perform significantly worse on executive function tests (e.g., SOPT, Stroop, & TOL) than the non-injured groups, and that group differences would be particularly evident among the adolescents, but less evident among the children. Finally, it was hypothesised that performance on the executive function tests would predict performance on the high-demand prospective memory task.

Note that comparisons with non-injured young adults were not made in Study 2. Eighteen- to 21-year-olds were included in Study 1 purely as a means of demonstrating that the development of prospective memory follows an upward
trajectory to a peak in adolescence, then flattens between adolescence and early adulthood.

Method

Participants

Thirty-four children and adolescents with TBI were recruited from the brain injury rehabilitation centres at the Royal Children's and Mater Misericordiae Children's Hospitals, Brisbane, Australia. Participants who met the inclusion criteria were identified from a review of the rehabilitation centres' consecutive admissions. Consent was solicited by phone or mail by hospital staff. Approximately 60% of those contacted - mainly parents, as the majority of children and adolescents were under 18-years-of-age - consented in writing to take part in the study.

Inclusion criteria of the study were that the young people:

(a) had suffered a moderate to severe TBI (as inferred from a GCS score of 12 or less, or by medical diagnosis) - note that 3 participants with mild to moderate TBI were included because they were reported to be experiencing ongoing cognitive difficulties
(b) were able to read, at least at an average level for their age
(c) had resolved PTA at least 6 months prior to testing
(d) had no severe perceptual, motor, language, behavioural or communication problems that would prevent them from doing the experimental tasks.

Table 11 shows details of the children’s and adolescents’ brain injuries.

All participants with TBI attended government or private schools full time, with the exception of two, one who lived on a farm and studied by correspondence, and the other who had left school and worked full time. Table 12 shows how the TBI sample compared with the children and adolescents assessed in Study 1 (controls) on gender, age and estimated IQ, which was assessed using the WASI (The
Table 11

*Nature of Injuries of Children and Adolescents with TBI*

<table>
<thead>
<tr>
<th>Patient #</th>
<th>Sex</th>
<th>Age at testing (years)</th>
<th>Age at injury (years)</th>
<th>Interval between injury and testing (months)</th>
<th>Nature of injury</th>
<th>Severity</th>
<th>GCS on admission</th>
<th>Length of Time in hospital (weeks)</th>
<th>Neurological case notes, CT and/or MRI findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>13</td>
<td>11</td>
<td>28</td>
<td>MVA (pedestrian)</td>
<td>Severe</td>
<td>4</td>
<td>22</td>
<td>Contusions in R temporal &amp; frontal lobes; Diffuse axonal injury; Fractured L mandible at temporo-mandibular joint; Fractured floor L middle cranial fossa</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>19</td>
<td>8</td>
<td>132</td>
<td>MVA (bicycle)</td>
<td>Severe</td>
<td>3</td>
<td>10</td>
<td>R occipital fracture; R occipital haematoma; L parietotemporal subdural haematoma with some midline shift to R; Posterior fossa oedema &amp; severe generalised Cerebral swelling</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>11</td>
<td>10</td>
<td>14</td>
<td>MVA</td>
<td>Severe</td>
<td>3</td>
<td>9</td>
<td>Multiple cerebral contusions (frontal &amp; L anterior temporal lobe); Subarachnoid haemorrhage; Increased intracerebral pressure; Diffuse axonal injury; Multiple facial fractures</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>16</td>
<td>13</td>
<td>35</td>
<td>Motorbike</td>
<td>Severe</td>
<td>7</td>
<td>11</td>
<td>Diffuse axonal injury &amp; small petechial haemorrhages; Small haemorrhagic contusions in R basal ganglia, internal capsule &amp; lentiform nucleus</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>13</td>
<td>12</td>
<td>14</td>
<td>MVA</td>
<td>Severe</td>
<td>4</td>
<td>6</td>
<td>L temporal lobe fractures; L temporo-parietal extradural haematoma; Fractured L orbital wall &amp; nose; Generalised seizures</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>16</td>
<td>15</td>
<td>20</td>
<td>Thrown from horse</td>
<td>Severe</td>
<td>4</td>
<td>5</td>
<td>Frontal lobe and R putamen haemorrhages; Diffuse axonal injury; Fracture of R C2 lamina</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>11</td>
<td>8</td>
<td>40</td>
<td>MVA (scooter)</td>
<td>Severe</td>
<td>4</td>
<td>4</td>
<td>R temporo-parietal fracture with subdural haematoma; R parietal-occipital infarct; Cerebral oedema &amp; midline shift</td>
</tr>
</tbody>
</table>
Table 11 continued

<table>
<thead>
<tr>
<th>Patient #</th>
<th>Sex</th>
<th>Age at testing (years)</th>
<th>Age at injury (years)</th>
<th>Interval between injury and testing (months)</th>
<th>Nature of injury</th>
<th>Severity</th>
<th>GCS on admission</th>
<th>Length of Time in hospital (weeks)</th>
<th>Neurological case notes, CT and/or MRI findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>M</td>
<td>9</td>
<td>6</td>
<td>40</td>
<td>MVA (pedestrian)</td>
<td>Severe</td>
<td>5 - 6 PTA = 21 days</td>
<td>5</td>
<td>L frontal contusion; L naso-ethmoid fracture; Undisplaced skull fracture (L frontal bone); Small amt. parenchymal haemorrhage; No cerebral oedema</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>11</td>
<td>10</td>
<td>18</td>
<td>MVA (pedestrian)</td>
<td>Severe</td>
<td>7 PTA = 56 days</td>
<td>9</td>
<td>Diffuse axonal injury with bifrontal and L temporal contusions</td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>13</td>
<td>5</td>
<td>102</td>
<td>MVA</td>
<td>Severe</td>
<td>4 - 5</td>
<td>2</td>
<td>Depressed frontal skull fracture extending into R orbit &amp; ethmoid region; Subgaleal Haematoma; L occipital fracture</td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>13</td>
<td>11</td>
<td>24</td>
<td>MVA</td>
<td>Severe</td>
<td>7 PTA = 40 days</td>
<td>5</td>
<td>L occipital and R frontal (contracoup) contusion; Basal skull fracture; Orbital floor fracture Bilateral peri-orbital haematoma</td>
</tr>
<tr>
<td>12</td>
<td>F</td>
<td>14</td>
<td>13</td>
<td>20</td>
<td>Fall from horse</td>
<td>Severe</td>
<td>8 PTA = 15 days</td>
<td>5</td>
<td>R frontal haemorrhage; R posterior horn intraventricular haemorrhage Bifrontal loss of grey/white matter differentiation</td>
</tr>
<tr>
<td>13</td>
<td>M</td>
<td>10</td>
<td>9</td>
<td>16</td>
<td>Ran into industrial sprinkler</td>
<td>Severe</td>
<td>6 - 7 PTA = 9 days</td>
<td>2</td>
<td>Frontal &amp; parietal fractures; Coup &amp; contracoup midbrain shear injuries Widespread changes in cerebrum, R cerebellum &amp; midbrain</td>
</tr>
<tr>
<td>14</td>
<td>F</td>
<td>8</td>
<td>6</td>
<td>25</td>
<td>MVA (pedestrian)</td>
<td>Severe</td>
<td>8</td>
<td>2</td>
<td>Multiple facial fractures in anterior, lateral &amp; medial maxillary sinus walls bilaterally; Comminuted displaced fracture of nasal bones extending into frontal bone</td>
</tr>
<tr>
<td>15</td>
<td>M</td>
<td>15</td>
<td>4</td>
<td>133</td>
<td>Fall (5 m)</td>
<td>Severe</td>
<td>N/I*</td>
<td>3</td>
<td>Swollen R cerebral hemisphere with 5 mm subdural haematoma extending over R cerebral hemisphere &amp; into interhemispheric sulcus Diffuse axonal injury</td>
</tr>
<tr>
<td>Patient #</td>
<td>Sex</td>
<td>Age at testing (years)</td>
<td>Age at injury (years)</td>
<td>Interval between injury and testing (months)</td>
<td>Nature of injury</td>
<td>Severity</td>
<td>GCS on admission</td>
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</tr>
<tr>
<td>-----------</td>
<td>-----</td>
<td>------------------------</td>
<td>-----------------------</td>
<td>---------------------------------------------</td>
<td>-----------------</td>
<td>----------</td>
<td>-----------------</td>
<td>-----------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>16</td>
<td>M</td>
<td>13</td>
<td>3</td>
<td>117</td>
<td>MVA (pedestrian)</td>
<td>Severe</td>
<td>6</td>
<td>2</td>
<td>N/I*</td>
</tr>
<tr>
<td>17</td>
<td>F</td>
<td>14</td>
<td>7</td>
<td>85</td>
<td>MVA</td>
<td>Severe</td>
<td>8</td>
<td>2</td>
<td>L subdural haematoma; Generalised cerebral Swelling; 3 cm laceration of L scalp; Seizure activity</td>
</tr>
<tr>
<td>18</td>
<td>M</td>
<td>13</td>
<td>5</td>
<td>96</td>
<td>MVA</td>
<td>Severe</td>
<td>8</td>
<td>2</td>
<td>Small L subdural haemorrhage; R frontal parenchymal haemorrhage; Small subarachnoid haematoma; Frontal contusion; Seizure activity; Depressed skull fracture of L temporo-parietal bone</td>
</tr>
<tr>
<td>19</td>
<td>M</td>
<td>9</td>
<td>1</td>
<td>85</td>
<td>MVA</td>
<td>Severe</td>
<td>8</td>
<td>2</td>
<td>L base of skull fracture extending into petrous bone with blood in L middle ear &amp; sinuses Diffuse axonal injury</td>
</tr>
<tr>
<td>20</td>
<td>M</td>
<td>14</td>
<td>13</td>
<td>15</td>
<td>MVA (bicycle)</td>
<td>Severe</td>
<td>8</td>
<td>3</td>
<td>Bilateral thalamic haematomas; L internal capsule haemorrhage</td>
</tr>
<tr>
<td>21</td>
<td>F</td>
<td>8</td>
<td>4</td>
<td>46</td>
<td>MVA (pedestrian)</td>
<td>Severe</td>
<td>8</td>
<td>1</td>
<td>Fracture of vertex of skull; Generalised cerebral oedema with marked reduction of lateral &amp; 3rd ventricles</td>
</tr>
<tr>
<td>22</td>
<td>M</td>
<td>13</td>
<td>5</td>
<td>94</td>
<td>MVA</td>
<td>Moderate</td>
<td>11</td>
<td>2</td>
<td>Comminuted depressed fractures to frontal bone involving both orbital plates Small area superficial haemorrhage &amp; contusion to R frontal bone; Bilateral periorbital haematomas</td>
</tr>
<tr>
<td>23</td>
<td>M</td>
<td>11</td>
<td>6</td>
<td>61</td>
<td>MVA</td>
<td>Moderate</td>
<td>10</td>
<td>&lt;1</td>
<td>Brief loss of consciousness; Extradural haematoma in R middle cranial fossa; Moderately severe concussive brain injury</td>
</tr>
<tr>
<td>24</td>
<td>F</td>
<td>9</td>
<td>2</td>
<td>85</td>
<td>Fall down stairs</td>
<td>Moderate</td>
<td>10</td>
<td>1</td>
<td>L frontal contusion with L frontal bone fracture extending into ethmoid air cells Tonic-clonic seizures</td>
</tr>
</tbody>
</table>
Table 11 continued

<table>
<thead>
<tr>
<th>Patient #</th>
<th>Sex</th>
<th>Age at testing (years)</th>
<th>Age at injury (years)</th>
<th>Interval between injury and testing (months)</th>
<th>Nature of injury</th>
<th>Severity</th>
<th>GCS on admission</th>
<th>Length of Time in hospital (weeks)</th>
<th>Neurological case notes, CT and/or MRI findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>M</td>
<td>11</td>
<td>2</td>
<td>106</td>
<td>Fall (4 m)</td>
<td>Moderate</td>
<td>N/I*</td>
<td>1</td>
<td>Depressed L periotal skull fracture and fracture of L petrous temporal bone; R side focal seizure</td>
</tr>
<tr>
<td>26</td>
<td>M</td>
<td>10</td>
<td>4</td>
<td>72</td>
<td>Fall off bunk bed</td>
<td>Moderate</td>
<td>N/I*</td>
<td>1</td>
<td>Displaced fracture of R temporo-parietal skull; No loss of consciousness</td>
</tr>
<tr>
<td>27</td>
<td>M</td>
<td>17</td>
<td>14</td>
<td>31</td>
<td>MVA (pedestrian)</td>
<td>Moderate</td>
<td>13 - 14 PTA = 4 days</td>
<td>1</td>
<td>R frontal bone fracture; R fronto-temporal subdural haematoma; 6 mm midline shift at level of 3rd ventricle</td>
</tr>
<tr>
<td>28</td>
<td>F</td>
<td>7</td>
<td>2</td>
<td>61</td>
<td>Fall from swing</td>
<td>Moderate</td>
<td>15</td>
<td>3</td>
<td>L parietal fracture and subdural haematoma; Seizure activity; Moderate head injury</td>
</tr>
<tr>
<td>29</td>
<td>M</td>
<td>7</td>
<td>2</td>
<td>64</td>
<td>Fall from kitchen bench</td>
<td>Moderate</td>
<td>N/I*</td>
<td>N/I*</td>
<td>R &amp; L frontal contusions with some oedema; L parietal skull fracture; No loss of consciousness</td>
</tr>
<tr>
<td>30</td>
<td>F</td>
<td>8</td>
<td>4</td>
<td>9</td>
<td>Kicked by horse</td>
<td>Moderate</td>
<td>14</td>
<td>&lt; 1</td>
<td>No loss of consciousness at time of injury but level of consciousness deteriorated and proceeded to generalised tonic-clonic seizure Depressed R frontal skull fracture; Small extradural haemorrhage</td>
</tr>
<tr>
<td>31</td>
<td>M</td>
<td>13</td>
<td>8</td>
<td>107</td>
<td>Struck by motorbike at race track</td>
<td>Moderate</td>
<td>N/I* PTA = 24 h</td>
<td>&lt; 1</td>
<td>Loss of consciousness ~ 30 min; Depressed fracture R temporal bone; Extradural haemorrhage</td>
</tr>
<tr>
<td>32</td>
<td>M</td>
<td>12</td>
<td>7</td>
<td>64</td>
<td>Fall (2 m)</td>
<td>Mild/Moderate</td>
<td>12</td>
<td>&lt; 1</td>
<td>Large R temporo-parietal contusion with mild Oedema; Loss of consciousness ~ 30 s; Nil fractures; Nil mass effect</td>
</tr>
<tr>
<td>33</td>
<td>M</td>
<td>9</td>
<td>4</td>
<td>54</td>
<td>MVA (bicycle)</td>
<td>Mild/Moderate</td>
<td>N/I*</td>
<td>N/I*</td>
<td>Loss of consciousness &lt; 5 m; Scalp lacerations; Admitted to ICU (3 days) but not ventilated (discharge records Wellington Hospital, NZ)</td>
</tr>
<tr>
<td>34</td>
<td>M</td>
<td>14</td>
<td>8</td>
<td>77</td>
<td>Kicked in head (school-ground fight)</td>
<td>Mild/Moderate</td>
<td>N/I*</td>
<td>&lt; 1</td>
<td>Length of LOC** unknown; When found severely concussed Mild oedema; No focal neurological abnormalities</td>
</tr>
</tbody>
</table>

*N/I = Not indicated, or notes missing from file; ** LOC = Loss of consciousness
Psychological Corporation, 1999). Note that while in Study 1, the children and adolescent age groups were predetermined at 7 to 10 years and 13 to 16 years respectively, in Study 2, the child-adolescent distinction was more arbitrary because the TBI population is restricted in number. For the current purposes those aged 7 to 11 years comprised the child subgroup, and those aged 12 to 19 years comprised the adolescent subgroup.

Independent-groups t tests showed there were no significant differences in ages between the children with TBI and the non-injured children, $t(44) = 1.40, p > .05$, nor between the adolescents with TBI and the non-injured adolescents, $t(44) = 0.78, p > .05$.

Table 12

Gender, Mean Ages, and Estimated IQs (and Standard Deviations) by Subgroup

<table>
<thead>
<tr>
<th>Group</th>
<th>Controls</th>
<th>TBI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Children</td>
<td>Adolescents</td>
</tr>
<tr>
<td>n</td>
<td>30</td>
<td>28</td>
</tr>
<tr>
<td>Females</td>
<td>17</td>
<td>12</td>
</tr>
<tr>
<td>Males</td>
<td>13</td>
<td>16</td>
</tr>
<tr>
<td>Age Range</td>
<td>7 – 10 yrs</td>
<td>13 – 16 yrs</td>
</tr>
<tr>
<td>Mean Age (SD)</td>
<td>8.57 (1.17)</td>
<td>14.57 (1.29)</td>
</tr>
<tr>
<td>Estimated IQ (SD)</td>
<td>114.80 (9.55)</td>
<td>111.82 (10.84)</td>
</tr>
</tbody>
</table>
Overall, the groups were also matched on education, socio-economic backgrounds (i.e., lower-middle, and upper-working classes), geographical locations (i.e., outer suburban, regional and rural areas), and race (i.e., Anglo, European, or Asian descent). However, it is apparent from Table 12 that taken as a whole, those in the control groups, had similar numbers of males and females, while the TBI groups had more than a 2:1 ratio of males to females, which reflects the worldwide trend for males to be over-represented in TBI statistics (Goldstein & Levin, 1987; Kraus, 1995). Also, a one-way ANOVA showed significant differences in estimated IQ among the subgroups, $F(3, 88) = 5.77, p < .01$. Planned comparisons showed that estimated IQs were not significantly different between the non-injured and injured children, $t(88) = 0.91, p > .05$, but were significantly different between the non-injured and injured adolescents, $t(88) = 3.03, p < .01$.

**Design**

The main part of the study comprised a mixed-factorial, 2 x 2 x 2 design, with Demand (low and high) of the ongoing task a within-subjects variable, and Group (control and TBI), and Age (children and adolescents) between-subjects variables. The total number of responses to prospective cues was the dependent measure.

**Materials and Tasks**

The tasks used in the current study were the same as those used in the previous developmental study with two exceptions. First, as noted, the Importance (stressed and unstressed) variable in the prospective-memory manipulation was excluded. Second, an additional executive-function test, namely, the Wisconsin Card Sorting Test (WCST, Berg, 1948; Grant & Berg, 1948) was included. The WCST was
included as a means of isolating further, if possible, cognitive elements that prospective memory and executive processing have in common.

**Wisconsin Card Sorting Test (WCST)**

The WCST was originally developed to assess abstract reasoning ability and the ability to shift cognitive strategies in response to changing circumstances (Berg, 1948; Grant & Berg, 1948). As such, the WCST is generally considered a test of executive functions, in particular, the functions of developing a problem-solving strategy and adapting the strategy in the face of changing contingencies in order to achieve a future goal (Luria, 1973; Shallice, 1982). The current study employed the Computer Version - 2: Research Edition (Heaton, 1993).

The test consists of 128 cards, presented one at a time on the computer screen. The cards vary in colour, form and number. Four key cards remain permanently at the top of the screen and examinees are asked to match the 128 cards as they appear with one of the four key cards. Examinees are not told which aspect of the stimulus cards to match when sorting but are given feedback, "Right" or "Wrong" by the computer following the placement of each card. The first criterion is colour and after ten correct matches this criterion changes to form without the knowledge of the respondents. Then, after ten correct form matches, the criterion changes to number before reverting to colour, form, and number again. Testing terminates after the achievement of all six categories or after the placement of all 128 cards. The most widely used scores are for Categories Achieved, Perseverative Responses, and Perseverative Errors (Lezak, Howieson, & Loring, 2004). For this study the percentage of perseverative errors was used as the dependent measure because it is
understood to be best for detecting difficulties in conceptual flexibility (Lezak, et al.), which is a cognitive skill similar to that required in switching attention from an ongoing to a prospective task on the appearance of a prospective cue.

In terms of reliability, true scores were estimated by assessing 46 normally-developing children and adolescents twice, one month apart. Results showed average generalisability coefficients of .57, demonstrating moderate reliability overall (Heaton, Chelune, Talley, Kay, & Curtiss, 1993). In terms of validity, the WCST perseverative score was found to load on the same factor as Piagetian formal operations (Shute & Huertas, 1990). Further, the WCST has been widely used in clinical and research contexts and has been found to be sensitive to a wide range of brain impairments including, Parkinson's Disease (Beatty & Monson, 1990), Korsakoff's Syndrome (Janowsky, Shimamura, Kritchevsky, & Squire, 1989), and seizure disorders (Hermann, Wyler, & Richey, 1988). Of particular note, the WCST generally (though not always, Lezak, et al., 2004) has been found to be sensitive to disorders involving the prefrontal cortex. For instance, the WCST has distinguished patients with lesions in the dorsolateral region of the prefrontal cortex and those with lesions in various other cortical regions (Milner, 1963). Further, when performing the WCST, greater regional cerebral blood flow was evident in prefrontal regions in controls than in unmedicated patients with chronic schizophrenia (Weinberger, Berman, & Zec, 1986). Similar findings have been noted in children. For example, the WCST was found to distinguish between children in control groups and those with various focal prefrontal lesions (Heaton, et al.), and in those with attention deficit disorders (e.g., Benson, 1991).
**Procedure**

All assessments were conducted in quiet locations in the participants' homes. Given that processing speed is often slower after a brain injury, the participants were given additional time to practice the lexical-decision tasks if required. Additionally, because those with TBI sometimes tire more readily than others, they were given longer rest breaks between assessment tasks as required. The order of testing was the same as that used in Study 1, namely, that half of the participants performed the low-demand, computerised task first, then the SOPT, WASI, manual reading task with comprehension questions, Stroop, TOL, the high-demand task, and finally the WCST. The other half performed the high-demand task first and the low-demand later. Parents answered the questionnaires while their children completed the assessments, and the one subject aged over 18 years completed the questionnaire after he had completed the other tasks. To ensure respondents had understood and remembered instructions on the computerised tasks, they were asked to restate the instructions. And, to understand their thought processes regarding the prospective cues, participants were asked the same questions as were asked in Study 1, that is, whether they looked out for the cues all the time, or only remembered the cues when they saw them.

**Results**

*Data Screening and Statistical Analyses*

There were no outliers and corrections for non-normal distributions were not calculated as the TBI sample was relatively small and it was decided not to trim the data but to rely on the robustness of the ANOVA test (Howell, 1999). And, although
significant differences were found in estimated IQ between the adolescents with TBI and their non-injured age peers, there were no significant correlations between estimated IQ and key dependent measures in ANOVA tests. Therefore estimated IQ was not used as a covariate. The accepted alpha level was $p < .05$ for all analyses.

**Manipulation Checks**

*Remembering What to Do*

Despite relatively high levels of forgetting on the prospective-memory tasks by some of the participants with TBI, without exception, all were able to restate with 100% accuracy what they had to do if letter strings represented words or non-words, and if they saw an italic letter. And, note that no respondents had perfect responding to prospective cues. However, three adolescent respondents were so consistently poor, despite managing the ongoing task very well and having plenty of time to respond to the prospective cues, that these individuals were given an additional manipulation check. Specifically, to eliminate the possibility of an unreported visual problem, after completing both versions of the computerised task, they were retested on 1 block of the high-demand condition and asked to indicate orally when they saw an italic letter. With reminding of what they had to do, each scored 4 out of 4 on this task.

*How Participants Remembered to Respond to the Prospective-Memory Cues*

Table 13 shows the frequencies of remembering strategies used by the children and adolescents with TBI. It can be seen that most children and adolescents reported only thinking of the cues when they saw them appear. However, some did report looking out for the cues. Despite this, it can be seen from the results of the ANOVA
later that this strategy was not very successful in helping to remember the prospective cues.

Comprehension of Reading-Based, Manual Tasks

Most TBI participants scored 100% on the reading comprehension questions. Some made one or two errors. However, all comprehended well enough to indicate engagement in the reading process.

Table 13

TBI Group Frequencies of Remembering Strategies

<table>
<thead>
<tr>
<th>Strategy Used</th>
<th>Group Frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remembered only when saw the cues</td>
<td>Children 56.2%</td>
</tr>
<tr>
<td>Thought about all the time/Looked out for the cues</td>
<td>37.5%</td>
</tr>
<tr>
<td>Remembered only when saw the cues at the start, but with the reminders, began</td>
<td>0.0%</td>
</tr>
<tr>
<td>to think about all the time and looked out for the cues</td>
<td></td>
</tr>
</tbody>
</table>

Accuracy of Lexical-Decision Making

To check whether the cognitive demands were similar across the ages and injury status (with TBI or without), group comparisons were made on lexical-decision accuracies. Table 14 shows mean lexical decision accuracies and standard deviations as a function of Demand, Age and Injury. A 2 x 2 x 2 mixed-factorial ANOVA showed that there was a main effect for Demand, $F(1, 88) = 71.57, p < .001$,
indicating that overall, lexical-decision accuracies were better in the low- than in the high-demand conditions. However, there was no significant Demand x Injury interaction, $F(1, 88) = 1.85, p > .05$, no Demand x Age interaction, $F(1, 88) = 0.96, p > .05$, and no Demand x Injury x Age interaction, $F(1, 88) = 2.59, p > .05$.

Table 14

Mean Percentage of Lexical-Decision Accuracy (and Standard Deviations) as a Function of Demand, Age and Injury Status

<table>
<thead>
<tr>
<th>Demand</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Children</td>
<td>91.67%</td>
<td>3.30%</td>
</tr>
<tr>
<td>Adol.</td>
<td>95.00%</td>
<td>2.89%</td>
</tr>
</tbody>
</table>

Further, there was no main effect for Age, $F(1, 88) = 2.71, p > .05$, and no main effect for Injury, $F(1, 88) = 0.004, p > .05$. Group reductions in accuracy from low- to high-demand conditions were, non-injured children 5.93% ($SE = 0.96$), children with TBI 2.56% ($SE = 1.38$), non-injured adolescents 5.21% ($SE = 1.01$), and adolescents with TBI 5.50% ($SE = 1.15$). Results of a one-way ANOVA showed that there were no significant differences in accuracy reductions among the four groups, $F(3, 88) = 1.53, p > .05$. Taken together, these results show that overall, individuals found the high-demand condition harder than the low-demand condition. But, there were no differences between groups within conditions, suggesting that the cognitive demands were similar across groups.
**Dual-Task Prospective-Memory Tasks**

**Computerised Task**

Table 15 shows the mean number of prospective cues remembered and standard deviations for the TBI and control groups, and the two different age groups: children and adolescents in both the low- and high-demand conditions. It can be seen that overall, participants responded to more prospective cues in the low-demand than in the high-demand conditions; that those in the TBI group responded to fewer cues than those in the control group; and that children responded to fewer cues than adolescents. The results of a 2 x 2 x 2 mixed-factorial ANOVA showed a main effect of Demand, $F(1, 88) = 77.72, p < .001$, indicating that overall participants performed significantly better in the low- than high-demand conditions. There was also a main effect of Injury, $F(1, 88) = 12.88, p < .01$, indicating that overall those in the TBI

Table 15

**Mean Number (and Standard Deviations) of Prospective-Memory Cues Responded to as a Function of Demand, Age and Injury Status**

<table>
<thead>
<tr>
<th>Demand</th>
<th>Control</th>
<th>TBI</th>
<th>Control</th>
<th>TBI</th>
<th>Control</th>
<th>TBI</th>
<th>Control</th>
<th>TBI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Children</td>
<td>8.00</td>
<td>2.46</td>
<td>6.81</td>
<td>1.94</td>
<td>5.43</td>
<td>2.54</td>
<td>5.26</td>
<td>2.52</td>
</tr>
<tr>
<td>Adolescents</td>
<td>10.46</td>
<td>1.20</td>
<td>8.39</td>
<td>2.62</td>
<td>8.82</td>
<td>2.29</td>
<td>6.11</td>
<td>3.10</td>
</tr>
</tbody>
</table>
groups remembered significantly fewer prospective cues than controls. Further, there was a main effect of Age, $F(1, 88) = 22.77$, $p < .001$, indicating that overall the children remembered significantly fewer prospective cues than the adolescents. There was no Demand x Age interaction, $F(1, 88) = .30$, $p > .05$; no Injury x Age interaction, $F(1, 88) = 2.96$, $p > .05$; and no three-way, Demand x Injury x Age interaction, $F(1, 86) = 1.96$, $p > .05$. Because there was a main effect for Injury, with those with TBI having lower overall prospective-memory scores than those in the control groups, it is likely that the TBI groups began from a lower baseline (i.e., had lower scores in the low-demand condition) than the controls. As stated in Study 1, if baselines were different, interactions between Demand and Injury should not be reported because the interactions would not account for relative group differences (Snodgrass, 1989) between the two demand conditions. It was therefore important to test whether there were group differences in baselines, and if differences were found, to estimate proportional declines in performance from the low- to high-demand conditions across the two groups.

The TBI groups’ baseline scores ($M = 7.65; SD = 2.42$) were lower than the controls’ ($M = 9.19; SD = 2.31$). An independent-groups $t$ test showed that the TBI groups’ baselines were indeed significantly lower than the control groups’, $t(90) = 3.04$, $p < .01$. As a follow up, proportional differences between low- and high-demand performances between groups were estimated using the following formula (Russo et al., 1995; Shum, Jamieson, Bahr & Wallace, 1999; Snodgrass, 1989; Stuss et al., 2001):

$$\left\{\frac{(\text{low-demand score} - \text{high-demand score})}{\text{low-demand score}}\right\} \times 100$$
Mean proportional-reduction scores and standard errors for each of the four subgroups are shown in Table 16. Results of planned comparisons showed that the proportional reductions from low to high were not significantly different for the two younger groups, $t(88) = -.70, p > .05$. However, the proportional reductions from low to high were significantly greater in adolescents with TBI than they were in non-injured adolescents, $t(88) = 1.73, p < .05$ (one-tailed).

Table 16

*Mean Proportional-Reduction Scores (and Standard Errors) from Low- to High-Demand Conditions as a Function of Subgroup*

<table>
<thead>
<tr>
<th>Group</th>
<th>Control</th>
<th>TBI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SE</td>
</tr>
<tr>
<td>Children</td>
<td>30.91%</td>
<td>5.52%</td>
</tr>
<tr>
<td>Adolescents</td>
<td>15.90%</td>
<td>3.57%</td>
</tr>
</tbody>
</table>

Manual task

The mean number of correct word substitutions during reading and standard deviations by subgroup were: non-injured children ($M = 9.58, SD = 3.24$); children with TBI ($M = 10.94, SD = 1.42$); non-injured adolescents ($M = 13.09, SD = 0.83$); and adolescents with TBI ($M = 11.61, SD = 1.61$). The means indicate that the children with TBI were substituting more than their non-injured age peers, and that the adolescents with TBI were substituting less than their non-injured age peers.

Results of planned comparisons showed that the children with TBI remembered to
substitute the target words significantly more than the children in the control group, \( t (88) = 2.06, p < .05 \). However, the reverse was the case with adolescents, where those with TBI remembered to substitute the targets words significantly less than did the non-injured adolescents, \( t (88) = -2.30, p < .05 \).

**Prospective Memory Questionnaire**

The mean total, everyday forgetting scores reported on the questionnaire for subgroups, and standard deviations were: non-injured children \((M = 21.13, SD = 5.55)\); children with TBI \((M = 26.06, SD = 7.17)\); non-injured adolescents \((M = 22.43, SD = 4.43)\); and adolescents with TBI \((M = 34.17, SD = 11.77)\). The means indicated that in general those with TBI were reported to be more forgetful on prospective intentions than those without TBI, and that this was particularly the case with adolescents with TBI. Results of planned comparisons showed that the children with TBI were reported to forget significantly more in everyday contexts than their non-injured age peers, \( t (88) = 2.22, p < .05 \). Similarly, adolescents with TBI were reported to forget significantly more in everyday contexts than their non-injured age peers, \( t (88) = 5.41, p < .001 \).

**Executive Function Tests**

**SOPT**

The mean number of pointing errors and standard deviations for the non-injured children, children with TBI, non-injured adolescents, and adolescents with TBI are shown in Table 17. It can be seen that the mean number of errors was similar between the two younger groups, but greater in the adolescents with TBI than non-
injured adolescents. The results of planned comparisons showed that the children with TBI were not significantly worse than the non-injured children on this measure of visual working memory, \( t(88) = -0.30, p > .05 \). However, the adolescents with TBI were significantly worse than the non-injured adolescents on visual working memory, \( t(88) = 2.39, p < .05 \).

Table 17

Mean Scores (and Standard Deviations) on Tests of Executive Function as a Function of Age and Injury Status

<table>
<thead>
<tr>
<th>Executive Function Test</th>
<th>Age</th>
<th>SOPT</th>
<th>Stroop</th>
<th>TOL</th>
<th>WCST (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Children</td>
<td>Con.</td>
<td>TBI</td>
<td>Con.</td>
<td>TBI</td>
</tr>
<tr>
<td></td>
<td>Age</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adol.</td>
<td>4.86 (3.12)</td>
<td>7.67 (3.24)</td>
<td>5.68 (6.84)</td>
<td>1.33 (7.20)</td>
<td>22.93 (3.16)</td>
</tr>
</tbody>
</table>

* N/A = Non applicable

Stroop

Table 17 shows that mean interference scores were similar between the two groups of children, but better in non-injured than in injured adolescents. The results of planned comparisons showed that there were indeed no significant differences between the two groups of children on the Stroop interference, \( t(88) = 0.01, p > .05 \). However, adolescents with TBI had significantly poorer interference scores than their non-injured age peers, \( t(88) = -2.31, p < .05 \).
Table 17 shows that both children’s and adolescents’ groups had similar planning scores on the TOL. Results of planned comparisons showed that there were no significant differences in total planning scores between the two children’s groups, $t(88) = 0.96, p > .05$, nor the two adolescent’s groups, $t(88) = -1.01, p > .05$.

To check whether the groups differed on other aspects of planning, analyses were run on the scores on the 5 easiest and 5 hardest problems, and on the number of problems solved on the first attempt. The results were no different from those using total scores.

**WCST**

Because the control groups were not administered the WCST, comparisons could only be made between the two TBI groups. Mean percentage of perseverative errors and standard deviations for the two TBI groups are shown in Table 17. An independent-groups t-test showed that there were no significant differences between the two injured subgroups in terms of percentage of perseverative errors, $t(32) = -0.27, p > .05$. To check whether the groups differed on other aspects of WCST performance, analyses were also run on the number of categories completed and on the total number of perseverative responses. The results were no different from those on the percentage of perseverative errors.

*Relationships between Executive Function Tests and Computerised Prospective Memory Tasks for the Two TBI Groups*

To examine the relationship between performance on the computerised prospective-memory tasks and the four components of executive functions in the TBI
groups, two hierarchical multiple regressions were conducted. The dependent variables were the low- and high-demand scores on the prospective-memory tasks, and the independent variables were estimated IQ, group (dummy coded), and the four executive-function measures (SOPT, Stroop, TOL and WCST). To evaluate the unique contribution of the measures of executive function, IQ was entered into the regression equations first, followed by group.

Table 18 summarises the results of the hierarchical regression of the measures of executive function on the low-demand task. After step 1, with IQ in the equation, $R^2 = 0.03, F(1, 32) = 0.84, p > .05$. Group was added to the equation in step 2. After this step, $R^2 = 0.24, F(2, 31) = 4.78, p < .05$, and $R^2$ change = 0.21, $F$ for change (1, 31) = 8.51, $p < .01$. The scores on the measures of executive function were added to the equation in step 3. After this step, $R^2 = 0.30, F(6, 27) = 1.95, p > .05$. The $R^2$ change for the last step was 0.07 and was not statistically significant, $F$ for change (4, 27) = 0.65, $p > .05$.

Table 19 summarises the results of the hierarchical regression of the scores on the measures of executive function on the high-demand level for the TBI groups. After step 1 with estimated IQ in the equation, $R^2 = 0.11, F(1, 32) = 4.12, p < .05$. Group was added to the equation in step 2. After this step, $R^2 = 0.29, F(2, 31) = 6.20, p < .01$, and $R^2$ change = 0.17, $F$ for change (1, 31) = 7.46, $p < .05$. The measures of executive function were added to the equation in step 3. After this step, $R^2 = 0.43, F(6, 27) = 3.45, p < .05$. The $R^2$ change for the last step was 0.15, $F$ for change (4, 27) = 1.77, $p > .05$. From Table 19 it can be seen that the TOL was a significant predictor of the high-demand score in those with TBI, $\beta = -.38, p < .05$. 
Table 18

*Hierarchical Multiple Regression of Measures of Executive Function on Low-Demand Prospective Memory Measure*

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>Low-Demand</th>
<th>IQ</th>
<th>Group</th>
<th>SOPT</th>
<th>Stroop</th>
<th>TOL</th>
<th>WCST</th>
<th>B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IQ</td>
<td>.16</td>
<td>.47</td>
<td>.25</td>
<td>.10</td>
<td>.18</td>
<td>.10</td>
<td>.20</td>
<td>.04</td>
<td>.16</td>
</tr>
<tr>
<td>2</td>
<td>Group</td>
<td>-.33</td>
<td>.47</td>
<td>-.23</td>
<td>-.11</td>
<td>-.11</td>
<td>.10</td>
<td>.14</td>
<td>-2.48</td>
<td>-.52*</td>
</tr>
<tr>
<td>3</td>
<td>SOPT</td>
<td>-.13</td>
<td>-.23</td>
<td>.25</td>
<td>.10</td>
<td>.18</td>
<td>.11</td>
<td>.22</td>
<td>.03</td>
<td>.05</td>
</tr>
<tr>
<td></td>
<td>Stroop</td>
<td>-.11</td>
<td>.20</td>
<td>.14</td>
<td>-.22</td>
<td>.15</td>
<td>-1.13</td>
<td>-1.6</td>
<td>-.03</td>
<td>-.08</td>
</tr>
<tr>
<td></td>
<td>TOL</td>
<td>.10</td>
<td>.21</td>
<td>-.31</td>
<td>-.22</td>
<td>.15</td>
<td>-1.13</td>
<td>-.16</td>
<td>-.03</td>
<td>-.08</td>
</tr>
<tr>
<td></td>
<td>WCST</td>
<td>.18</td>
<td>-.11</td>
<td>-.05</td>
<td>.37</td>
<td>-.19</td>
<td>-.14</td>
<td>.07</td>
<td>.07</td>
<td>.15</td>
</tr>
</tbody>
</table>

Mean: 7.65, 107.03, .47, 8.56, 2.20, 21.09, 11.88
SD: 2.42, 10.27, .51, 3.87, 6.82, 2.96, 5.34

R = .55, $R^2 = .30$

* $p < .01$
Table 19

*Hierarchical Multiple Regression of Measures of Executive Function on High-Demand Prospective Memory Measure*

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>High-Demand IQ</th>
<th>Group</th>
<th>SOPT</th>
<th>Stroop</th>
<th>TOL</th>
<th>WCST</th>
<th>B</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IQ</td>
<td>.34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>.09</td>
<td>.34*</td>
</tr>
<tr>
<td>2</td>
<td>Group</td>
<td>-.21</td>
<td>.47</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-2.65</td>
<td>-.47*</td>
</tr>
<tr>
<td>3</td>
<td>SOPT</td>
<td>-.31</td>
<td>.23</td>
<td>.25</td>
<td></td>
<td></td>
<td></td>
<td>-.14</td>
<td>-.19</td>
</tr>
<tr>
<td></td>
<td>Stroop</td>
<td>.17</td>
<td>.20</td>
<td>.14</td>
<td>-.11</td>
<td></td>
<td></td>
<td>-.04</td>
<td>.10</td>
</tr>
<tr>
<td></td>
<td>TOL</td>
<td>.52</td>
<td>.21</td>
<td>-.31</td>
<td>-.22</td>
<td>.15</td>
<td></td>
<td>.36</td>
<td>.38*</td>
</tr>
<tr>
<td></td>
<td>WCST</td>
<td>.07</td>
<td>-.11</td>
<td>-.05</td>
<td>.37</td>
<td>-.19</td>
<td>-.14</td>
<td>.13</td>
<td>.24</td>
</tr>
</tbody>
</table>

Mean: 5.56, 107.03, .47, 8.56, 2.20, 21.09, 11.88
SD: (2.86), (10.27), (.51), (3.87), (6.82), (2.96), (5.26)

R = .66, R² = .43

*p < .05;  † p = .051*
Discussion

The aim of the current study was to examine the effects of paediatric TBI on prospective memory, and to be guided by the prefrontal-lobe model. Children aged 7 to 11 years, and adolescents aged 12 to 19 years were compared with aged-matched controls - the children and adolescents from Study 1 - on computerised prospective-memory tasks. The ongoing components of the main prospective tasks varied in the degree of cognitive demand required in their execution. In addition, those in the TBI groups were compared with their non-injured peers on standardised measures of executive function, on a reading-based prospective task, and a self-report measure of everyday prospective memory. Further, performance on the tests of executive function were used to predict performance on the computer-based prospective-memory task.

Note that all respondents remembered the instructions, even those with the poorest response rates to the prospective cues. In addition, the poorest responders were shown not to have missed the cues because of visual difficulties. This point is followed up on later in the Discussion. Further, the manipulation check on the accuracies of lexical-decision making as a function of demand, injury and age indicated that: (a) the cognitive demand manipulation was effective, and (b) that the different length letter strings appeared to produce the same demands across the injury and age groups. These suggest that the task adjustment for children was justified.

As hypothesised, the children and adolescents with TBI, on the whole, were found not to perform as well on the computerised prospective-memory tasks as the children and adolescents in the control group. And, overall, there was an age effect
such that the adolescents performed better than the children, but there was no
interaction between age and injury status, suggesting that in general it made no
difference to prospective recall whether those with TBI were under or over the age of
puberty. However, in general, it was found that prospective recall was poorer when
the cognitive demand of the ongoing task was greater. And, as noted from the
proportional-reduction scores, the effect of the cognitive demand was significantly
greater in adolescents with TBI than in the non-injured adolescents, but there were no
significant differences between the children with TBI and the non-injured children.

Possibly because of a lack of sensitivity of the task, on the manual-based
reading task, the children with TBI remembered to substitute the target words
significantly better than the non-injured children. However, the reverse was the case
with adolescents. The non-injured adolescents remembered to substitute more target
words than the adolescents with TBI. In terms of everyday prospective forgetting, as
reflected by the total scores on the questionnaire, there were significant effects of
injury. Both the children and adolescents with TBI were reported by their parents to
forget more future intentions than was reported by the parents of the non-injured
children and adolescents.

With respect to executive functioning, the children with TBI performed as
well as their non-injured peers on visual working memory as measured by the SOPT.
However, adolescents with TBI performed significantly more poorly on the SOPT
than their non-injured counterparts. A similar pattern was found with the Stroop.
There were no significant differences between the two groups of children in terms of
focused attention, but the adolescents with TBI had significantly poorer interference
scores than adolescents in the control group. Planning scores, as measured by the TOL, failed to show any differences at all between those with TBI and those without, whatever their ages. And, on the WCST, which was only performed by the TBI groups, there were no differences in percentage of perseverative errors between those in the pre-puberty and post-puberty age groups.

In those with TBI, it was found that performance on the TOL was a significant predictor of performance in the high-demand condition, but not in the low-demand condition of the computer task. Other measures of executive function (viz., SOPT, Stroop, and WCST), however, did not predict performance in either condition of the computer task.

Several conclusions can be drawn from the results of this study. First, paediatric TBI appears to adversely affect prospective remembering, and concurs with McCauley and Levin’s (2004) results, which found that children and adolescents with severe TBI, treated as a single group, remembered significantly fewer prospective cues than those with mild TBI or severe orthopaedic injuries. Evidence from studies of adults with TBI also provides support. For example, Maujean and colleagues’ (2003), and Shum, Valentine, and Cutmore (1999), found that young adults with TBI remembered fewer prospective intentions than their age-matched peers. These findings are not surprising given the degree of damage to the frontal regions that occurs with TBI (Adams et al., 1980; Holbourne, 1943; Levin et al., 1991). In the current sample (see Table 11, Nature of Injuries), 16 out of 34 (i.e., 47%) had primary injuries in frontal regions, with three others noted to have subcortical damage with diffuse axonal injury that may possibly have extended into prefrontal regions.
Second, in line with findings in adults with TBI (Maujean et al., 2003), in normal children when ongoing tasks were interrupted (Kvavilashvili et al., 2001), and in ageing adults (Kidder et al., 1997), increases in the cognitive demand of the ongoing task caused decreases in prospective remembering. Evidence for the effects of cognitive demand on prospective remembering was also found in the developmental study (Study 1). Taken together, these findings support the idea that the cognitive resources required in prospective remembering are limited in capacity, and when the bulk of those resources is directed towards an ongoing activity, fewer are available to execute the prospective task.

Third, the effect of the cognitive demand was more apparent in the adolescents with TBI than in non-injured adolescents, but not more apparent in children with TBI than in non-injured children. If it is true that the prefrontal regions are the anatomical substrates of prospective memory and that these regions reach a peak of maturity around puberty, then the particular vulnerability of adolescents with TBI to prospective-memory impairments is not surprising. The logic suggests that normally developing pre-pubescent children without full prefrontal connectivity, would not be able to plan and executive complex future intentions as well as those with complete connectivity. This expectation was realised in Study 1 where the children’s prospective memory was poorer than the adolescents’, but the adolescents’ was on a par with the young adults’. Therefore, on the same tasks involving the same anatomical regions, children with TBI may not manifest any abnormalities compared with controls. In contrast, adolescents, in whom prefrontal connectivity has been disrupted by brain injury would be expected to show impairments compared with
controls. And, perhaps the degree of impairment might be greater in those adolescents injured before puberty (and prefrontal maturity), than in those injured after the onset of puberty. Unfortunately, pre- and post-puberty comparisons were not made in the current study because there were insufficient adolescents available with a “post-puberty” injury. And, further, it would be informative to reassess the younger children in the current sample after they reached adolescence to see if they “grew into” prospective-memory problems. Growing into cognitive difficulties with maturity is frequently reported in the paediatric TBI literature especially in children with prefrontal damage (e.g., Ylvisaker, 1998; Anderson et al., 2000).

Fourth, three of the adolescents were observed to make accurate lexical decisions in a time-efficient manner on the ongoing task, but to fail consistently to respond to prospective cues. On checking, it was confirmed that they could: (a) remember what to do, and (b) see the cues. The behaviour of these respondents reflected a problem described by Cockburn (1996), who noticed that some patients with prefrontal lesions were aware of what they had to do but were unable to translate that awareness into action. For example, they might say, “I am going to put this chocolate away until tea time”, and as they were saying it, unwrap the chocolate and eat it immediately.

Fifth, as expected, the reading-based prospective task produced the same general pattern of results within the adolescent groups as did the computerised prospective task, in that non-injured adolescents remembered to substitute significantly more words than adolescents with TBI. However, the children’s results were unanticipated. Rather than there being similar performances between the two
groups, those with TBI outperformed the controls. As indicated in the Discussion section of Study 1, the reading task was less able to be controlled than the computer task and therefore may have been more vulnerable to variabilities in reading abilities. However, given the apparent greater vulnerability of adolescents with TBI to injury effects on ‘prefrontal-type processes’, it is likely that the reading task was sensitive to these injury effects in the older age group.

Sixth, in Study 1, the questionnaire did not discriminate between the normally developing groups. It was therefore concluded that the instrument may not be sensitive to age effects in children. However, Study 2 found the questionnaire to be sensitive to brain-injury effects. A revised conclusion may be, therefore, that the questionnaire is sensitive in distinguishing prospective-memory capacity in those with and without TBI, as was found by Roche and associates (2002), but not sensitive in distinguishing minor variations that occur within groups with normal, age-appropriate prospective memory. Also, in Study 1, parents of the non-injured individuals were aware that those with TBI would also be assessed, and may therefore have overstated their children’s prospective memory capacity to reassure the examiner (or themselves) of their children’s “normality”.

Seventh, the SOPT and Stroop revealed similar patterns to the proportional declines from low- to high-demand conditions on the prospective task. Specifically, they indicated diminished performances in adolescents with TBI compared to the other adolescents, but similar performances in the two groups of children. These patterns give further support to the prefrontal model. Note, however, unlike the case with the non-injured groups, the SOPT and Stroop did not predict performance on the
computer tasks in those with TBI. This may reflect heterogeneity within the TBI subgroups.

Eighth, the TOL produced the opposite effects to the SOPT and Stroop. It failed to distinguish the TBI groups from the control groups, yet was a significant predictor of performance on the high-demand version of the prospective-memory task in those with TBI. Considered together, it is clear that though there is a relationship between executive functions and prospective memory, this relationship is tenuous and complex. On the one hand, in normally developing young individuals, aspects of working memory, as estimated by the SOPT, and focused attention, as estimated by the Stroop, were associated with prospective memory. On the other hand, in children and adolescents with TBI, planning ability, as estimated by the TOL, was associated with prospective memory. Given that those with TBI were poorer on the prospective tasks than the controls, it may mean that working memory and focused attention are more related to effective prospective remembering than are planning skills. Support for this conclusion may lie in the self-reports by adolescents of their thinking processes on the computerised task, where approximately 50% of those without injuries, but fewer, approximately 40%, of those with TBI, reported looking out for the prospective cues. This may mean that the non-injured adolescents were more attentive, and kept the intention to respond activated more in working memory.

Finally, the WCST, in failing to distinguish the children and adolescents with TBI, suggests once more that maturity did not confer an advantage on the adolescents with TBI. By contrast, this maturity advantage was evident for the non-injured adolescents on the other executive-function tests. Similarly, in other studies (e.g.,
Chelune & Thompson, 1987; Paniak, Miller, Murphy, & Patterson, 1996), the WCST itself has been shown to discriminate between normally developing children and adolescents. In terms of WCST-prospective-memory relationships, in the current study the WCST did not predict prospective-memory performance. This tends to indicate that cognitive flexibility, as indicated by the number of perseverative errors, was not associated with prospective remembering in the TBI groups. Of course, more would have been revealed about overall trends in WCST performance and relationships to prospective memory had the control groups also performed this task.

In general, the current study provided additional evidence that TBI affects prospective memory in children. And, in showing that adolescents with TBI performed worse than non-injured adolescents, but that children with TBI were no worse than non-injured children, the study provided additional support for the prefrontal hypothesis. Further, clues were provided about some of the cognitive processes involved in prospective remembering by comparing it with executive functions in brain-injured, and non-brain-injured children and adolescents.

However, the study had limitations. First, the TBI sample was smaller than the control sample. Similarly, there were fewer adolescents with TBI who were injured during or after the onset of puberty than injured at earlier ages. Consequently, the prefrontal model was not tested as stringently as possible. Also, the reading-based prospective task, despite discriminating well between the injured and non-injured adolescents, was probably not as sensitive to age or injury effects as other tasks because it may have been confounded by the effects of variations in reading speed. And, the WCST was not performed by the non-injured groups.
As follow-ups it is recommended that adolescents injured during childhood be compared with age-, gender-, and injury-matched adolescents injured during or after the onset of puberty. Similarly, the prefrontal model of prospective memory would be tested more precisely if young people with TBI were compared more precisely according to injury sites. Alternatively, functional neuroimaging (e.g., fMRI or PET scans) might be used in children to identify brain regions involved during the execution of prospective-memory tasks. Further, it would be informative to reassess, after they reach adolescence, the children with TBI from the current study. Of greater immediate interest, however, is to find out more about the effects of TBI on prospective memory in the real world. Certainly, the computerised experimental tests revealed impairments among those with TBI. And, this was supported by the parents’ reports of greater prospective forgetting among the children and adolescents with TBI than among the controls, which in turn was supported by Roche et al.’s (2002) findings that families of young adults with TBI rated the young adults’ everyday prospective forgetting as worse than did families of age-matched controls.

However, the real test of how sensitive the tests and questionnaires are to injury effects is to go into the field and find out as much as possible about how children and adolescents with TBI are coping with the memory demands of everyday life. The best way to make such an enquiry is to use a qualitative approach (Silver, 2000). Described in Chapter 5, which follows, is an outline of Study 3 that investigated the real-world experiences of young people with TBI in terms of memory functioning. An interview-based, phenomenological methodology was used to conduct this investigation.
CHAPTER FIVE

Study 3: Interview study of the effects of paediatric TBI on memory

As stated in Chapters 1 and 2, to date, most research on the effects of paediatric TBI on memory has assessed explicit memory (e.g., Jaffe et al., 1992; Yeates et al., 1995), the retrospective memory subtype requiring conscious awareness of past learning experiences. However, none of this research looked at explicit memory functioning in everyday contexts. And again, as reported earlier, only two known studies (i.e., Shum et al., 1999; and Ward et al., 2002) have investigated implicit memory, which requires no conscious awareness, in children with TBI. Further, apart from the study by McCauley and Levin (2004) and Study 2 reported in this thesis, no others exist on the effects of paediatric TBI on prospective memory. Moreover, in general, all memory research involving children with TBI has been conducted in university laboratories, or under controlled experimental conditions. None, or very few studies, has investigated how well or how poorly children remember in real-world contexts.

The present study aimed to compare the everyday experience of children with TBI on the three main memory types discussed in Chapter 2, namely, explicit and implicit (retrograde), and prospective memory. In particular, Study 3 sought to:

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(a) gain deeper insights into the nature and extent of memory deficits in paediatric TBI, and to ascertain the effects of deficits on everyday life; (b) discover whether families use their own interventions; and (c) determine the efficacy of these interventions in alleviating disability.

It was believed that deeper insights would be gained by going into the field and using a phenomenological approach for several reasons. First, the results of experimental tasks and standardised tests mainly show whether participants succeed or fail to meet particular behavioural criteria. They do not indicate the meanings of these behaviours in terms of how they affect children's functioning in everyday life. For instance, a quantitative measurement of memory that indicates a memory deficit does not necessarily show whether that impairment translates into a disability or handicap in the real world (Ewing-Cobbs, Levin, & Fletcher, 1998). Nor do quantitative data collected over one or two sessions provide a dimensional perspective on how memory functioning might vary from circumstance to circumstance, or from day to day (Silver, 2000). Further, there is evidence that laboratory studies of young children's memory can underestimate their capacities. For example, Baker-Ward, Orstein, and Gordon (1993) reported in a study of normal memory development, that preschoolers' recall of toy objects during laboratory testing was poor. However, after testing, the children were able to list in correct order the names of all the other children who were to appear in the testing room. This information was acquired incidentally and spontaneously. By contrast, Ewing-Cobbs and colleagues stated that the results of standardised memory tests may overestimate the abilities of children with TBI. Overestimation of day-to-day abilities could occur because most
commercially available standardised tests of memory assess discrete functions, and children are generally assessed in a one-on-one situation. However, it is much more likely that deficits will be apparent in real life because those situations require more focused and divided attention, the generalisation of previously learned information, and retention of information over longer periods of time.

Second, as previously stated, most data on the effects of paediatric TBI on memory have been derived from studies of explicit memory, with little exploration of how paediatric TBI affects implicit or prospective memory. Consequently, the knowledge base is limited. To widen the knowledge base on the effects of TBI on children's memory functioning, a broad-brush approach was adopted in this study. Qualitative methodologies are the best means of gaining a broad view because a diverse range of issues can be explored at one time (Berg, 2001).

Third, in Study 2 parents reported in the questionnaire that their children with TBI had higher rates of prospective forgetting than parents of non-injured children the same ages had reported in Study 1. While these reports of relative impairment in children with TBI correspond with findings from the adult TBI literature (e.g., Roche et al., 2002), and are interesting, the reports explain very little about the precise nature of the forgetting or the circumstances in which it occurs. A good way to explore these issues in greater depth is to speak at greater length about them to parents. Face-to-face interviewing was considered the best means of doing this, because, although the data could have been obtained by more elaborate questionnaires, the information received is always constrained by the content of the questions asked (Cockburn, 1996). The content of the questions, in turn, is constrained by the existing knowledge
base, which is limited in this instance. As a valid alternative, parents were asked open-ended questions designed to elicit detailed information about: whether or not their children have memory failures; the most common types of memory failures; and the circumstances under which forgetting occurs.

Parents, rather than their children, were interviewed because parents were regarded as more reliable judges. Clearly, if the children’s memories are poor or if they lack insight into their actions, they may fail to acknowledge lapses made and may report their memories to be better than they actually are (Cockburn, 1996). Lack of awareness of the effects of injury has been reported in several studies of children with TBI (see for example Jacobs, 1993; and Lazar, 1997). Further, children with TBI could suffer language impairments or have insufficiently developed language skills to express themselves adequately.

Method

Participants

Thirteen custodial parents of children and adolescents with TBI took part in face-to-face interviews. These parents were not involved in Study 2. Eleven were mothers, and two were fathers. Participants were recruited through the paediatric brain injury rehabilitation clinics at the Royal Children's and Mater Misericordiae Children's Hospitals, Brisbane, Australia. Lists of consecutive admissions of children and adolescents with TBI were compiled. Hospital staff phoned parents who lived within 2 hours' drive of Brisbane in order from these lists. When 13 agreed to be interviewed, information sheets and consent forms were posted to them.
The sample of 13 parents was deemed to be both manageable in number, given the large volume of data gathered in interviews, and adequate in representation, given that the children were reported by hospital staff to be a relatively heterogeneous group in terms of current age, age at injury, and the site and severity of injury. Note that after interviewing parents, the principal researcher consulted the children's medical records to categorize them into one of three severity groups: mild, moderate, or severe. The categories were based on specific references to the severity of the injuries noted on medical charts. If, however, no specific severity diagnoses were noted on the charts, the injuries were categorised according to severity criteria listed in Table 1 on Page 7, with Fletcher and colleagues’ (1990) stipulation that those with GCSs of 13 be classified as moderate if the injury was complicated by skull fracture. Table 20 shows details of the young people's injuries, plus other demographics.

All of the families were Anglo-Australian, lived in outer suburban, regional, or rural areas, and belonged to either the upper-working, or lower-middle classes. At the time of the study, all of the children were at school. Nine were at government-funded public schools, three at privately-funded church schools, and one was being schooled at home by correspondence.

**Design and Procedure**

Prior to the interviews, most parents (except 4, whose children had been participants in an earlier, unrelated research project) were unknown to the principal researcher.
Table 20
Injuries of Children and Adolescents whose Parents were Interviewed, N = 13

<table>
<thead>
<tr>
<th>Patient Number</th>
<th>Gender</th>
<th>Age (years)</th>
<th>Age at injury (years)</th>
<th>Interval between injury &amp; interview (months)</th>
<th>Nature of injury</th>
<th>Severity</th>
<th>GCS score on admission</th>
<th>Length of time in hospital (weeks)</th>
<th>Neurological Case Notes, CT and/or MRI findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>14</td>
<td>6</td>
<td>101</td>
<td>Pedestrian-vehicle accident</td>
<td>Severe</td>
<td>4-5</td>
<td>17</td>
<td>Intracerebral haematomas incl. thalamic region Effacement of 3rd &amp; 4th ventricles Midline shift to L, Pituitary fossa fracture R parietal depressed fracture</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>16</td>
<td>8</td>
<td>82</td>
<td>Pedestrian-vehicle accident</td>
<td>Severe</td>
<td>3-4</td>
<td>12</td>
<td>L parieto-temporal haematoma Midline shift to R R occipital skull fracture, Posterior fossa oedema Severe generalized cerebral swelling Some effacement of 4th ventricle</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>14</td>
<td>12</td>
<td>22</td>
<td>Motorbike accident (farm)</td>
<td>Severe</td>
<td>7</td>
<td>4</td>
<td>Small focal areas of abnormal, increased signal in antero-medial aspect of R temporal lobe &amp; inferior R frontal lobe; Findings consistent with multiple, small focal areas of infarction related to shearing injury (MRI)</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>12</td>
<td>8</td>
<td>48</td>
<td>Trail bike accident</td>
<td>Severe</td>
<td>N/I*</td>
<td>8</td>
<td>Severe injury Cerebral oedema with compression of R lateral ventricle (CT) Small bilateral frontal haematomas Shearing of R basal ganglia (MRI)</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>9</td>
<td>6</td>
<td>47</td>
<td>Pedestrian-vehicle accident</td>
<td>Severe</td>
<td>7</td>
<td>2</td>
<td>Contusion of L fronto-parietal region Some petechiae in frontal &amp; temporal lobes</td>
</tr>
<tr>
<td>6</td>
<td>M</td>
<td>13</td>
<td>8</td>
<td>62</td>
<td>Pedestrian-vehicle accident</td>
<td>Severe</td>
<td>6</td>
<td>3</td>
<td>Bifrontal petechial haemorrhages @ boundary gray/white matter Cerebral oedema &amp; contusion R fronto-parietal regions</td>
</tr>
<tr>
<td>Patient Number</td>
<td>Gender</td>
<td>Age (years)</td>
<td>Age at injury (years)</td>
<td>Interval between injury and interview (months)</td>
<td>Nature of injury</td>
<td>Injury Severity</td>
<td>GCS score on admission</td>
<td>Length of time in hospital (weeks)</td>
<td>Neurological case notes, CT and/or MRI findings</td>
</tr>
<tr>
<td>----------------</td>
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<td>-----------------------------------------------</td>
<td>-----------------</td>
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<td>-----------------------------------------------</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>13</td>
<td>4</td>
<td>105</td>
<td>Fall from the back of an open truck</td>
<td>Severe</td>
<td>N/I*</td>
<td>2</td>
<td>Swollen R temporo-frontal cerebral hemisphere; Cerebral oedema with subdural haematoma in R cerebral hemisphere &amp; interhemispheric Sulcus; Diffuse axonal injury</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>10</td>
<td>9</td>
<td>17</td>
<td>Passenger, Motor Vehicle accident</td>
<td>Moderate</td>
<td>13</td>
<td>2</td>
<td>Compound fracture L frontal &amp; temporal bone; Some bone fragments depressed, &lt; 5 mm; Intracerebral &amp; subarachnoid blood with contused brain underlying fracture</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>10</td>
<td>7</td>
<td>33</td>
<td>Fall from motorbike (in driveway)</td>
<td>Moderate</td>
<td>15</td>
<td>2</td>
<td>Linear fracture in R temporal bone; No intracranial pathology</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>9</td>
<td>8</td>
<td>15</td>
<td>Fall (4 m)</td>
<td>Moderate</td>
<td>13</td>
<td>2</td>
<td>Complex fracture R orbit (eye region) of skull; R extradural haematoma in fronto-parietal region</td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>12</td>
<td>8</td>
<td>52</td>
<td>Assault</td>
<td>Mild</td>
<td>N/I*</td>
<td>Nil</td>
<td>Brief (unspecified) LOC Temporal lump; Mild oedema, but no focal neurological abnormalities</td>
</tr>
<tr>
<td>12</td>
<td>M</td>
<td>14</td>
<td>2</td>
<td>156</td>
<td>Pedestrian-vehicle accident</td>
<td>Mild</td>
<td>N/I*</td>
<td>&lt; 1</td>
<td>Found unconscious (LOC&lt;sup&gt;†&lt;/sup&gt; = 2 min approx.), but conscious on admission; Occipital lump, Apnaeic swelling; No focal neurological signs within 48 hrs. observation</td>
</tr>
<tr>
<td>13</td>
<td>M</td>
<td>14</td>
<td>8</td>
<td>74</td>
<td>Bicycle-vehicle accident</td>
<td>Mild</td>
<td>N/I*</td>
<td>2</td>
<td>Brief (unspecified) LOC&lt;sup&gt;‡&lt;/sup&gt; at accident site</td>
</tr>
</tbody>
</table>

Note: * N/I = Not indicated; † LOC = Loss of consciousness
Further, it was decided not to consult the children's medical charts until after the interviews. Having limited background knowledge was deemed to be helpful in minimising interview bias, and therefore, maximising the validity of the data.

After rapport building, to obtain some background and establish a context, parents were asked about their children's pre-injury developmental history, and circumstances surrounding the injuries (e.g., how, where and when the injuries occurred). There were no pre-determined questions. Parents were free to "tell their stories" in their own way. However, after a period of listening by the interviewer, the "conversation" was moved towards the topic of memory functioning by asking parents open-ended, critical-incident questions, such as: "Tell me about a recent situation when your child forgot something that affected him significantly, or had consequences for you or others.". Follow-up questions were unstructured. The questions needed to be spontaneous to respond appropriately to what parents were saying. For instance, the questions might have been: "How often does that happen?, or "How does that compare with your other children's behaviour?". Six of the 13 parents (parents of Patients 1, 3, 7, 8, 11 & 12 noted on Table 20) interviewed were well prepared for the sessions. They had observed their children's memory functioning closely over the preceding days or weeks, taken copious notes, and in one instance, asked the child's teacher for information as well. These six parents provided completely unsolicited data on most topics. However, to ensure all three memory categories (viz., explicit, implicit, and prospective) were explored, and to assist less well-prepared parents who reported memory failure by their children, but were unable to think of examples, "forgetting" cards were given to all parents. These cards were
provided mainly as memory cues, to help parents recall their own children's instances of forgetting. Twenty-one cards comprising seven examples each of memory failures in the three domains of memory of interest were shuffled so that parents viewed them in random order. Examples of statements illustrative of explicit, prospective, and implicit forgetting were respectively:

"Forgets where he puts things, or loses things frequently"

"Forgets to take one-off items to school (e.g., permission slips)"

"Forgets learned patterns or sequences (e.g., a route to a familiar place)"

See Table 21 for a full list of illustrative examples noted on the cards.

All parents, including those who had been well prepared, looked at all cards. Prepared parents followed the following procedure: (1) read the cards one by one, setting aside any instances of forgetting or remembering they had previously described; (2) sorted the remaining cards into two categories: forgets and does not forget; (3) re-read the cards in the forgets category; and (4) either used the examples of forgetting noted on the cards as cues to trigger their own examples of forgetting, or indicated, "yes, that's an example of something my child forgets"; and (5) elaborated on the instances of forgetting (e.g., frequency and circumstances). Non-prepared parents followed the same procedure, excluding step (1). Note that all 13 parents, after considering the examples written on the cards, were quite definite about whether these examples of forgetting applied to their children or not.
### Table 21

*List of 'Scenarios' Presented to Parents on Cards, Which Illustrated Three Types of Forgetting: Explicit, Implicit, and Prospective*

<table>
<thead>
<tr>
<th>Explicit</th>
<th>Implicit</th>
<th>Prospective</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Can't remember all the items on a short list.&quot;</td>
<td>&quot;Seems to forget learned patterns or sequences (e.g., a route to a familiar place).&quot;</td>
<td>&quot;Forgets to take one-off items to school (e.g., permission slips, money for excursions).&quot;</td>
</tr>
<tr>
<td>&quot;Forgets what he or she did a week ago.&quot;</td>
<td>&quot;Has difficulty following a set routine (e.g., getting ready for school).&quot;</td>
<td>&quot;Doesn't remember to pass on messages (e.g., phone, teachers').&quot;</td>
</tr>
<tr>
<td>&quot;Forgets what he or she did yesterday.&quot;</td>
<td>&quot;Leaving aside physical disabilities, my son or daughter seems to have forgotten how to perform some physical or motor tasks that he or she could do before (e.g., kick a ball, ride a bicycle, use a computer mouse, play a musical instrument).&quot;</td>
<td>&quot;Forgets to do school projects or assignments.&quot;</td>
</tr>
<tr>
<td>&quot;Has trouble remembering facts or details for school examinations.&quot;</td>
<td>&quot;Has difficulty following the rules of games (e.g., computer games, board games, sport).&quot;</td>
<td>&quot;Forgets to turn up to appointments, either at all, or on time.&quot;</td>
</tr>
<tr>
<td>&quot;Finds it difficult to remember people's names.&quot;</td>
<td>&quot;Finds it difficult learning from negative consequences experienced in the past (e.g., avoiding a dog that bit him/her).&quot;</td>
<td>&quot;Forgets to do important, non-routine chores (e.g., feed a pet).&quot;</td>
</tr>
<tr>
<td>&quot;Can't remember the names of characters from his or her favourite book or film.&quot;</td>
<td>&quot;Finds it difficult learning from positive consequences experienced in the past (e.g., repeating a behaviour for which he or she was praised or rewarded).&quot;</td>
<td>&quot;Forgets to turn off applicances when finished using them.&quot;</td>
</tr>
<tr>
<td>&quot;Has trouble recognizing people he or she has met recently.&quot;</td>
<td>&quot;Finds it difficult to learn set patterns or sequences (e.g., speech patterns, spelling rules, musical rhythms).&quot;</td>
<td>&quot;Forgets family members' birthdays.&quot;</td>
</tr>
</tbody>
</table>
Parents were interviewed either in their homes or at Griffith University for approximately 2 hours. With their consent, the interviews were audiotaped. Data were analysed using the principles of content analysis. This involved: (1) listening to the tapes; (2) transcribing into written text; (3) coding the data; (4) transforming the codes into categorical labels or themes; (5) sorting by categories and identifying patterns, relationships, and similarities or disparities; (6) examining sorted materials to isolate meaningful patterns and processes; and (7) considering identified patterns in the light of previous research and theories (Berg, 2001). Note that the analyses generally proceeded in the order listed (i.e., steps 1 to 7). However, the steps sometimes overlapped, or proceeded backwards, when for clarification purposes, the tapes needed to be replayed. Step 3, coding, involved naming or articulating what was perceived to be happening in an incident described. This incident was named, and its name, or label, represented the interviewer's interpretation of what was occurring in that incident. In the early stages of analysis, a given incident was labelled in as many different ways as could be extrapolated. This brainstorming of possible interpretations ensured the broadest possible thinking about the incident. Later, the incident's "ultimate" meaning was decided through contrast and comparison with other data (i.e., after Steps 5, 6, and 7 of the process of content analysis; Locke, 2001).

Results

Parents' descriptions of their children's memory functioning were classified within the following major themes: (a) memory functioning in general; (b) prospective memory; (c) explicit memory; (d) non-memory variables such as
personality attributes and motivation; (e) implicit memory; and (f) intervention strategies used by parents. Data from one parent were excluded from the analyses because during the interview it was discovered that the child (Patient Number 6, in Table 20) had a premorbid learning, developmental, or intellectual disability that made it difficult to compare pre- and post-injury functioning. Despite this adolescent's medical records indicating that he had suffered a severe TBI, his mother noted that she was unable to tell whether her son's cognitive functioning, including memory, was worse (or better) since his brain injury. Ironically, she commented that her son appeared to be more stable emotionally since his injury. She attributed this to his now having a recognizable "excuse" for being "slow". All other 12 parents reported that prior to injury, their children had normal cognitive functioning, and had met all developmental milestones at appropriate times. These parents reported that they could confidently compare pre- and post-injury functioning.

In Table 20, the injuries are listed as Severe, Moderate, or Mild. However, given the small sample size, the injuries are hereon in described as either minor, which combines the mild and moderate categories, or severe, based on distinctions described by Kibby and Long (1996) in their review of the literature on minor TBI.

Memory Functioning in General

Table 22 gives a summary of memory difficulties reported by the 12 parents whose data were analysed. The memory problems are categorized as: Overall Memory Functioning; Prospective Memory, Explicit Memory, and Implicit Memory. The table also includes the children's and adolescents' Patient Numbers, as listed in Table 20, to help identify the young person being described.
Table 22

Summary of Memory Difficulties Reported for 12 Children and Adolescents

<table>
<thead>
<tr>
<th>Patient number*</th>
<th>Gender</th>
<th>Injury Severity</th>
<th>Overall memory functioning</th>
<th>Prospective memory loss</th>
<th>Explicit memory loss</th>
<th>Implicit memory loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>Severe</td>
<td>Very poor; memory problems rated as greatest impairment</td>
<td>Severe; affects functioning</td>
<td>Severe</td>
<td>None noted</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>Severe</td>
<td>Very poor; memory problems rated as greatest impairment</td>
<td>Severe; affects functioning</td>
<td>Severe</td>
<td>None noted</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>Severe</td>
<td>Good</td>
<td>Minor; Only difficulty reported was occasional failure to pass on messages</td>
<td>Minor</td>
<td>None noted</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>Severe</td>
<td>Very poor</td>
<td>Severe; affects functioning</td>
<td>Severe</td>
<td>Minor; possibly some problems with impulsivity</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>Severe</td>
<td>Good</td>
<td>Minor; although, falling behind in spelling because forgets to bring home spelling lists</td>
<td>Minor</td>
<td>None noted</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>Severe</td>
<td>Very poor</td>
<td>Severe; consistent failure in cancelling intentions</td>
<td>Severe</td>
<td>Sometimes a problem during morning rush</td>
</tr>
<tr>
<td>8</td>
<td>M</td>
<td>Minor[^]</td>
<td>Good</td>
<td>Minor</td>
<td>Minor</td>
<td>None noted</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>Minor[^]</td>
<td>Good</td>
<td>Minor</td>
<td>Minor</td>
<td>None noted</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>Minor[^]</td>
<td>Moderately good, but with inconsistencies</td>
<td>Moderate</td>
<td>Minor</td>
<td>None noted</td>
</tr>
<tr>
<td>Patient number *</td>
<td>Gender</td>
<td>Injury severity</td>
<td>Overall memory functioning</td>
<td>Prospective memory loss</td>
<td>Explicit memory loss</td>
<td>Implicit memory loss</td>
</tr>
<tr>
<td>------------------</td>
<td>--------</td>
<td>----------------</td>
<td>----------------------------</td>
<td>-------------------------</td>
<td>---------------------</td>
<td>---------------------</td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>Minor §</td>
<td>Poor; inconsistent; fluctuating</td>
<td>Minor</td>
<td>Problems with contextual markers</td>
<td>None noted</td>
</tr>
<tr>
<td>12</td>
<td>M</td>
<td>Minor §</td>
<td>Very poor; memory problems rated as greatest impairment</td>
<td>Moderate</td>
<td>Severe</td>
<td>None noted</td>
</tr>
<tr>
<td>13</td>
<td>M</td>
<td>Minor §</td>
<td>Very poor</td>
<td>Severe</td>
<td>Severe</td>
<td>None noted</td>
</tr>
</tbody>
</table>

*Patient numbers correspond with those listed in Table 20. Note that details of Patient No. 6 have been omitted as this adolescent's data were not analysed; § Minor = Moderate and Mild
All parents reported some memory problems among their sons and daughters, including the parents of children with minor TBIs. Twenty-five per cent declared that their children's (Patients 1, 2 and 12) memory problems were their most serious concern. One of these parents, whose child (Patient 1) was injured at 6-years-of-age and who was 14 at the time of interview, stated: "I think I now take note more of what [my daughter] remembers, as that stands out because so much else is forgotten". Another said that her son (Patient 12) can remember one thing at a time, but has trouble with more than one. For instance, if she tells him to turn the volume down on the television and to do something else as well, she stated that, "You can see him walking around and looking up as if to ask, 'What do I have to do, turn the TV down and what else?'". Of the other nine participants, five said their children's (Patients 4, 7, 10, 11 and 13) forgetting was a problem, but that factors such as poor motivation, aggression, or mood disorders were of equal concern. The remaining four parents commented that although their children (Patients 2, 5, 8 and 9) sometimes forgot things, these memory slips were not serious enough to interfere with their day-to-day functioning.

**Prospective Memory**

All parents reported prospective forgetting by their children, although those who said their children were functioning well (i.e., the parents of Patients 3, 5, 8 and 9), described the forgetting as not significant. Interestingly, two of the children (Patients 3 and 5) said to be remembering quite well prospectively, had severe TBIs. Note however, that despite the mother of Patient 5 saying that her 9 year-old son's prospective memory was quite good, she stated at a later stage during the interview
that her son was falling behind in his spelling at school. When the interviewer followed up on the issue of the boy's spelling difficulties, the mother stated that her son's problems with spelling were not due to difficulties with spelling per se, but to his repeated failures to remember to bring home his word lists for spelling practice. It appeared, after all, that he was experiencing some difficulties with prospective memory.

Typically, prospective memory failures involved forgetting to take items to school, pass on messages, do chores, and keep appointments at the appropriate times or without reminders. The mother of one of the children (Patient 1) mentioned how dependent her 14-year-old daughter is on her as a consequence of prospective forgetting. She said, "[my daughter] depends on me for a lot of things. For example, she wouldn't say, 'Have you remembered to pack my excursion money, Mum?', or 'here is a message from my teacher'. She never gives a thought to these things".

Similarly, the parents of a teenage boy (Patient 12) with a minor injury stated that he "passes on messages about gym tournaments days after he was supposed to tell us". Another boy with a minor injury (Patient 13) was said to have such poor prospective memory that his mother fears for his safety while she is at work. She is a single mother and either arranges for him to visit friends, or phones him regularly from work to check that he has not, for instance, forgotten to switch off the stove. She said, "I stay on the phone while he does things". Equally stressed by her son's prospective-memory failures was the mother of Patient 7. She said her son with severe TBI frequently leaves for school with his lunch left on the kitchen bench, and fails to take messages, consent forms and homework. His forgetting caused her to "rant and rave"
at him. She felt concerned that he lacked self-responsibility. She also related how her son enjoys school sports and tries hard to remember to take his sports uniform to school on the correct days. He successfully remembers to pack his school bag with all the appropriate articles the evening before, but forgets that he has done so, and the next morning searches everywhere for the "missing" items. When he cannot find them he screams and kicks his bedroom wall in frustration. It seems all stages of prospective memory (e.g., forming, planning, acting on, and cancelling intentions), as described by Brandimonte (in Passolunghi et al., 1995) are achieved successfully except the final stage that involves cancelling the intention once it is acted upon.

Given the stated links between prospective memory and executive functions, it was not surprising that several parents reported their children having difficulties with executive-type processes. In particular, Patients 1 and 2, who were both reported to have severe prospective memory impairments, were also reported to have severe impairments in executive functions. For example, Patient 1 has problems reading subtle nonverbal cues. She interprets quite literally innuendo and sarcastic tones directed towards her by other children. Her mother said that these upset her, but not her daughter because their meanings were lost on her. Similarly, she has difficulties with discourse, either in initiating or maintaining conversations, or understanding humour that involves the manipulation of language. Given that she reads well and writes her own stories, her problem appears not to rest in the "mechanics" of language but in its freeform expression where spontaneity depends on the ability to integrate social cues and nuances. In addition, Patient 1 was said to have trouble planning and organizing even the most basic tasks.
The mother of Patient 2 presented a similar story. Her son, aged 16 at the time of interview, undertook his schoolwork by correspondence, which requires good planning, and a systematic, logical approach to problem solving. His mother used to help him organise his study material and do a study plan. He seemed to manage quite well with her assistance. But when he reached an age that she thought he ought to be able to do this for himself, he fell way behind with his reading and assignment work because he seemed unable to manage all the information. His inability to plan and integrate information at the age his mother expected him to be able to, could be the case of a child "growing into" a problem as he matured.

Explicit Memory

Seven parents reported that their children (Patients 1, 2, 4, 7, 11, 12 and 13) had difficulty remembering facts and events when they were reminded specifically of the "learning" occasion. This explicit forgetting applied to children with severe and minor TBIs. A particularly salient example of this type of memory loss was experienced first hand by the primary researcher. On arriving at the family's home, she was met by the 16-year old (Patient 2) with a severe TBI. Six months previously, the researcher had worked for two hours on a one-to-one basis on a different research project with the young man. She recognized him instantly, but when she asked if he remembered her or the occasion, he said, "No", and indeed there was nothing in his manner to indicate any recall or recognition.

The mother of a son with a minor TBI (Patient 13), aged 14 at the time of interview, and injured at age 8, stated: "He can't remember what he's just read. And he likes to build things, but keeps forgetting where he's put the tools." Similarly, he was
reported to, "Only remember one thing at a time. For example, if I tell him to brush his teeth and put on deodorant, he will only remember both if I stand beside him and remind him."

Several parents reported that their children (Patients 1, 4, 5, 11, 12 and 13) had difficulty remembering when asked to recall outright, but could remember if they were given prompts or were asked to recognize rather than recall. The failure of direct recall, but success of cued recall and recognition suggested that the children were encoding the information, but were having trouble retrieving it. In the words of one mother (of Patient 1): "It's all in there but she can't pull it out". However, the same parent later commented that: "Some things she can't recall, even with lots of reminders". This failure to remember, despite being cued, suggested that there were at least occasional encoding problems, which was reinforced by the fact that three children (Patients 1, 11 and 12) were reported to encode without temporal or contextual markers. For instance, the mother of Patient 1 described how an incident might occur and she and her child would discuss it at length. Then, two weeks later the child would say, "Guess what, Mum…", and relate the same incident as though it had just happened and the mother knew nothing about it. Two other parents, both of children with minor injuries (Patients 11 and 12), reported similar phenomena. One said that her son (Patient 11) "forgets what he was doing yesterday - not the event, but the sequence and context in which it occurred". The other (parent of Patient 12) said, "He sometimes remembers something, but can't remember when it happened."

Explicit memory functioning was also described as variable or fluctuating. The mother of Patient 11 said, "It's like a light bulb going on and off. He can't remember
names of characters from books, et cetera, though this is intermittent. He will forget today, but remember tomorrow”. Some children were also said to retain certain facts and events and not others. The girl with the severe TBI (Patient 1), for example, was reported to be quite good at remembering numbers (e.g., birthdays, telephone and school identification numbers), and the words of songs she liked, but usually forgot what she did on her visits to her father, where she had been a week ago, and the names of people she had just met.

Non-memory variables: explicit and prospective memory

Several parents reported non-memory factors (e.g., planning and organising, and motivation) overlapping with their children's ability to remember. The overlapping seemed to occur mainly with prospective, but also with explicit remembering. In terms of organising, there was the case of the boy (Patient 7), already referred to, who packs his sports equipment the night before required. Unfortunately, despite his pre-planning, he fails to remember that he has already executed his plan. Another boy, with a severe TBI (Patient 3), does a similar thing, though his efforts are more successful. His mother reports that he plans out his school-related commitments in advance and either writes himself notes and lists, or asks his mother to do it for him. Consequently, he never forgets to take messages to school, to complete assignments on time, or to take consent forms back and forth between home and school. However, he often does forget to pass on telephone messages, possibly because these are unplanned, falling outside the regular weekly schedule.
Motivation also appears to make a difference, particularly with prospective remembering. One of the most remarkable examples of this came from Patient 1, whose mother claimed that, "She's lost so many things [functions]. She can't watch TV. It's too fast. She can't take it in. So food is something she loves, so she's very motivated when it comes to doing things for food". Although this adolescent often forgets what happened 10 minutes ago, and seems generally unable to anticipate the future, she will remember that they are going to town the following week because her mother promised she could have an ice-cream when they got there. Similarly, her support teacher noted, in typed comments given to the girl's mother, that the child usually remembers she has tuckshop (food takeaway days at school) without prompting. Further, she reminds her mother to give her money for tuckshop, even though this only occurs once every fortnight. Moreover, she never forgets to take cooking ingredients to school for home-economics classes. This specialised prospective remembering is also noted in the 16-year old boy with a severe TBI (Patient 2). His mother reported that he generally forgets routine and one-off appointments, to pass on messages, and to hand in school assignments on time. However, he never forgets his appointment with his psychologist. Apparently he likes and trusts his male therapist and looks forward to his visits. His motivation could also be related to his family situation. He lives with his mother and step-father, with whom he quarrels a great deal, and rarely sees his biological father. Having the opportunity to spend time with an empathic, supportive "father figure" may be a strong incentive to remember these appointments.
Motivational issues also appeared to impact on explicit memory. For example, the girl who loves food (Patient 1) not only remembered to take her cooking ingredients to school on the right day, mother says she, "can still remember the next day a lot of the ingredients she had used". She enjoys music as well. This may explain why she also remembers the words to her favourite songs.

**Implicit Memory**

Few children were reported to have implicit memory impairments, including those with the most severe injuries, one of whom (Patient 1) was said to "take a little while to learn new skills (e.g., puzzles and simple board games), but once she learns them, doesn't forget". Her learning-support teacher, again, in written comments, confirmed this by stating that when the child had to change rooms or buildings at school, she took a while to learn the new routes, but once established, was able to find her way without getting lost. And her mother reported being surprised that her daughter found her way to her father's house on her own one day after having been accompanied by her older sister on all previous occasions. However, one parent did report her son (Patient 7) having difficulties with following set routines. Possibly the procedures he failed to learn were more complex than the ones he remembered, or perhaps he failed because he was rushed (e.g., in the mornings before school). Interestingly, two parents also expressed concern that their children (Patients 4 and 7) may not learn from negative consequences, that is, have poor associative learning (implicit learning), and might therefore take unnecessary risks. It is possible, however, that risk-taking behaviour might not be due to a failure of implicit memory, but to impulsiveness or a failure to inhibit responses. In other words, these children
might repeatedly behave in ways that elicit unpleasant consequences for themselves, not because they failed to remember the relationship between the action and its consequences, but because they had difficulty controlling impulses to act.

*Intervention Strategies Used by Parents*

Six parents described strategies that have helped with their children's (Patients 1, 2, 3, 4, 5 and 7) remembering. Some of these strategies were devised by parents in direct response to recurring problems. Others were suggested by rehabilitation professionals, but adapted to suit the children's unique circumstances. Strategies included employing: (1) negative reinforcement, a form of operant conditioning; (2) rhyme and rhythm; (3) repetitive routines; (4) external aids; and (5) *scaffolding*, a metacognitive technique whereby problems are broken down into components. Two parents described using negative reinforcement, the use of which is illustrated in the case of Patient 2, who kept forgetting to return rented videos. His mother incurred great expense paying his overdue fines, and gave her son an "ultimatum". If he was late in returning them and a fine accrued, he would have to pay out of his pocket money. This strategy worked immediately. From that point on, he remembered to return the videos. Similarly, the mother of Patient 1 told her daughter that she was allowed to ask her mother the same question twice. After the second answer, the girl had to write the answer down on a piece of paper and was not allowed to ask her mother a third time. The daughter was thought to put more effort into remembering because she found that easier than having to find a notepad and pen to write things down. Of course, there is a possibility that these children were not forgetting these things in the first place, but had simply got into the habit of having their parents do
things for them. Perhaps the negative reinforcement was not teaching remembering, but teaching them to take back responsibility for themselves.

Another strategy was to employ rhyme and rhythm in teaching conversational skills. One mother used this. Her daughter (Patient 1) had difficulty responding appropriately to polite inquiries about her welfare so her mother made up a set of pat responses like lyrics to a song, then set them to the tune of "Waltzing Matilda", and sang them to her over and over. The mother said her daughter could remember these patterned, rhythmical phrases much better than she could if she had been simply told them.

Three parents said that establishing a repetitive routine for the execution of chores helped their children (Patients 1, 5 and 7) to remember. For instance, one mother typed up and posted a list of chores for her son (Patient 5) to complete every day. As he completed the chores, he had to strike them off the list. His mother kept up this procedure every day for three months. She reported that now he has memorised the list and takes great pride in informing her as he completes each task. There are some difficulties with this repetitive learning, however. The routines can become so entrenched they are nearly impossible to undo. The unlearning of reinforced responses proved to be difficult in the case of a child (Patient 1) who learned a set regime for taking medications. When the prescriptions changed, the mother had great difficulty getting her child to break the old routine.

Four parents declared trying external memory aids with their children (Patients 1, 2, 3 and 7). One of these parents said that external reminders were helpful to her son (Patient 3), who was reported earlier to write himself notes and lists to help him
remember school commitments. His school had helped too in colour coding his timetable. The other three parents did not have the same success with external aids. It seemed these prompts were only successful when the children were self-aware. If the young people had sufficient metacognitive abilities to know when their memory was failing, and if they were motivated, they might remember to consult their notes or lists. Conversely, if children were not conscious of forgetting, they would not know there was a need to use aids, and would therefore not comply (Fleming, Strong, & Ashton, 1998).

A strategy to help with problem solving was described by one mother. She used a scaffolding-type procedure. When her son (Patient 4) had a complicated task to perform, she would break it into manageable portions for him, explaining the logical sequences, that is, that Step 1 had to be completed before Step 2. As the boy often had trouble knowing where to start, she would say, "I think it will work best if you do this first. What do you think?". She said that once she got him started, he could usually follow through, so she would let him proceed until he needed some further guidance. She found that with this technique, he took more initiative and depended on her less as his "prosthetic frontal lobe" (Ylvisaker & Feeney, 1998).

Overall, intervention strategies were devised by trial and error. When something was tried and appeared to work, parents tended to reuse it, possibly adapting and refining it as they went along. The process required them to have good observational skills, to put in a lot of effort, and to be very patient. However, they believed their endeavours were worthwhile because when they found a strategy that
worked, it improved their children's everyday functioning, and lessened the burden on the family, even if only in small ways.

Discussion

Four main conclusions can be drawn from the parents' reports. First, prospective memory failure was both frequently reported, and said to cause the most stress and concern among parents. Further, person-attribute variables such as levels of motivation overlapped with prospective memory, though there was also evidence of interaction between motivation levels and explicit recall. In addition, although preplanning enhanced prospective remembering, the planning did not always help if the intention to act could not be cancelled once the action had been performed. Second, of the two types of retrospective memory, explicit was frequently impaired, and implicit generally preserved. Moreover, explicit memory functioning was variable, with inconsistencies in performance noted over time. Third, family-devised rehabilitative strategies helped improve memory performance, or compensated for memory losses. Finally, severity of TBI among the children did not necessarily match the severity of memory dysfunction reported. These findings will now be discussed.

The frequent reporting of impaired prospective memory and its related effects on everyday functioning provides ecological validity to the computerised, experimental measures used in Study 2. The current results also concur with findings by McCauley and Levine (2004) in their study of 10- to 19-year-olds with TBI, and in the adult TBI literature (e.g., Maujean et al., 2003; Roche et al., 2002; and Shum, Valentine & Cutmore, 1999).
In the current study, parents reported not only a high incidence of prospective memory failure, but also significant negative consequences of the forgetting for themselves as caregivers. This was particularly the case with parents of adolescents, who believed their children should be mature enough to remember appointments, pass on messages, and switch off appliances. Instead, many parents had to continue taking the responsibility of remembering these things on their adolescents’ behalf.

Certain non-cognitive variables were found to overlap with the children's prospective memory. For instance, sometimes when children were "rewarded" for remembering by achieving some positive payoff, their motivation to remember appeared to be able to overcome cognitive limitations, even in the case of children with the most severe TBIs. These findings of remembering when motivated, tend to support what has been found in research on prospective memory in general populations (Cockburn, 1996; Einstein & McDaniel, 1996; Winograd, 1988), including among children as young as 2 years (Somerville et al., 1983).

Note though that motivation to remember seemed also to apply to explicit recall, and suggests that Graf and Uttl (2002) were correct in arguing that person-attribute variables overlap as much with explicit as they do with prospective memory. Note also that motivation might affect forgetting as well as remembering. Specifically, the fact that children failed to turn up for dental appointments or to do homework, may not have been the result of prospective memory deficits, but simply of a desire not to do these things. One further point regarding motivation that is worth considering is its relationship in some instances to operant conditioning, in particular, learning through positive and negative reinforcement (e.g., receive an ice-cream; or
avoid paying fines if I remember). The motivation-conditioning relationship
could involve so-called somatic markers, which according to Damasio, Tranel, and
Damasio (1991), are links mediated by the ventromedial prefrontal region between
knowledge and emotions, and which allow people to learn from experiences that
involve positive or negative consequences (Ylvisaker, Szekeres, & Haarbauer-Krupa,
1998). Therefore, although motivation to remember is essentially an emotional rather
than a cognitive phenomenon, there may be cognitive elements involved. Further
investigations of this may shed more light on this possibility.

In some instances children were highly self-aware of their intentions to act and
preplanned to avoid forgetting. Preplanning was successful for some, but not for
others, however, as was the case with the adolescent who seemed to have to keep his
intention "alive" because he forgot that he had already acted to fulfil the intention.
His case demonstrates the complexity of prospective memory, and that it cannot be
assumed that just because an intention is kept in mind and acted upon at the right
time, the process is complete. Unless after one has acted, one remembers that the
action has been performed, the intention is kept in mind continuously, making
demands on cognitive resources needlessly.

Although parents reported difficulties with executive functions, and links have
been found between executive functions and prospective memory elsewhere (e.g.,
Studies 1 & 2; Kerns, 2000; Maujean et al., 2003; Shallice & Burgess, 1991;
Shimamura et al., 1991), no confirmation of a relationship between these two
"prefrontal" processes can be afforded by the anecdotal reports provided in the current
study.
The evidence provided here of impairments in explicit memory concurs with the results of quantitative studies that used tests of free recall, cued recall and recognition (e.g., Basset & Slater, 1990; Jaffe, et al., 1992; Roman et al., 1998; Yeates et al., 1995). Similarly, the infrequent reporting of implicit memory loss in day-to-day functioning tends to support the results of laboratory-based studies of visual priming and procedural learning, which found that children with moderate to severe TBI were unimpaired on these tasks compared with control groups (Shum, Jamieson, Bahr, & Wallace, 1999; Ward et al., 2002). Taken together, the parents' reports of impaired explicit and generally-preserved implicit memory in their children tend to demonstrate the ecological validity of a theorised functional dissociation between these two types of memory, which was first noted by Cohen and Squire (1980), and has been reported consistently since in adults (Ewert et al., 1989; Shum et al., 1996; Vakil, et al., 1996) and children with TBI (Shum et al., 1999; Ward et al., 2002). As stated in Chapter 2, this functional distinction suggests an anatomical dissociation (i.e., that different cortical areas mediate the two systems). Indeed, neuroimaging research has revealed that the medial-temporal lobes, hippocampus and frontal lobes are directly involved in explicit memory (Milner, Petrides, & Smith, 1985; Moscovitch, 1992; Nissen, 1992; Saint-Cyr & Taylor, 1992). By contrast, various inferior and posterior regions of the brain such as the basal nuclei (Saint-Cyr & Taylor) and the right occipital cortex (Gabrieli et al., 1995) appear to mediate implicit memory. Given that in this study most of the children's injuries were in the prefrontal and temporal regions, as indeed they are with most cases of TBI (Levin et al., 1989; Levin et al., 1991; Mendelsohn et al., 1992), it is not surprising that parents reported
numerous explicit-memory and few implicit-memory problems in their sons and daughters.

Another report by parents was of variability in explicit recall over time. In particular, children seemed to encode information successfully at times, but had trouble retrieving, as was evident from examples of children being able to remember when given prompts or cues. On other occasions, however, perhaps because of attention lapses or fatigue, encoding seemed to be compromised. Further, parents noted that sometimes their children could recall facts and events, but not where or when these occurred, as though they were encoded without any temporal markers. West (1996) argued that this decreased sensitivity to the contextual distinctiveness of information retained from the environment is due to prefrontal impairment. Milner and associates (1985) demonstrated this in an experiment. They found that patients with frontal-lobe damage were less able than controls to identify items that occurred most recently on a test, nor to be able to accurately estimate the frequency of occurrence. However, these same patients performed as well as controls on simple tests of recognition, suggesting that their inability to indicate where and how often were not attributed solely to a memory deficit. It may also suggest an interaction between the medial-temporal lobes and prefrontal regions in mediating encoding processes (Daselaar, Veltman, Rombouts, Raaijmakers & Jonker, 2003; Gabrieli et al., 1996; Ward, 2003).

Rehabilitative strategies employed by parents relied on behavioural conditioning, for example, the use of rewards and punishments. These strategies are commonly used in children with behavioural problems (Blackman & LeJeune, 1990;
Martin & Pear, 1996) and in TBI rehabilitation (Silver, Boake, & Cavazos, 1994; Ylvisaker & Feeney, 1998). However, Ylvisaker, Szekeres, and Haarbauer-Krupa (1998) warn that strategies that rely on consequences may not work in children with damage to the ventromedial region of the prefrontal cortex because the neural links between memory and emotions may be impaired. If rewards for remembering or behaving a particular way cannot evoke positive feelings in the child, then offering rewards would be a waste of time.

Other interventions used by parents included skills training that is underpinned by implicit memory (Squire, 1992). Strategies involved repetition, and the learning of set procedures and patterns. Similar strategies have been refined in teaching amnesic adults to use computers (Glisky & Schacter, 1987) and in eliminating errors from procedures and routines (Wilson & Evans, 1996). However, some caution is needed in employing these repetitive procedures. They may not generalise to other situations. And, if they become overlearned, it may be difficult to "untrain" the children if the procedures need to change in the future, as was apparent in the case of the child whose medication regime changed.

External memory aids such as lists, written messages and colour-coded planners were employed in facilitating prospective memory. These too are commonly utilised by rehabilitation professionals (Ownsworth & McFarland, 1999; Sohlberg & Mateer, 1989). However, though many parents tried these external aids, they appeared only to be successful in children with high self-awareness (i.e., conscious of their own difficulties). Other children failed to comply with these strategies, which tends to concur with findings by Fleming and colleagues (1998). Another procedure
used to help planning was scaffolding that involved helping the child plan out the problem to be solved, and filling in details for him when he was unable to make connections between parts of the plan. An elaborate version of this strategy is used with success in treating those with executive system deficits (Ylvisaker, Szekeres, & Feeney, 1998). Note that further study of individual needs and appropriate intervention strategies needs to be considered for these children.

One issue to note about the results of this study concerns the accuracy of the parents' reporting, which does not imply that parents were lying, but that because their judgements relied on subjective assessments, they may have overestimated or underestimated their children's cognitive abilities. For instance, some parents of the youngest children (i.e., 9- and 10-year-olds) reported prospective memory and executive system failures. Unless the parents had a sound basis for comparison (e.g., experience with other children in the family, or exposure to other children the same age outside the family), these reports may be overstated. This conclusion is based on the assumption that the prefrontal-lobe model of prospective memory is correct and that the prefrontal lobes do not fully mature until adolescence (Lehr, 1990; Marlowe, 2000; Yakovlev & Lecours, 1967). Therefore, as found in Study 2, children beneath the age of approximately 12 years with TBI, probably even those with focal prefrontal damage, should perform on a par with their age peers. Consequently, reports of prospective memory failure and executive dysfunction in the youngest children should be treated cautiously. Their difficulties may be developmentally rather than organically related. However, as also previously noted, as these children mature, they
may grow into these impairments if their injuries were located in the prefrontal regions (Ylvisaker, 1998).

A further issue to arise from this study was an unexpected relationship between injury severity and outcomes for some of the children. For instance, two young people with severe TBI were reported to be doing well overall in memory functioning. However, three with minor injuries were reported to have difficulties. Generally, outcomes can most reliably be predicted in the case of those with severe injuries, where typically, say Kibby and Long (1996, p. 160) "residual cognitive deficits are almost always present". Fortunately, for whatever reason, the two children with severe injuries whose outcomes are generally good, appear to be defying the trends. Conversely, the situation is less favourable for those children with minor injuries, who were reported not to be remembering well. Possibly, in the case of the boy injured at two years of age, the injury, although minor, may have been sufficiently serious to disrupt functions during a critical period of his development. Note that Ewing-Cobbs and colleagues (1998) stated that some of their studies of language and memory after TBI revealed that skills developing rapidly at the time of the injury were more adversely affected than well-established skills, despite the severity of the injury. And in the cases of the other two children whose CT scans revealed no brain abnormalities, yet who were reported not to be remembering well, there could be psychological (Kibby & Long; Powell, Collin, & Sutton, 1996), or other premorbid or postmorbid variables that explain their difficulties (Kibby & Long). For instance, one of these boys was allegedly kicked in the head at school, and from his mother's reports, had experienced anxiety symptoms since the incident. His
psychological state could also be exacerbated by the anticipation of a pending court case involving the alleged assault. The other boy may also experience stress-related symptoms because he is an only child, and lives with his single mother who had recently undergone heart surgery. Although these boys' difficulties may have a psychological rather than organic basis, it does not mean that their cognitive problems are not real of course, and further follow up is recommended, both in helping these children specifically, and in investigating non-organic factors in TBI-related outcomes in general.

This study has contributed to the understanding of the long-term effects of paediatric TBI on memory functioning in a number of ways. First, it validated the experimental, computerised, prospective-memory tasks used in Study 2 in demonstrating that TBI affects prospective memory in young people in everyday contexts. Second, it demonstrated that prospective memory can fail even after an intention to act has been fulfilled, keeping the intention activated needlessly. Third, it showed that planning can enhance prospective memory, and similarly that motivational or emotional factors can overlap with prospective and explicit memory, allowing even those with severe TBI to successfully remember future intentions and past events and facts. Fourth, this study revealed how individualised, contextually-appropriate rehabilitation strategies can improve the day-to-day memory functioning of children with TBI. And, finally, it showed that qualitative research has an important role to play in understanding the long-term effects of TBI. Specifically, this methodology was able to go beyond merely showing whether children succeeded or failed to remember. As conjectured by Ewing-Cobbs and colleagues (1998), the
qualitative approach provided an in-depth perspective on the conditions, circumstances, and environmental variables that impacted on memory functioning, and revealed intervention strategies that work in the real world.

However, several limitations are worthy of note. First, because it was qualitative, and the information provided was anecdotal and depended on parents' subjective judgements, the data may have been imprecise, exaggerated, or understated. For instance, because of the seriousness of TBI, parents may be overly sensitive to its possible effects, attributing all difficulties experienced by their children to their head injuries, and ignoring the effects of other factors. Second, everyday environments do not allow variables to be controlled. Therefore, the mechanisms that underlie memory failures cannot be identified. For instance, when an event is reported to be forgotten, because the researcher cannot be present at the time the event was experienced, it is impossible to determine if the forgetting represents encoding, storage or retrieval failure (Baker-Ward et al., 1993). A further limitation of this study is its restricted generalisability because it was based on a small, demographically-restricted sample, (viz., 12 participants).

Several recommendations are made for follow up. First, a study with a larger sample of children from a broader range of socioeconomic, ethnic, educational, and geographic backgrounds would be informative. Second, an in-depth investigation of minor TBIs would help in determining whether ongoing cognitive difficulties are organically or psychologically based. The use of functional imaging may be employed plus the testing for variables such as level of social support, and psychological abnormalities. Third, the role that non-memory factors such as
planning and motivation play in mediating both prospective and explicit memory would be interesting to pursue. Understanding the role of non-memory factors would be of theoretical interest, and could also have implications for rehabilitation. Fourth, regarding rehabilitation, the efficacy of some of the methods employed by parents in this study could be investigated further to see whether they may have more general applications.
CHAPTER SIX

General Discussion

The general aim of this thesis was to examine the effects of paediatric TBI on prospective memory. This examination had two main objectives: (1) to determine if paediatric TBI results in impairments in prospective memory, and, (2) if impairments were found to exist, to understand better why and how they occurred. To answer the if, why and how questions, children’s prospective memory was assessed quantitatively and qualitatively.

Is Prospective Memory Affected by Paediatric TBI?

The quantitative study revealed that compared with their non-injured peers, children and adolescents with TBI did indeed show deficits in prospective memory. This finding concurred with results found in the adult TBI literature (e.g., Maujean et al., 2003; Shum, et al., 1999), and in a recent study of children with TBI by McCauley and Levin (2004). Confirmation of the adverse effects of paediatric TBI on prospective memory also came from the qualitative study with anecdotal reports by parents indicating that prospective forgetting was not only common in their sons and daughters, but that the prospective forgetting was often the cause of much family stress and concern.

Interestingly, Study 2, in particular, revealed that not all young people with TBI manifest prospective forgetting to the same degree. In fact, it was found that adolescents with TBI showed greater levels of forgetting relative to non-injured adolescents than pre-adolescents with TBI showed relative to non-injured pre-adolescents. This finding had been expected given the evidence found from other
sources of the role of the prefrontal cortex in prospective memory (Mateer et al., 1997; Shimamura et al., 1991; West, 1996), and that myelination and synaptic connectivity reach a peak of maturity in that region of the brain around puberty (Lehr, 1990; Marlowe, 2000; Yakovlev & Lecours, 1967). The finding of selective, noticeable prospective memory loss in adolescents with TBI was also expected from the results of Study 1, which showed that overall, normally developing 13-year-olds remembered as well prospectively as normally developing 21-year-olds. Therefore, 13-year-olds with TBI, and in particular, those with prefrontal injuries, would be expected to “stand apart” from their non-injured peers.

Why TBI Affects Prospective Memory

In terms of why prospective memory impairments were found in young people with TBI compared with their non-injured counterparts, and why the problem was more visible in adolescents, the answer tends to be found in the prefrontal model. Specifically, the cognitive-demand manipulation, which varied the demands placed on attention and working memory, demonstrated that prospective memory performance decreased in proportion to the cognitive-demand increases on the ongoing task. It therefore appears that the capacity to remember prospectively is determined by the resource capacity of attention and working memory, which are understood to be mediated by the prefrontal cortex (Hanten et al., 2001). So, if an ongoing task takes up only a small amount of the available resources, sufficient capacity should remain to perform a prospective task effectively. By contrast, if an ongoing task takes up a large proportion of available resources, fewer of these resources should be left over to perform the prospective task. The opposite has also been found (e.g., Smith, 2003), where the large cognitive demands of a prospective task diminished the performance
of an ongoing task. By implication, those with limited prefrontal capacity in the first
place, that is: pre-pubescent children in whom the prefrontal regions are still not fully
developed; the aged, in whom prefrontal decay has begun; and those with TBI or focal
prefrontal lesions; should show deficits in prospective remembering as the cognitive
demands of the ongoing task or the prospective task increase. Note that any
prospective-memory situation where the cognitive demands are high, such as those
with many different prospective cues to remember, or in those in which there is a long
retrieval interval, higher rates of forgetting should occur than on prospective tasks on
which the cognitive demands are lower.

The prefrontal explanation for impaired prospective memory performance in
children with TBI also receives support from the evidence of relationships between
executive functions and prospective memory. As indicated, these relationships
probably exist because the prefrontal regions of the brain are the neuroanatomical
correlates of both processes. However, while this fact alone probably accounts for the
deficits in prospective memory and executive functions among those with: (a)
immature prefrontal lobes, and (b) injuries to those areas, it does not necessarily
indicate that the two processes are directly related. Nevertheless, the results of the
regression analyses suggested that there were elements of the current prospective
memory task that had a lot in common with certain executive functions. For instance,
in those without TBI, performance on the SOPT and Stroop predicted performance on
the high-demand version of the prospective-memory task. Given that the children,
adolescents, and adults showed similar patterns of performance on the prospective
memory tasks, and on the SOPT and Stroop, this suggested that the current
prospective tasks required good working memory and focused attention to be effective.

How Prospective Memory Succeeds or Fails: The Associated Processes

With respect to how prospective forgetting manifested itself, firstly, it was demonstrated through the failure to press the 6th key on the response box when italic letters appeared on the screen, and to a lesser extent, through the failure to change the target words in the reading task. These measures, in general, were sensitive to age and injury effects. However, they only gave a behavioural dimension to prospective memory. They did not show how or where those who forgot went wrong or why those who succeeded were successful. The manipulation checks helped provide some important insights into the processes of prospective memory. In particular, it was apparent from the 100% accuracy on the recall of task instructions by all participants on the computerised tasks that prospective forgetting was not due in this instance to failure of the retrospective component of the prospective memory task. Everyone remembered what they had to do and when they had to do it.

In terms of how respondents were alerted to the cues, there is some evidence that a heightened awareness of the cues, as demonstrated by reports of “looking out” for them, assisted in prospective remembering. This was evident among adolescents in particular, where around 50% of those who were not injured indicated keeping the intention to act in conscious awareness, with only around 40% of those with TBI indicating the same alertness. Given that keeping a thought suspended in conscious awareness probably depends on working memory capacity, and that adolescents in the control group were patently better at prospective remembering than their peers with
TBI, it is likely that the injury effects were due in part to diminished working memory capacity in those in the injured group.

However, despite some apparent advantage in looking out for the cues, this did not necessarily guarantee heightened prospective remembering. For instance, the non-injured young adults in Study 1 remembered as well as the non-injured adolescents, yet the adults did not report looking out for the cues as often as the adolescents. This discrepancy is borne out by reflections of one’s own prospective memory failures, when in spite of rehearsing the “to do” intention over and over, it can still nevertheless fail to be acted upon at the appropriate moment because of some distraction or loss of focus at that crucial moment.

Two particular peculiarities were noted among those with TBI who experienced high levels of prospective forgetting. One was the observation made during the execution of the computerised task where, despite seeming to be comfortable in performing the ongoing task and appearing to have plenty of time to see and respond to the prospective targets, three adolescents consistently failed to respond. The retrospective memory check indicated they had understood and remembered what they had to do, and an improvised “visual test” indicated they could see the targets. An explanation for their failure to respond to the targets was possibly that they were unable to translate the “plan” into an action. Cockburn (1996) reported a similar phenomenon in patients with prefrontal lesions where an intention was formulated and remembered but not acted on, as though the connection between the thinking and the doing was lost.

Two, during an interview with a parent in Study 3, she explained how her son formulated intentions, remembered the intentions, and acted at the appropriate time,
but then forgot that he had acted. This suggested that he was experiencing a retrospective memory failure, that is, forgetting what he had done. The consequence of his retrospective forgetting was that he kept the prospective intention continuously activated in conscious awareness needlessly, which was a waste of cognitive resources, and which caused great frustration.

The interview study also revealed another dimension to prospective memory, which undoubtedly applies to prospective memory (and explicit memory) across the board. Specifically, prospective memory was shown to interact with non-cognitive variables such as personality attributes and motivational forces, and suggests that training in self-awareness, tapping into personality strengths, and understanding what motivates individuals with TBI, has enormous positive implications for the rehabilitation of prospective (and explicit) memory impairments that result in disabilities.

Moreover, Study 3 demonstrated how interrelated prospective remembering is with independent living, especially among adolescents, and how impairments in prospective memory more than impairments in other forms of memory, can cause concern and stress among parents of children with TBI. Clearly, the ability to remember appointments, switch off appliances, take medications, and lock the doors to your home as you leave it, all impact on your ability to live independently. If you are a young person and cannot remember to do these things for yourself, then it may mean that you never truly become an independent adult because you will always depend on someone more “responsible” to take care of those things for you.

In terms of other attributes of prospective memory, the lack of a significant relationship between the computerised and manual prospective tasks reinforces the
idea explored in Chapter 2 that not all prospective memory tasks are the same. They may call on different processes. In the current tasks, there were differences in both the ongoing and prospective components. Although both ongoing tasks involved reading, the manual task was a “pure” reading and comprehension task, while the computerised task was more a spelling and word recognition task that required letters to be held in working memory. On the prospective component, in the manual task, the cues were identical and in sight at all times, while on the computerised task, the cue letters were different and only appeared randomly for brief moments. Despite their different natures, the lack of a relationship between them, they still produced identical age effects in the non-injured groups, and were able to distinguish adolescents with TBI from those without. It therefore appears that although the tasks were calling on different processes, those processes may nevertheless be dependent to some extent on prefrontal capacity. Refining the reading task in the future may shed more light on this possibility.

The idea that different prospective memory tasks call on different processes is reinforced by the results of the TOL. Given that TOL scores did not predict prospective-memory performance in the non-injured groups, it suggests that planning skills were not as important in executing the current prospective tasks. This may be because the “to do” action was not initiated by the respondents, therefore scheduling and planning were not required. By contrast, in self-initiated prospective tasks, planning might be vital. For example, as demonstrated in Study 3, the boy who planned his prospective tasks for the week, did not forget, whereas those who did not plan, did forget.
Note also that the relationships between prospective memory and executive functions were opposite in those with TBI than in their non-injured peers. Specifically, in those with TBI, the SOPT and Stroop did not predict performance on the computer task, but the TOL did. This trend may provide divergent evidence of the previously noted observation that working memory and focused attention were associated with effective prospective remembering on the high-demand computerised task, but planning capacity was not. Convergent evidence of the overlap between working memory and focused attention and prospective memory is also found in the self reports of thinking strategies, where more non-injured than injured adolescents indicated thinking about the prospective cues, that is, attending to the stimuli and holding the intention to act in mind.

In summary, prospective memory was found to be impaired in children, and particularly adolescents, with TBI. Further, these deficits appeared to result from limitations in attention and working memory capacity that are associated with the prefrontal cortex. Prospective forgetting was not associated with retrospective memory failures about what to do and when to do it. However, in some, prospective forgetting was associated with a failure to link the intention to act with actually carrying out the action. And, one adolescent was effective at remembering all the steps in executing a future intention, except the last, and forgot that he had acted. Further, prospective memory was found to interact with non-cognitive processes. It was also found that those with substantial prospective memory deficits depend on others to help them cope with everyday living. Finally, it was established that not all prospective tasks are the same, and that though the computerised task seemed to require working memory and attention to perform adequately, other tasks may call on
other cognitive processes such as planning ability to be performed adequately. Taken together, these findings show that the main aim of the research was achieved very well.

Other Contributions of This Research

As concluded, the current program of research has contributed greatly to the understanding of the effects of paediatric TBI on prospective memory. The richness of the data on *if, why* and *how* is owed significantly to the approaches taken in this investigation. Firstly, the quantitative TBI study was preceded by a developmental study. Secondly, the quantitative study of TBI was followed up with a qualitative study that not only enriched the findings about prospective memory, but contributed further to the understanding of how paediatric TBI affects other types of memory.

*Important Findings from the Developmental Study*

As advised by Lehr (1990), more can be understood about the effects of paediatric TBI by examining the experiences of children with TBI against a developmental backdrop. In acting on that advice, this thesis demonstrated that the early development of prospective memory from middle childhood to young adulthood does not follow a straight, gradually rising trajectory. Rather, it appears that there is an increase in prospective memory capacity in the years from around 7- to 10-years, to 13- to 16-years. Then, from early adolescence, the trajectory appears to plateau, with little difference in performance apparent between 13- to 16-years, and 18- to 21-years. This pattern was detected on both prospective memory tasks and two out of three executive function tasks, and suggests that the developmental trajectory of prospective memory is not simply a matter of children becoming more proficient at these tasks with age and experience. If it were just a matter of growing older and
wiser, the trajectory would rise steadily higher from childhood to adulthood, and not reach a peak in early adolescence and then flatten out towards adulthood as it appeared to do in this research. Clearly, something other than ordinary maturational processes must explain this trend.

The evidence provided from the Age X Cognitive Demand interaction, as evidenced by the different proportional reductions from low- to high-demand conditions across groups, plus the age effects evident on the executive function tasks provided strong evidence that it was prefrontal maturity in particular that explained the unusual developmental trajectory of prospective memory. It was expected that the importance manipulation (i.e., stressing and not stressing the importance of responding to the prospective targets) would support the prefrontal hypothesis further. However, there were very likely design flaws in this study that prevented the importance effect from appearing. Possibly, the task instructions overstated the significance of the “background” reading task so participants were skeptical about focusing on the prospective cues, and the between-subjects design was not powerful enough to detect an importance effect. Nevertheless, given the plausibility of an importance effect when tasks compete for attention, as was found by Kliegel and colleagues (2001), and Kvavilashvili (1998), it is recommended that this effect be studied further in subsequent studies of prospective memory in children.

*Important Findings from the Qualitative, Interview Study*

As indicated, Study 3, the qualitative study, also increased the depth of understanding of the effects of TBI on prospective memory (and other types of memory). In particular, the interview study provided clear evidence of the powerful effects of motivational forces and the role of planning in overcoming or minimising
the effects of prospective and explicit memory losses. The qualitative study also demonstrated the association between prospective memory and independent living. Further, this study found ecological validity for the commonly reported dissociation between explicit and implicit memory. Children and adolescents who habitually forgot names, places and events, were generally able to follow procedures, remember routes to familiar places, and learn by association. Moreover, much was learned about the importance of temporal markers in encoding explicit memory. Without the markers, semantic memory lacks a context, and worse, may lead to poor episodic memory, which in turn, could “rob” young people of a past.

In terms of the relationship between injury severity and outcome, it is generally agreed that outcomes can be predicted most reliably in those with severe TBI, where typically cognitive deficits persist (Kibby & Long, 1996). However, as found in Study 3, some of the children with severe TBI were functioning at a high level. By contrast, some with minor TBI were functioning poorly. There may be several reasons why children with mild brain injuries do not recover, or appear not to recover, as well as expected. First, their difficulties may be exaggerated because of an over-sensitivity to the effects of TBI, where any cognitive or behavioural difficulties are automatically attributed to the TBI. In fact, they may be due to other factors. Second, there may be organic changes in the brain as a result of a mild TBI that are not detected by the usual radiological means. So, the brain appears not to be injured, but in fact, it may be injured. Third, the injury, though mild, and though ordinarily not severe enough to cause harm, may have corresponded with a critical period of development, which in turn interfered with subsequent stages of development.
Finally, interviews with the parents provided excellent suggestions for rehabilitation of memory difficulties.

**Contributions of this Research to the Plasticity Debate**

With respect to the children and adolescents with TBI, it might be concluded from the findings noted so far that the age of injury was significant, and in particular, that being injured as a child afforded an advantage compared with being injured as an adolescent. If this were true, it might give support to the “Kennard” principle, which supports the idea that the younger brain is more “plastic” than the older brain and that therefore, younger children have the potential to recover from TBI better than those who are more mature. Note, however, that nothing like this can be concluded from the current research because of unknown variables. For example, first, might the children with TBI from the current study “grow into” prospective memory and executive function deficits as they reach adolescence? The only way to know this would be to conduct a longitudinal study that retested the current children with TBI and their age peers from the control group at around puberty or soon after on the same measures. Those same children should then be retested in early adulthood. And, second, in the adolescents with TBI, were there any differences in prospective memory and executive function performances between those injured before puberty and those injured after puberty? Unfortunately, in the current research, there were not enough adolescents injured post-puberty to make the appropriate comparisons. Again, a pre- and post-injury comparison of adolescents with TBI is recommended for future research.
Limitations of the Current Research

As noted during the Discussion sections at the end of each of the three studies, this program of research had several limitations. First, there were design flaws with respect to the importance manipulation in Study 1. Perhaps, with some adjustments, the manipulation might have been implemented with the TBI groups in Study 2. The importance manipulation might possibly have been more sensitive to injury effects than it was to age effects in Study 1. Second, the sample of children with TBI could have been larger. Further, the reading-based task seemed to be subject to the effects of variability in reading ability and therefore lacked the sensitivity of the computerised task. In future, the task might benefit from manipulations of prefrontal processing demands. Finally, in not administering the WCST to the non-injured groups, injury effects could not be assessed fully, nor could the role of cognitive switching in prospective remembering be measured.

Recommendations for Follow-Up Research

Firstly, it is important to apply what has been learned about why and how children with TBI have prospective memory difficulties. For example, it is now clear, that the ability to remember prospectively is affected by the level of cognitive demand required to perform a task. Given that young individuals with TBI frequently have restricted prefrontal capacity, their parents, teachers and rehabilitation professionals, should be made aware of the need not to place too great a demand on their already limited resources. So, for instance, prospective tasks should be kept simple, be few in number, and should not be given during busy periods. Similarly, given the role of attention and working memory in prospective remembering, it is imperative to always ensure that when setting a task, the young person with TBI is paying attention, and
that the environment is as free as possible from distractions. Further, it would probably be beneficial to teach some self-awareness skills, to take full advantage of personality strengths, and try to identify and work around weaknesses. And, it would undoubtedly help to spend the time to find out the young persons’ likes and dislikes so that motivational factors can be harnessed as much as possible. Moreover, teaching planning skills would be advantageous. Diary writing is an obvious choice. However, electronic planning devices could also be employed. And, the intervention strategies implemented by parents should be investigated further and applied more widely, as appropriate.

Secondly, an important challenge for future research is to “test” further the prefrontal-model of prospective memory in children. Knowing the neuroanatomical substrates of this type of memory is important in: (a) understanding more about brain-behaviour relationships; and (b) improving predictions of outcomes after injury to that part of the brain, which in turn should better inform the design of rehabilitation programs. Further assessments of the prefrontal model, and investigations of age-of-injury effects could be conducted concurrently if the current children with TBI, and their non-injured peers, were reassessed on the same prospective memory and executive function tasks after they reach adolescence. Similarly, the prefrontal model would be assessed more precisely if adolescents injured before the onset of puberty were compared with those injured after puberty. Another way to test the prefrontal theory would be to do lesion studies in children and adolescents with TBI. Comparisons on prospective-memory tasks between children and adolescents with focal prefrontal, diffuse prefrontal, and extrafrontal injuries would shed more light on this question of whether the prefrontal regions are involved in prospective memory.
Thirdly, other directions in exploring the prefrontal hypothesis are recommended. First, it would be informative to measure prospective memory performance using other methods of manipulating prefrontal capacity. Processes associated with the prefrontal regions, such as working memory, attention, cognitive switching, planning, and reading non-verbal cues suggest themselves as variables that may be manipulated as ongoing tasks. And, rather than having just two levels, there might be several levels, which would help in teasing out more precisely at what point cognitive load or demand exceeds the capacity of the brain to effectively execute two competing tasks. Second, aspects of the prospective task might be varied. For instance, as demonstrated by Kvavilashvili and colleagues (2001) manipulating the location or timing of the prospective cue so that it either interrupts or does not interrupt the performance of an ongoing task, helps demonstrate that the capacity to remember prospectively is dependent on the amount of cognitive resources available. Third, as indicated in the section on limitations, reassessing the importance manipulation with greater care is also potentially informative in testing the prefrontal hypothesis. Fourth, given that prospective memory is not a unitary construct, it would be useful to compare different types of prospective tasks under similar conditions. This would help make it clearer whether different prospective tasks, for example, time-based or event-based, or single tasks versus multiple tasks, require different levels of cognitive resources to execute.

Fourthly, any further exploration of the development of prospective memory needs to incorporate children from a wide age range. However, as realised in the pilot for Study 1, including children across a wide age range presents difficult design challenges. Using the same tasks for 7-year-olds and 18-year-olds produced different
cognitive demands in those age groups. And, that was obviously found to be the case by others previously (e.g., Hitch et al., 1988; Hitch et al., 1989). So, the choices for future explorations of the early development of prospective memory are to find identical ongoing tasks that produce identical cognitive demands for all ages. Perhaps visual-based ongoing tasks might be an option. Or, use adaptations of the same task as was used in the current studies. Whatever choice is made, given what was found in this research, it behoves those in the future to “prove” as well as possible that their ongoing tasks do indeed represent equal demands for all the age groups in the study.

Finally, given the number of possible explanations for poor outcomes after mild or minor TBI, there is much that can be gained from following up on this field in the future. Investigations of psychological and social factors, and the employment of diagnostic tools such as PET scans and brain-chemistry analyses may shed more light on why some children with mild TBI have poor outcomes. More discriminating tests would assist in diagnosing and predicting outcomes more reliably, and would therefore also result in earlier interventions for those found to have previously-undetected brain abnormalities.
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