Executive Function: A comparison between Normal Ageing Adults and Older Adults

suffering Traumatic Brain Injury.

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Table of Contents

List of Tables

Chapter 8 – Older Adults, TBI and Executive Function

Chapter 9 – Study 1 – The Impact of Age on Executive Function

Chapter 10 - Study 2 - The Impact of TBI on Executive Function for Older Adults

Chapter 11 - General Discussion

List of Figures

Chapter 2 - Executive Function the Construct

Chapter 4 - Review of Popular Measures of Executive Function and other Relevant Instruments

Chapter 5 - Literature Review of the Process Fractionation of Executive Function

Chapter 8 – Older Adults, TBI and Executive Function

Chapter 9 – Study 1 – The Impact of Age on Executive Function:

Aims, Method and Results

Abstract

This thesis contrasted the performance of normal ageing adults with older TBI patients on one of the most elusive neuropsychological constructs, executive function. Executive function purportedly controls and integrates cognitive activity, reflecting conscious, strategic goal-directed operations (Stuss & Levine, 2002). However, debate rages as to whether executive function is actually a distinct construct, or merely represents g (Salthouse, 2005; Wood & Liossi, 2007).

With respect to normally ageing, it is promulgated that executive functions are among the first to be impacted given that the 'seat' of executive function, the frontal lobes, decline at a faster rate than other brain regions (West, 1996). The pathophysiology of traumatic brain injury (TBI) also renders the frontal lobes and thus executive function vulnerable (McDonald, Flashman & Saykin, 2002), and older adults have the second higher incidence of TBI. As such, both groups represent logical choices to study and a research paucity exists (Garden, Phillips & MacPherson, 2001; Rappoport et al. 2006). This thesis aims to reduce this paucity by further elucidating the executive function of both these populations. A secondary aim is to further examine the utility of the Alternate Uses (AU) Test (Guilford, Christensen, Merrifield & Wilson, 1978) as a measure of executive function.

Study 1 examines the performance of a normal ageing cohort ($n= 100$, age range 50-79 years) on measures of executive function, memory and processing speed. An age related decline was hypothesised to differentially impact executive measures. The results however ran

contrary to predictions; while there was some impact of age on executive function, memory and information processing speed also suffered.

Study 2 recruited a group of older TBI sufferers ($n = 20$, age range 50-79 years) at 6-12 months post injury. Patients were tested against age and education matched controls from Study 1. Executive function was expected to be preferentially impacted by TBI and this hypothesis was supported. The Alternate Uses paradigm showed sensitivity to both normal ageing and TBI.

Ultimately, the author postulates that executive function may not be a particularly useful concept among normal populations. The equivocal state of the literature, historical problems with defining and measuring executive function and doubt as to whether executive function merely represents *g,* coupled with the lack of a differential age decrement in the current study all contribute to this viewpoint.   Executive *dysfunction* on the other hand has long held relevance in clinical settings.

CHAPTER 1

Overview of the Thesis

Australia, as a developed country has an increasingly ageing population (Myburgh et al. 2008). This is due both to people living longer and the post World War II baby boom (Goldstein & Levin 2001; Hickman, Howieson, Dame, Sexton & Kaye, 2000). The phenomenon will increase as the baby boomer generation reaches 65 years and older (Myburgh et al., 2008). Traumatic brain injury (TBI) is also a major public health issue (Helps, Henley & Harrison, 2008) and underfunded and under studied in Australia (Hillier, Hillier & Metzer, 1997). Aside from representing a major health concern, TBI is of particular relevance to the field of ageing as older adults have the second highest incidence of TBI (Goleburn & Golden, 2001; Myburgh et al., 2008).

Negatively impacted by both normal ageing and TBI, executive function is a logical focus for those with an interest in the cognitive outcomes of either group (Banich, 2009; Bryan & Luszcz, 2000a; Wood & Liossi, 2007). Executive dysfunction is the most common presenting problem in neuropsychological practice (Stuss, & Levine, 2002) and executive functions are among the earliest cognitive competencies impacted by the normal ageing process (Bryan & Luszcz, 2000a). Tests of executive function are relevant in a wide range of clinical and research contexts and executive deficits feature in a wide range of neuropsychiatric conditions (Banich, 2009; Lezak, Howieson & Loring, 2004). Over 2500 articles were published on executive function between 1996 and 2006 (Alvarez & Emory, 2006) and the construct is a relatively recent focus of neuropsychological interest (Jurado & Rosselli 2007; Phillips, 1997; Salthouse, 2005). Nevertheless, executive function remains controversial, and poorly defined and understood. Chapter 2 covers executive function as a

construct, issues of definition, the evolution of theoretical perspectives and introduces some of the controversy around validity, explored in greater detail in subsequent chapters.

The measurement of executive function is the most challenging and problematic area of neuropsychology (Crawford, 1998; Levine, Stuss, & Milberg, 1995). In addition to the issues inherent with the measurement of executive function, there are also methodological issues salient to research in the fields of both cognitive ageing and TBI to consider. Specific methodological issues in the study of TBI are held over until Chapter 8. Chapter 3 covers the issues pertaining to measurement in ageing and executive function. Chapter 4 gives in depth coverage to popular measures of executive function and additional non-executive measures employed by the current investigation.

Although a central executive has been proposed, there is good evidence to suggest that executive function is not unitary (Banich, 2009; Miyake et al., 2000). Process-fractionation models seek to delineate the actual processes occurring when a task postulated to require executive function is performed. The relative contribution of various processes (memory, attention), the non-random involvement of processes which are not intended to be measured (motor speed, visual scanning skill), and the degree of dependence or interdependence of specific executive sub-processes (e.g. inhibition, monitoring, set-shifting) are examined (Miyake et al., 2000). Chapter 5 reviews the literature concerning process fractionation models of executive function.

Chapter 6 covers the neuropathological aspects of ageing and theoretical models of cognitive ageing. Review of the literature investigating the impact of age on executive function is contained within Chapter 7. Chapter 8 deals with TBI in detail. Coverage is given to the pathophysiology and epidemiology of TBI, including the factors that make older adults both more vulnerable to deleterious effects post injury, and those that make them the age group with the second highest incidence of TBI. Methodological issues in the field are

also covered in Chapter 8 before the disparate bodies of literature dealing with the cognitive sequelae of mild TBI (mTBI), the cognitive outcome of older adults suffering TBI, and the impact of TBI on executive function are reviewed.

This thesis comprises two Studies. Study 1 examines executive function in a large normal ageing cohort aged 50-79 years. Measures of information processing speed and memory were also included so that the frontal ageing hypothesis (West, 1996) could be tested against competing global accounts of cognitive ageing. A contribution of this study was the sampling of a narrow age range facilitating the further delineation of the course of executive function in older adulthood. In this field extreme age-group designs predominate. Such designs do not allow examination of whether cognitive decline is gradual, or sharper after a ctricial period is reached. This is seen as an important question by Hedden and Gabrieli (2004). Study 2 examined executive functioning in a cohort aged 50-79 years who had suffered TBI of mild-to-moderate severity in the preceding 6-12 months. This severity range was chosen as most TBI sustained by older adults are within this range, yet paradoxically, very little is known about cognitive outcome at this end of the injury spectrum for older adults (Rapoport et al., 2006). The non-acute post injury phase was chosen given that the chronicity of deficits remains a critical issue (Binder, Rohling & Larrabee, 1997; Lezak et al., 2004). An additional aim of this thesis was to further examine the utility of the Alternate Uses (AU) test (Guilford, Christensen, Merrifield & Wilson, 1978) as a measure of executive function among the two populations of interest (Bryan, & Luszcz, 2000a; Butler, Rorsman, Hill & Rogerio, 1993). As such it was included in both studies.

Chapter 9 details and discusses Study 1, while Chapter 10 details and discusses Study 2. Finally, Chapter 11 provides a general discussion of this thesis, summarising the main results and discusses these in relation to the existing literature, in addition to making suggestions for future research.

CHAPTER 2

Executive Function the Construct

2.1 Defining Executive Function

Executive function is a term that has been fairly well known within the neuropsychological nomenclature for the past two decades. Lezak (1982) popularised the umbrella term 'executive functioning' and Baddeley and Wilson (1988) coined the term *dysexecutive* syndrome. Dysexecutive syndrome refers to the problems that can occur post brain-injury with the break-down in control functions for cognitive, emotional and behavioural responses (Lezak, Howieson & Loring, 2004; Chan & Manly, 2002). Executive function has become a pronounced focus of interest in the field (Jurado & Rosselli, 2007; Phillips, 1999; Salthouse, 2005), with over 2500 articles published between 1996 and 2006 (Alvarez & Emory, 2006).

The field remains both controversial and unclear. Executive function is a psychological construct, and not an anatomical one (Strauss, Sherman & Spreen, 2006; Stuss, 2006) and the term has been a theoretical rather than operational definition (Burgess, 1997). There is little agreement within the literature as to what executive function is, or what the executive functions actually are (Banich, 2009; Daniels, Toth & Jacoby, 2006; Jurado & Rosselli, 2007; Wecker, Kramer, Wisniewski, Delis & Kaplan, 2000).

Banich (2009), Burgess (1997), Lezak et al., (2004) and Stuss et al., (2006), all suggest that executive functions are the most complex of behaviours, whose purpose is to facilitate the ability of the organism to respond in an adaptive manner to novel situations. Bryan and Luszcz (2000a) postulate that executive function controls and integrates cognitive activity, and thus reflects conscious, strategic goal-directed operations. Alvarez and Emory (2006) suggest that executive function describes the process of higher-level functions

controlling lower-level ones. Thus, executive function can be thought of as a meta-cognitive process, the process of an individual marshalling their cognitive resources to adapt to the demands of the real world. Executive behaviours also extend beyond the cognitive to emotional regulation and social interaction. The inappropriate social behaviour of individuals who have suffered frontal lesions is a case in point (Lezak et al., 2004). The social and emotional aspects of executive function are beyond the scope of this review.

Executive function has typically been the concern of those working in rehabilitation settings (Burgess, 1997) and executive dysfunction is the most common presenting problem in neuropsychological practice (Stuss, & Levine, 2002). Executive deficits are a feature of a wide range of neuropsychiatric conditions including ADHD, substance abuse, traumatic brain injury, schizophrenia, the dementias and Parkinson's disease (Banich, 2009; Elliott, 2003; Jester et al., 2009; Kennedy, et. al, 2008) and declines in executive functioning are also associated with advancing age (Bryan & Luszcz, 2000a; Lowe & Rabbitt, 1997; Piguet, et al., 2005). When executive systems break-down, behaviour is poorly organised, poorly controlled and disinhibited (Elliott, 2003; Jurado & Rosselli, 2007). Thus, research has been initially driven by the practical need to understand executive function, rather than as a theoretical endeavour.

2.2 Theories of Executive Function

The field of neuropsychology has lacked an over-arching theory of executive functions. Burgess (1997) calls for the study of executive function to be informed by advances in cognitive neuropsychology, and to attempt to do more than merely describe behaviour or link behaviour with brain structure. Miyake et al., (2000) lamented the "lack of a compelling theory of executive functions" (p. 50), as have Wood and Liossi (2007) since. Banich (2009) has very recently attested that her laboratory, in conjunction with others at the Universities of Colorado and Illinois, will seek to fill this void by developing a theory that

can "better account for the many disparate pieces of knowledge currently available" (p. 92). Such a theory is yet to emerge.

As the construct was rooted in the neuropsychological study of the problems experienced by patients suffering frontal lesion damage (Miyake et al., 2000; Hedden & Yoon, 2006), historically the terms frontal and executive function have been used interchangeably (Strauss et al., 2006). Anatomically the frontal lobes are the seat of executive functioning (Lezak et al., 2004; Stuss, 2006) and the prefrontal cortex is of particular importance (Elliott, 2003; West, 1996). While the other lobes are largely devoted to the processing of sensory information, the frontal cortex is distinct by being generally responsible for the processing of actions (Fuster, 2002). Of course, executive function is not purely frontal in that other cortices are recruited in the service of goal directed behaviour. For example, temporal integration is the result of cooperation between prefrontal and subcortical structures within the frontal lobe and then parietal, occipital and temporal lobes (Fuster, 2002). Thus using the terms frontal and executive interchangeably is unsuitable (Strauss et al., 2006), and has been a source of considerable confusion within this field (Alvarez & Emroy, 2006; Elliott, 2003; Strauss et al., 2006; Stuss, 2006).

2.3 Evolution of Theoretical Perspectives

Luria's (1973) contribution to the field of executive function, before the term was even coined, was to attempt the breaking down of complex cognitive operations into their smaller component parts. Thus Luria endeavoured to operationalise rather than simply describe novel problem-solving and goal-directed behaviour. He suggested that the role of the frontal lobes was to program, monitor and regulate behaviour, giving birth to a three stage theory of executive function. Following Luria, Lezak (1982) popularised the umbrella term 'executive functioning' and expanded Luria's three stages to four components: volition, planning, purposive action and effective performance. Lezak also suggested instruments for

measuring executive function. Baddeley and Hitch's (1974) model of working memory, and Norman and Shallice's (1986) Supervisory System then had a further influence on the field, as each features a central 'executive.' They are described forthwith

2.4 The Central Executive

As an alternative model of short-term memory to that of Atkinson and Shiffrin (1968), Baddeley and Hitch (1974) offered a model featuring three parts. The term working memory (WM) was used as opposed to short-term memory, reflecting that information was both stored *and* manipulated. Germane to this thesis, this model contained a central executive as depicted in Figure 2.1. The central executive was postulated to function as an attentional control system, integrating auditory and visual information from the other slave systems, the phonological loop and the visuospatial sketch-pad (Baddeley, & Della Sala, 1998; Baddeley, & Hitch 1974). A fourth component, an episodic buffer, was later added to the model (Baddeley, 2000).
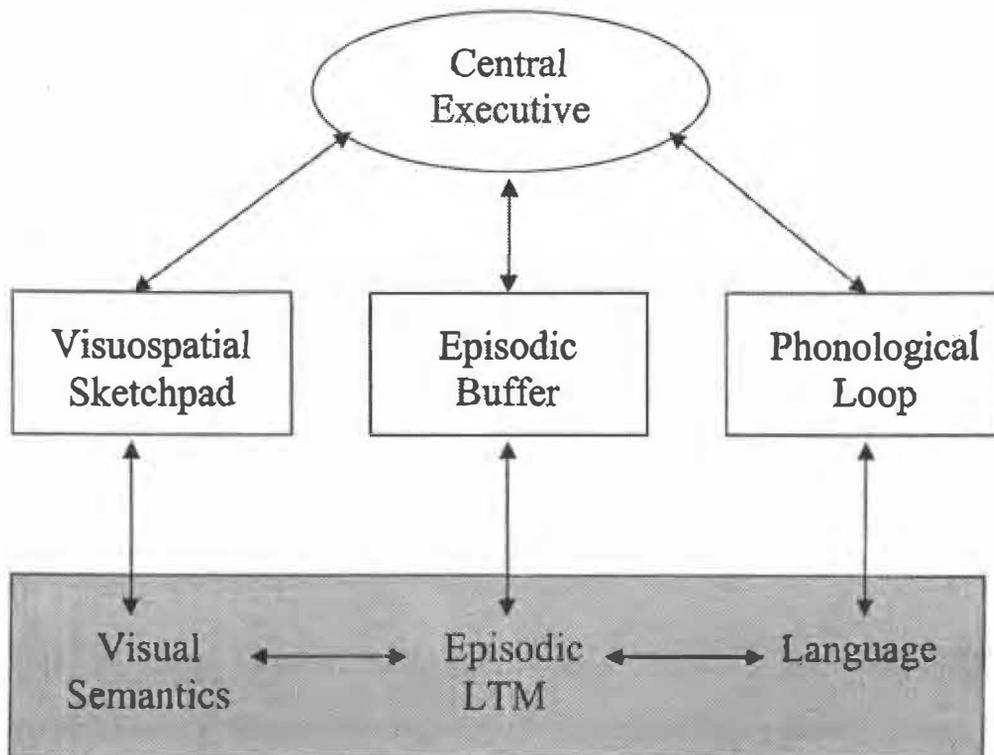
Figure 2.1. Baddeley's revised working memory model. LTM = long-term memory. From "The Episodic Buffer: A New Component of Working Memory?" by A.D. Baddeley, 2000, *Trends in Cognitive Sciences, 4*, p. 421.

Following on from Baddeley and colleagues, Norman and Shallice (1986) introduced

the concept of the Supervisory System. The model, depicted in Figure 2.2, translates

elements of Luria's (1973) ideas into the argot of cognitive psychology and information-

processing theory (Stuss, Shallice, Alexander & Picton, 1995). The model is primarily

concerned with the control of attention, and a central premise is the distinction between

automatic processing and the processing required in novel situations. Novelty of course, is

theorised to draw upon executive function. With a familiar task, habitual and even automatic

responses are enacted. If the task is novel, controlled processing is required, and a selection

of alternatives are formulated and evaluated. Habitual responses may need suppression until

their appropriateness can be established by the Supervisory System, a central executive.
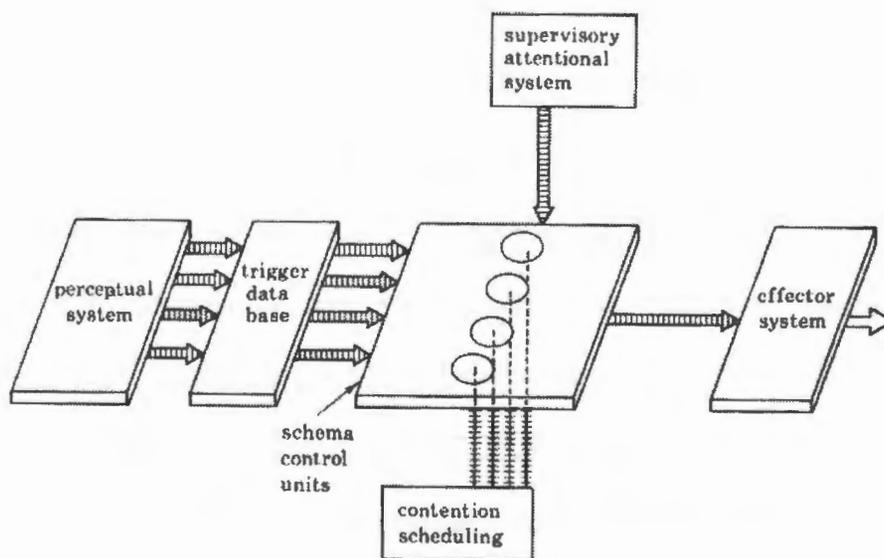
Figure 2.2. A simplified version of the Norman & Shallice model representing the flow and control of information. The lines with arrows represent activating input, the crossed lines represent the primarily mutually inhibitory function of contention scheduling. Adapted from "Specific Impairments of Planning" by T. Shallice, 1982, *Royal Society of London Philosophical Transactions Series B, 298*, p. 200.

As with Lezak (1982), Norman and Shallice not only made a contribution to theory,

but also towards the development of measurement instruments. The Tower of London (ToL)

and Cognitive Estimates Test were devised to test the model as opposed to relying on traditional neuropsychological measures (Bryan, & Luszcz, 2000a).

2.5 An Alternate Account – is Executive Function simply *g*?

An alternate account questions the very validity of executive function as a construct. The position proposed by Duncan, Johnson, Sawles and Freer (1997) and held by Crawford, Bryan, Luszcz, Obonsawin & Stewart (2000), Salthouse (2005) and Wood and Liossi (2007) is that executive function is actually not distinct from general intelligence or "*g*." This postulate, comes in part from the strong correlations between executive measures and other measures of cognition (Obonsawin et al., 2002). However, data has been produced documenting independent contributions to variance in cognitive function, over and above *g*, attributable to executive function (Jester et al., 2009; Levine, Stuss & Milberg, 1995; Strauss et al., 2006; Stuss & Alexander, 2000) refuting explanations of executive function as being non-distinct from *g*. The work of Duncan et al., (1997), Salthouse (2005) and Wood and Liossi (2007) is reviewed in more detail in Chapter 5 and Section 7.1.

2.6 Process Fractionation Models of Executive Function

Although a central executive has been proposed, there is good evidence to suggest that executive unction is not unitary (Fisk & Sharp, 2004; Miyake et al., 2000). There is no homunculus, no little man in the head (Kennedy et. al, 2008; Stuss & Levine, 2002). The debate is lively, Lowe and Rabbitt (1997) suggests that a range of different "frontal" tasks can be employed when considering executive function, and Wecker et al., (2000) note that "many executive function tests do not delineate what is being assessed" (p. 412). While earlier models had a unitary flavour, more recently, Fisk and Sharp (2004) cite a "growing consensus" toward the fractionability of executive processes.

If executive function is to be fractionated, again definitional and operational difficulties abound. Broadly, executive function can be thought of as being made up of

'planning,' 'inhibition,' 'monitoring' and 'control.' These constructs map roughly onto Luria's (1973) framework of, 'program', 'monitor' and 'regulate', and overlap with Lezak's (1982) subsequent notions of 'volition', 'planning', 'purposive action' and 'effective performance.'

Process-fractionation models seek to delineate the actual processes occurring when a task postulated to require executive function is performed. The relative contribution of various processes (memory, attention), the non-random involvement of processes which are not intended to be measured (motor speed, visual scanning skill), and the degree of dependence or interdependence of specific executive sub-processes (e.g. inhibition, monitoring, set-shifting) are examined.

A landmark paper in the attempt to advance theory and present executive function as a fractionable construct was published by Miyake et al., (2000). Miyake and colleagues concluded that there is both diversity and unity within executive function and a hypothesised three-factor model of executive function was supported. The processes identified were Shifting, Updating and Inhibition. A several studies since have examined the validity of separable executive functions. Such endeavours are reviewed in Chapter 5. Before such endeavours are reviewed, consideration of measurement issues in executive function, and review of the more commonly used instruments is timely.

CHAPTER 3

The Measurement of Executive Function within the fields of Ageing and Traumatic

Brain Injury

According to Crawford (1998), executive function can be "regarded as constituting the most problematic area in neuropsychological assessment" (p. 209). There is a need for an increase in the sensitivity of which we can measure executive function, and for greater construct and ecological validity (Burgess et al., 2006; Chan, Shum, Toulopoulou, & Chen, 2008). The need for more valid and sensitive measures will only escalate as the neuropsychologist is increasingly asked to describe function and establish the degree of impairment, as opposed to being asked to localise lesions as in years gone by (Norris & Tate, 2000). Additionally, as our understanding and conceptualisations of executive function become more sophisticated, so too must our measurement instruments, especially with increased emphasis being placed on the fractionation of executive processes (Banich, 2009; Lezak, Howieson & Loring, 2004).

In addition to the issues inherent with the measurement of executive function, there are also methodological issues salient to research in the fields of cognitive ageing and TBI to consider. Measurement issues in the study of ageing will be covered briefly, before issues germane to the measurement of executive function are covered in more depth. Specific methodological issues in the study of TBI are held until Chapter 8, where the epidemiology and pathophysiology of TBI are also dealt with.

3.1 Methodological and Measurement Issues in Ageing Research

A basic consideration in the field of ageing is whether to conduct longitudinal or cross-sectional research (Kail & Cavanaugh, 2000; Hedden & Gabrieli 2004). Longitudinal research reduces measurement error as every participant serves as their own control, while

having the limitations of being logistically more difficult and being time and resource intensive (Hedden & Gabrieli 2004; Park, Polk, Mikels, Taylor & Marshuetz, 2001). Ideally, longitudinal research would cover a minimum of three time-points allowing the detection of curvilinear trends (Christensen et al., 2008). Attrition is often a problem in longitudinal ageing research as mortality and the move from community to institutional settings over the duration of a study is not uncommon (Kail & Cavanaugh 2000; Park et al., 2001). Selective attrition is also an issue, where more interested and motivated individuals, who are often more educated and of higher socioeconomic status, remain (Bieliasuskas, 2001). Another problem that can arise with longitudinal designs, quite salient to executive function, is the possibility that repeated measurement decrease novelty and thus validity (Hedden & Gabrieli 2004; Ettenhofer, Hambrick, & Abeles, 2006; Strauss, Sherman & Spreen, 2006). The related issue of the novelty criterion is examined in Section 3.4.

A cross-sectional approach collects data from different groups (e.g. old vs. young, clinical vs. non-clinical) at a single point in time, or at a number of separate points in time (Kail & Cavanaugh 2000; Park et al., 2001). Such an approach is also not without its disadvantages. This design is associated with the problem of increased measurement error (Howell, 1997). Further, rather than simply increasing random error, cohort effects can exacerbate error in a systematic way as groups can differ on many factors including education, nutrition, and frequency of exposure to words or concepts (Bieliasuskas, 2001; Hedden & Gabrieli 2004; Park et al., 2001). As age groups become more extreme cohort effects typically become more pronounced (van Hooren et al., 2007).

Meta-analyses are well situated to examine the influence of moderator variables of test performance and age (Bieliasuskas, 2001), and for dealing with a sometimes disparate and voluminous literature (Bopp & Verhaegen, 2005; Marczyk, DeMatteo, & Festinger, 2005). Irrespective of which type of design is employed, there are both greater inter- and

intra- individual differences associated with advanced ageing (Bryan, & Luszcz, 2000a; Hedden & Gabrieli 2004; Raz, 2004). Extreme age group designs have been the most frequently used paradigm in the study of executive function and ageing, which is clearly evident in the literature review to follow in Chapter 7.

Another issue in the field of neuropsychology concerns the appropriateness, quality and availability of existing norms (Strauss et al., 2006). For cognitive tests, norms for older adults tend to be from small samples, often of North American origin (Clark et al., 2004). Clark and colleagues also suggests that the ten year age bands typically employed are too broad when studying older adults. Thus any research efforts to contribute more relevant norms, more stratified norms, or norms based on larger samples are meritorious (Strauss et al., 2006).

In the study of ageing, there are important considerations in regard to screening of samples. Screening is necessary to reduce the impact of extraneous variables. Studies of normal cognitive ageing may be contaminated by the inclusion of pre-clinical dementing individuals, which may inturn lead to an overestimation of age related differences (Bieliasuskas, 2001; Hedden & Gabrieli 2004). Thus screening for the presence of such disorders is advisable although we can never be sure that such individuals have not been included (Buckner, 2004; Lezak et al., 2004). Raz (2004) advocates even further screening for cerebrovascular disease, stroke and diabetes due to the negative influence on cerebral structure and function. Most of the studies of normal cognitive ageing reviewed in Chapter 7 select participants as community dwelling, and exclude on the basis of neuropsychological conditions and major physical or psychiatric illness. So while the careful screening of samples is certainly advocated, judiciousness is recommended due to the potential for samples to become increasingly less representative the more heavily they are screened (Cahn-Wiener, Malloy, Boyle, Marran & Salloway, 2000; Rapoport et al., 2008). The danger is that

the performance of older adults may actually be overestimate due to an unrepresentatively healthy sample (Hedden & Gabrieli, 2004).

3.2 Difficulties with Definition, Operationalisation and Validity

The terms 'frontal' and 'executive' have often been used interchangeably within neuropsychology (Bryan, & Luszcz, 2000a; Strauss et al., 2006). As individuals with frontal lobe lesions had difficulty on many of the most popular measures such used today, such as the Wisconsin Card-Sorting Test (WCST), Phonemic Fluency, Semantic Fluency, Design Fluency and the Stroop, these tasks came to be regarded as tests of frontal function (Lezak et al., 2004; Strauss et al., 2006). In a rather circular fashion, the approach was then to label tests sensitive to frontal damage as 'executive tests,' and then to validate such tests on those with frontal lesions (Chan et al., 2008; Stuss & Levine, 2002).

This is problematic as a relationship between frontal damage and impairment on a particular test does not automatically render the task a valid test of executive function (Bryan, & Luszcz, 2000a), and is also inaccurate as both frontal and non-frontal areas are recruited in the performance of such tasks (Strauss et al., 2006). More recently, the call has been made to examine the properties of such measures and the processes they invoke with greater reference to definitions of executive function and theory (Banich, 2009; Miyake et al., 2000). However, it is difficult, as suggested by Jurado and Rosselli (2007), to establish the validity of a group of tests, when the construct itself is ill defined.

Newer tests such as the Tower of London (ToL), Cognitive Estimates Test (CET), and the Self-Ordered Pointing Task (SOPT) have been developed from the cognitive neuroscience literature (Bryan, & Luszcz, 2000a; Phillips, Wynn, McPherson & Gilhooly, 2001). Such measures were devised based on the actual processes *theorised* to make up executive function, and *then* validated by their ability to detect executive dysfunction within populations who have sustained frontal lobe damage (Bryan, & Luszcz, 2000a; Chan et al.,

2008). An area of opportunity in the study of executive function is to further validate both the newer and existent measures, that is to establish what is actually being measured when a purportedly executive task is administered (Jurado & Rosselli, 2007; Miyake et al., 2000).

3.3 Task Purity / Impurity

The issue of the degree of task purity / impurity is another challenge. As a meta-process, executive function, by very definition covers multiple cognitive domains and thus tasks cannot be considered process 'pure' (Ettenhofer et al., 2006; Stuss et al., 2002). Performance on any individual task represents the pooled outcomes of many distinct functional processes both executive and non-executive (Miyake et al., 2000; Rabbitt, 1997). Further, to be valid, executive measures also require a fair degree of complexity, rendering them effortful (as opposed to automatic) (Chan et al., 2008; Shallice, 2002). However, increasing complexity is psychometrically paradoxical because as intricacy increases tasks load on multiple executive and non-executive processes (Strauss et al., 2006; Stuss, & Alexander, 2000). It is difficult enough to establish the purity of different executive tasks from one another, and even more difficult to distinguishing between 'executive' and 'non-executive' ones (Bryan & Luszcz, 2000a).

3.4 Novelty and Ecological Validity

A major threat to the validity of test of executive function is the need for novelty (Lezak et al., 2004; Stuss, & Levine, 2002). When studying executive function we seek to generalise from these experimental tasks as to how individuals will marshal their cognitive resources when faced with a new situation in the real world. Thus, novelty is necessary by definition. Achieving novelty however is difficult to say the least, especially if a measure is to also be reliable (Ettenhofer et al., 2006; Strauss et al., 2006). To quote Burgess (1997), "the measurement of behaviour in novel settings is like shooting a moving target" (p. 110).

In routine, over-learned tasks, the demands on executive function are reduced or even minimal. Neuropsychological tests generally have the following properties; instructions are clear, trials are short, initiation is prompted by the examiner and goals and successful performance are typically well-outlined (Bamdad, Ryan and Warden, 2003; Garden, Phillips & MacPherson, 2001). These same properties pose a threat to the validity of executive function and lead some writers to go as far suggesting that the structure of the testing situation functions as frontal lobes by proxy (Lezak et al., 2004; Wood & Liossi, 2007). It is far from unusual in the clinical realm for an individual to appear unimpaired on standard tests of executive function while very real problems in daily life ensue (Kennedy et. al, 2008; Lezak et al., 2004; Spencer & Johnson-Greene, 2009). The situation may arise out of both a lack of sensitivity and a lack of ecological validity on the part of existing measures (Bamdad et al., 2003; Burgess et al., 2006).

As aforementioned in Section 3.1, the novelty criterion can be threatened further in executive function research employing a longitudinal design. Chan and colleagues (2008) suggest that even when parallel versions of a task are used novelty may be compromised after even a single administration, as do Lowe and Rabbitt (1997). Lezak et al., (2004) consider some tests such as the WCST to be "one shot." However, the argument against repeated measurement of executive function is mixed. West, Murphy, Armilio, Craik and Stuss, (2002) produced data to suggesting that practice effects, on the tasks they used at least, are negligible, as did Ettenhofer et al (2006). The issue can also be addressed in part by the use of psychometrically adequate parallel forms (Ettenhofer et al., 2006; Strauss et al., 2006). Due to the varying properties across different instruments it is wise to consider suitability for repeated measurement on a test by test basis.

3.5 Reliability

Given the difficult state of affairs in relation to defining and operationalising executive function and the multi-factorial nature of the construct, it is unsurprising that there are also reliability issues with many measures of executive function. Low correlations between tests of executive function are common, with inter-correlations being typically around $r = .4$ or lower (Lowe & Rabbitt, 1997; Miyake et al., 2000; Obonsawin et al., 2002). It is difficult to ascertain the extent to which the tasks themselves have inherently poor reliability, or merely reflect the involvement of non-executive processes, and differences in strategies employed to complete the task or different aspects of executive function (Chan et al., 2008; Jester et al., 2009). As aforementioned in Section 3.4, decreased novelty after a prior administration may also reduce reliability. Measures that have greater external validity such as the Multiple Errands Test (MET, Shallice & Burgess, 1991) or the Alternate Uses (AU) Test (Guilford, Christensen, Merrifield & Wilson, 1978), both reviewed forthwith in Chapter 4, typically have inherent difficulties with objective scoring (Bryan, & Luszcz, 2000a; Knight, Alderman & Burgess, 2002).

3.6 Sensitivity

Sensitivity of measures employed is an issue in both the clinical and experimental realm. Clinically, measures must be able to detect the dysexecutive problems that manifest themselves as very real problems in living while not being readily apparent on such instruments as the WAIS or the WMS (Lezak et al., 2004; Strauss et al., 2006). Experimentally, when studying 'normal' adults, tests must be sensitive enough to detect sub-clinical decrements in function (Bryan, & Luszcz, 2000a), or when examining conversion rates from mild cognitive impairment to dementia (De Jager, Hogervost, Combrinck, & Budge, 2003).

Sensitivity is a particular issue for some of the more traditional measures of executive function (Butler, Rorsman, Hill & Rogerio 1993). As aforementioned, most of these traditional measures were developed on patients with frontal lesions (Lezak et al. 2004; Strauss et al., 2006). As such, the question arises when a lack of differences in normal populations is apparent, as to whether the lack of difference reflects the absence of an age related decline, or merely a lack of sensitivity on the part of traditional clinical neuropsychological measures employed (Bryan, & Luszcz, 2000a). Compounding the situation, the most sensitive measures are long and unpleasant (such as the WCST), which may make them less than ideal for use with older adults and other populations (Bryan, & Luszcz, 2000a; Lezak et al., 2004).

3.7 Heterogeneity of Measures Employed

There is no "gold standard" for measuring executive function (Banich, 2009; Ettenhofer et al., 2006) thus the heterogeneity of measures employed is another complicating factor (Hart, Whyte, Kim & Vaccaro, 2005; Strauss et al., 2006). This makes cross-study comparisons difficult. Even if one took a popularist approach and used the most common measures (the WCST, the Stroop, the Trail Making Test, Phonemic and Semantic Fluency), multiple variations of these measures exist further complicating matters. Often adoption of variants makes methodological sense, such as versions of Card-Sort or Tower type tasks, where length and difficulty are manipulated intentionally. In other cases deviations from established versions and procedures are perplexing and add unnecessary 'noise' to an already befuddling field (Hart et al., 2005).

3.8 Summary

There are design and measurement issues germane to the fields of both cognitive ageing and executive function. All research warrants careful sampling and the field of ageing is one where this is particularly salient. Inter and intra-individual differences become more

pronounced with advanced age (Ardilia, 2007; Raz, 2004) and cohort effects can inflate measurement error (Hedden & Gabrieli, 2004; Lezak et al., 2004). The measurement of executive function is especially problematic (Crawford, 1998; Phillips, 1997). Among the difficulties that exist are heterogeneity of measures used and the lack of a 'gold standard' (Strauss et al., 2006). Due to the inherent complexity of the construct, and difficulties in defining and operationalising executive function, validity and reliability problems abound (Lezak et al., 2004; Chan et al., 2008). Despite advances in the field, the measurement of executive function remains a challenge to neuropsychologists and others concerned with the construct (Banich, 2009; Chan et al., 2008). Thus, while existing measures may be inadequate, insensitive or invalid on multiple grounds, they nevertheless are the best tools we have at the current time. The measures most relevant to this thesis are reviewed in the next Chapter.

CHAPTER 4

Review of Popular Measures of Executive Function and other Relevant Instruments

Although readers will be familiar with many of them, it is useful to cover the measures of executive function most commonly encountered within the literature. Broadly, measures can be considered 'traditional,' that is coming out of efforts to study frontal function, including such measures as Trail Making Test (TMT), the Wisconsin Card Sort (WCST), the Stroop and various fluency paradigms, or as being 'newer,' arising from a cognitive neuroscience approach, with the Cognitive Estimates Test (CET), the Self-Ordered Pointing Test (SOPT), and Tower Tests, among others, serving as exemplars (Bryan, & Luszcz, 2000a; Lezak, Howieson, & Loring, 2004; Phillips, Wynn, McPherson, & Gilhooly, 2001). The Alternate Uses (AU) task (Guilford, Christensen, Merrifield & Wilson 1978) is also covered in particular detail given the secondary of aim of this thesis to further test its usefulness as a measure of executive function. Two relatively recent batteries, the Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan & Kramer, 2001), and the Behavioural Assessment of Dysexecutive Syndrome (BADS; Wilson, Alderman, Burgess, Emslie, & Evans, 1996) will also receive attention. After measures of executive function are detailed, selected divergent measures used by the current investigation will also be reviewed.

4.1 Fluency Tasks

Fluency tasks utilise the technique of item generation and are frequently used in neuropsychology to assess executive function. Although procedures vary across the numerous paradigms, basically, participants are required to produce as many unique responses as they can while avoiding repetitions. While memory and associational networks are implicated, such tasks are argued to tap executive processes as better strategy usage, mediated by executive function, aids performance (Bryan, & Luszcz, 2000b; Butler,

Rorsman, Hill & Rogerio, 1993). These tasks also have other executive components as they require initiation, monitoring of output and remaining cognisant of rules (Lezak et al., 2004; Strauss et al., 2006). Fluency measures are typically conceptualised as measures of cognitive flexibility (Henry & Crawford, 2004).

4.1.1 Phonemic Fluency

Henry and Crawford (2004) suggest that Phonemic Fluency tasks were originally devised as measures of Verbal Intelligence Quotient (VIQ), while they are now frequently used to assess executive function (Lezak et al., 2004; Phillips, 1999). Participants are typically asked to produce words beginning with a particular letter, over a short time period (typically one minute). The 'F, A and S' combination, originating with Benton is the best known, giving rise to the name 'FAS' (Tombaugh, Kozak, & Rees, 1999). Subject are informed that the use of proper nouns is prohibited, as are variations of the same word (fly, flew, flying) and repetitions. The term COWA or COWA T (Controlled Oral Word Association Task) is used by some researchers to refer to Verbal fluency only, and by others to refer to both Phonemic and Semantic Fluency tasks being administered. As such, the moniker COWAT is avoided herein to remove confusion.

Phonemic Fluency tasks are thought to be executive in nature as strategic retrieval of information is required, as well as monitoring of output to ensure that responses confirm to task rules and are goal relevant (Bryan, & Luszcz, 2000a; Turner, 1999). Phillips (1997) suggests that someone with inefficient executive function employs poorer strategy and thus generates fewer words. However, the validity of Phonemic Fluency as a measure of executive function is contestable, as many authors suggest that the act of performing letter fluency may be a straight, simple process of lexical access rather than one which is executively demanding (Fisk & Sharp, 2004; Ross, Hanouskova, Giarla, Calhoun & Tucker, 2007; Shores, Carstairs & Crawford, 2006).

According to a comprehensive norming study by Tombaugh et al., (1999), Phonemic Fluency performance is more education than age sensitive, with these variables accounting for 18.6% and 11% of the variance respectively. Thus, Lezak et al., (2004) advocate the use of norms that take into account demographics. Gender effects are minimal although there is sometimes a slight advantage in favour of educated females (Lezak et al., 2004; Tombaugh et al., 1999).

Parallel forms such 'CFL', 'BHT' and 'PRW' exist (Bennett, Ong & Ponsford, 2005a; Ross et al., 2007; Troyer, Moscovitch & Winocur 1997), with high reliability being noted (Lezak et al., 2004; Troyer et al., 1997). Lezak et al. note that scores are fairly stable across time making the task suitable for longitudinal work. Ettenhofer, Hambrick, and Abeles (2006), Ross et al., (2007) and Tombaugh et al. (1999), have all recorded test-retest reliability between r .73-.84.   The utility of qualitative scoring methods is covered forthwith in Section 4.1.3.

In terms of sensitivity, there is often a failure to detect age differences within normal populations (Bryan, & Luszcz, 2000b; Troyer et al., 1997; Parkin, & Java, 1999; Phillips, 1999; Rhodes, & Kelley, 2005; Troyer et al., 1997; 2000). Bryan and Luszcz (2000a) suggest the task may not be sensitive enough to detect differences in non-clinical samples although Tombaugh, et al., (1999) recorded declines after 59 years of age when education is held constant by using a broad age range and regression methods. An alternate explanation for the lack of age related differences in normal populations is offered by Hughes and Bryan (2002). They suggest that the superior word knowledge of older adults assists their performance when compared with their younger counterparts, masking differences which may otherwise be apparent. In contrast to the measure's status within the field of ageing, the sensitivity of the Phonemic Fluency tasks to the impact of TBI is well established (Belanger, Curtiss, Demery, Lebowitz & Vanderploeg, 2005; Henry & Crawford, 2004).

4.1.2 Excluded Letter Fluency

The Excluded Letter Fluency paradigm originated with Crawford, Wright and Bate (1995). This task requires participants to articulate as many words as possible that *do not* contain specified letters (*E* and *R,* or parallel in form *A* and *T*) in two 60 second trials (Hughes & Bryan, 2002; Strauss et al., 2006). By increasing the tasks demands the paradigm is thought to involve more than just straight lexical access and is thus a more potentially valid alternative to the standard Phonemic Fluency task (Shores et al., 2006). Crawford et al., (1995) have demonstrated TBI sensitivity and Bryan and Luszcz (2000b) demonstrated age sensitivity. Bryan and Luszcz (2000b) and Hughes and Bryan, (2002) have recorded internal consistencies between *r* .61-.76 for trials using the letters "A" and "E." Shores et al., (2006) published reliability and normative data from a large sample of young adults aged 18-34 years. In the Shores et al. cohort, internal consistency between the letters A, E and I was $r =$ .84, and 1-year test-retest reliability coefficient was $r = .67$. A degree of discriminant validity is evident as the measure correlated at only $r = .45$ with WAIS-R full scale IQ scores (Shores et al.). The Excluded Letter Fluency paradigm has not yet been widely adopted.

4.1.3 Semantic Fluency

Semantic Fluency tasks require respondents to name as many category members as they can think of, most commonly 'animals,' or 'grocery items' (Lezak et al., 2004; Tombaugh et al., 1999). Category members can start with any letter and repetitions are to be avoided (Strauss et al., 2006). The Semantic Fluency task is both one of the more sensitive traditional neuropsychological measures and one of the more widely employed (Lezak et al., 2004; Henry & Crawford, 2004). The need to generate a self-initiated search strategy is said to reflect executive process (Bryan, & Luszcz, 2000a).

In terms of scoring, the most common index is the total number of correct responses less errors (repetitions or non-category members). Some researchers also investigate

'Clusters' and 'Switching' of responses on this task, and also have done so to a lesser extent with the Phonemic Fluency paradigm (Hughes & Bryan, 2002; Raskin & Rearick, 1996; Ross, et al., 2007; Troyer, 2000). 'Clusters' are defined as with the number of words within a particular Semantic or Phonemic category, and 'Switching' as the process of moving from one Cluster to the next. The work of Ross et al., suggests that scoring systems for calculating clusters and switches have poor inter-rater and test-retest reliability. Hughes and Bryan (2002) and Raskin and Rearick (1996) both produced results where such additional analyses were largely uninformative. The interested reader can see Mayr (2002) for further critique of the methods for calculating such indices, and also Lezak, et al., (2004).

Test-retest reliability for the Semantic Fluency task over one month is moderate at $r = .56$ according to Bird, Papadopoulou, Ricciardellie, Rossor and Cipolotti (2004), although when studying older adults over a relatively short time period Ettenhofer et al., (2006) returned a much higher $r = .81$. It is unsurprising that reliability for Semantic Fluency is lower than for Phonemic Fluency as only one trial is used for the former, in contrast to the typical three for the later (Ross et al., 2007; Strauss et al., 2006). Results from the norming study by Tombaugh et al. (1999) indicate Semantic Fluency to be sensitive both to age (accounting for 23.4% of the variance) and education (accounting for 13.6% of the variance). Lezak et al., (2004) advocate the use of norms that take into account demographics, such as those offered by Tombaugh et al. (1999). Gender effects are noted as being insignificant (Lezak et al., 2004; Tombaugh et al., 1999). The sensitivity of the Semantic Fluency paradigm to TBI has also been established (Henry & Crawford, 2004; Raskin, & Rearick, 1996).

4.1.4 Alternate Uses (AU) Test

The desirability of developing and validating brief tests of executive function has raised interest in adapting other measures (Butler et al., 1993; Levine, Stuss, & Milberg,

1995). A measure of Ideational Fluency, the Alternate Uses (AU) Test, also known as Uses for Objects, is one such example. Originally devised as a test of divergent thinking (Guilford et al., 1978; McCrae, Ehrenberg & Costa, 1987), this task can be considered executive in nature by virtue of not only requiring the participant to select appropriate search strategies, but by also representing a novel and somewhat ambiguous situation (Bryan, & Luszcz, 2000a; Turner, 1999).

The AU test requires participants to give as many different uses for a particular object (for example, 'bottle,' 'paper clip,' and 'hat') as possible within a specified time period. The time given per trial, the number of trials and the stimulus objects themselves vary considerably across the literature. Responses are scored as either correct or incorrect. Errors include perseverations, repetitions and merely describing the object rather than giving a use (Bryan, & Luszcz, 2000a). Researchers concerned with the study of creativity also score responses for the degree of novelty by either making a subjective judgement or by calculating infrequency of response statistically (Hocevar, 1979).

McCrae, et al., (1987) professed to document declines in divergent thinking with advanced age, although with the exception of the 'consequences' test, measures employed were more tests of Phonemic and Semantic Fluency, despite the monikers used. Butler et al., (1993), claimed to be the first to apply AU test to a clinical population although Grattan and Eslinger (1989), and Wilson and Gilley (1992), were both published earlier. Grattan and Eslinger sampled a mixed lesion group and investigated cognitive flexibility and empathy. Differences between control subjects and patients on empathy are reported, but the AU data is only reported as correlation coefficients of its relationship with empathy. It is frustrating that Grattan and Eslinger did not make control versus clinical group comparisons for the AU task. Wilson and Gilley (1992) demonstrated a lack of significant differences between Parkinson's sufferers and controls subjects on the AU task. Butler and colleagues (1993)

documented significantly poorer AU performance for those with frontal lobe lesions in comparison to normal controls. Turner (1999) demonstrated impaired AU performance in Autism sufferers when contrasted with normal controls, and also impaired performance for autistic subjects with high intellectual functioning on the task relative to controls with IQ scores lower than 76. In contrast to Wilson and Gilley, differences between matched controls and Parkinson's sufferers were documented by Tomer, Fisher, Giladi and Aharon-Peretz (2002).

Bryan and Luszcz (2000b), Parkin and Java, (1999) and Parkin and Lawrence (1994) have all shown the AU task to be age sensitive. In terms of sensitivity to TBI, Milders, Fuchs and Crawford (2003) recorded a trend for poorer performance of TBI sufferers relative to controls, while Crawford et al., (1995) published a conference abstract suggesting that the AU task was the most sensitive of verbal fluency measures employed within a TBI sample.

In terms of established psychometrics, Bryan and Luszcz (2000b) recorded internal consistency between the objects 'bottle' and 'paper clip' to be $r = .72$, and inter-rater reliabilities of between r .70-.99. Bryan and Luszcz (2000a; 2000b) note that objective scoring of the task is difficult and that considerable training and discussion among raters was necessary before reliability could be achieved. By way of convergent validity, Parkin and Lawrence (1994) noted an $r = .38$ between Alternate Uses and Phonemic Fluency after the influence of IQ was partialled out, while Obonsawin et al., (2002) recorded an $r = .47$ between AU performance and Phonemic Fluency which reduced to $r = .26$ once WAIS-R IQ was partialled out. Turner (1999) argues for ecological validity, postulating that the ability to generate a new idea or line of action is a necessary component in the executive control of behaviour. Publication of further psychometric and normative data is needed, as is the establishment of standard procedures.

4.1.5 Figural Fluency

Figural Fluency tests, also known as Design Fluency, were designed to be analogous to their verbal counter parts (Goebel, Fischer, Frestl & Menhdorn, 2009; Strauss et al., 2006). Such tasks require respondents to generate as many novel abstract designs as possible. As with Verbal Fluency tasks, such tests are argued to be executive in nature as better strategy usage aids performance (Goebel et al., 2009). Early 'free' conditions were difficult to score reliably (Lezak et al., 2004; Strauss et al., 2006) which led to the development of figural versions. Subjects are given dotted matrices, and required to connect dots to produce unique designs. The most common versions are the Ruff Figural Fluency Test (RFFT; Ruff, Evans, & Marshall, 1986) and its forerunner, the Five Point Figure Test (FPFT; Regard, Strauss & Knapp, 1982; Goebel et al., 2009). The Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan & Kramer, 2001; reviewed subsequently in Section 4.10) also contains a variant. The FPFT is within the public domain while the RFFT is commercially distributed (Lezak et al., 2004; Strauss et al., 2006).

The principal difference between the FPFT and the RFFT are the matrices. The FPFT stimuli are pages with identical square grids, featuring a five-point dot design arranged in eight rows of five columns (Strauss, et al., 2006). The RFFT stimuli pages also feature five dots matrices (Ruff et al., 1986). The RFFT stimuli are more complex than that of the FFPT, being asymmetrical and changing across five successive trials. Trial 1 features the standard 5 dot grid, while trials 2 and 3 feature the same grid with the addition of distracter stimuli (diamonds and lines respectively). In trials 4 and 5 distracter stimuli are absent, while the dot matrices are variations on the original from trial 1 (Ross, Foard, Hiott and Vincent, 2003; Strauss, et al., 2006).

Figural fluency tasks are usually scored for productivity in the same manner as verbal ones, that is, the total number of correct designs minus errors, and for total perseverative

errors. Goebel et al., (2009) and Ross et al., (2003) have also devised qualitative ratings of strategy employed during performance of the FPFT and the RFFT respectively. The usefulness of such qualitative scoring needs to be established further.

Despite similar psychometric properties, there are poor correlations between the three most popular variants of this task (Strauss et al., 2006). Both the RFFT and the FPFT are typically free of gender effects and feature high inter-rater reliability (Goebel et al., 2009; Lezak et al., 2004; Ross et al., 2003; Strauss et al., 2006). Both paradigms are subject to considerable practice effects (Goebel et al., 2009; Kraybill & Suchy, 2008; Ross et al., 2003) which could render them unsuitable for repeat administration.

In terms of validity, in a study by Goebel and colleagues (2009), the FPFT correlated significantly with IQ score and Trail Making Test Part-B (TMT-B) performance only, but not with Phonemic Fluency. Kraybill and Suchy (2008) noted a similar relationship between the TMT-B, the RFFT, and a lack thereof for Phonemic Fluency. Thus, while exhibiting executive properties, Figural Fluency paradigms seem most similar to the TMT-B in requiring flexibility in the visuospatial domain as opposed to being visual analogues of verbal fluency (Kraybill & Suchy, 2008; Strauss et al., 2006). In terms of motor skill, Kraybill and Suchy examined the contribution of motor processes to RFFT performance. Ruff et al., (1986) had previously noted a relationship between performance and motor speed in severe but not moderate TBI cases. Kraybill and Suchy found that RFFT productivity did not correlate with a measure of motor fluency (making unique hand movements) and that the contribution of motor speed was relatively low (4.5%) giving further evidence of validity. Milders et al., (2003) reported that depressed motor speed in TBI patients did not fully account for the differences between TBI sufferers and controls on this measure.

Figural fluency measures are sensitive to both age and education (Lezak et al., 2004; Strauss et al., 2006). In the study of the FPFT by Goebel et al., (2009) education accounted

for 26.8% of the variance in performance, with a further 18.7% accounted for by age. Conversely, Kraybill and Suchy (2008) found only a slight correlation with age for the RFFT, however the age range of their sample was more restricted (18-60 years). Ross et al., (2003) and Ruff, Light and Evans (1987) have both shown the RFFT to be age sensitive. Ruff et al. (1986) and Milders et al. (2003) have shown the RFFT to be sensitive to the impact of TBI.

4.2 The Stroop Task

The Stroop Task is one of the most widely used neuropsychological measures and the prototypic paradigm for examining individual differences in susceptibility to interference (Banich, 2009; Stuss, Floden, Alexander, Levine, & Katz, 2001). Multiple versions exist, including the commercial 'Golden' version, a version included in the D-KEFS and the Victoria version (Lezak et al., 2004; Strauss et al., 2006). In the 'classic' paradigm individuals first read the names of colours written in black ink, followed by naming colour patches, and finally, naming colours printed in a non-corresponding colour (Stuss et al., 2001). Pachana, Thomspon, Marcopulos & Yoash-Gantz (2004) have developed a variant specifically for use with older adults to get around the issue of blue / green confusion, although such an issue was not identified in review by Bryan and Luszcz (2000a). The Pachana et al. version of the Stroop does not appear to have been widely adopted, having not been encountered in any of the literature reviewed in subsequent Chapters.

All Stroop trials are timed and it is the slowing of performance in the final trial (the 'interference' or 'incongruent' trial) or the comssion of errors which are of primary interest (Bryan, & Luszcz, 2000a; van der Elst, van Boxtel, van Breukelen & Jolles, 2006). Although variants on the control trials exist, the interference condition is common across versions. Scores obtained are either time to complete the various trials, or number of items completed within a certain time period (depending on the version used), and the number of errors made. Interference indexes can also be calculated and are preferable to simply taking

the score for the incongruent trial as such a calculation allows for correction in baseline variability in processing speed (Strauss et al., 2006; Troyer, Leach, & Strauss, 2006). Analysis of errors is less common, especially among normal ageing samples, due to the low frequency in which such errors occur (Strauss et al., 2006; Stuss et al., 2001). When errors occur on the incongruent trial, they reflect the failure of inhibition.

The Stroop test can be considered an executive control task as it requires the avoidance of a habitual but goal-irrelevant response (word reading) in favour of a less-practiced but goal-relevant one (naming the colour of the ink in which the word is written) (Bugg, DeLosh, Davalos, & Davis, 2007; van Hooren, Valentuin, Ponds & van Boxtel, 2007). The data of Troyer et al., (2006) provides strong support for the Stroop's validity as a test of the executive domain of inhibition, rendering an age related global slowing explanation far less tenable. The Stroop is known to be age sensitive (Bryan, & Luszcz, 2000a; Klein, Ponds, Houx & Jellemer 1997; van Boxtel, ten Tusscher, Metsemakers, Willems & Jolles, 2001; van der Elst et al., 2006; Troyer et al., 2006; Wecker, Kramer, Wisniewski, Delis & Kaplan, 2000) and is also sensitive to the impact of TBI (Chan, 2000), but not within mTBI range (Strauss et al., 2006). The impact of age had a far larger effect (r =. 62) than the contribution of education (r .14 -.24) according to Troyer et al., (2006). In Klein et al.'s (1997) study, IQ contributed around 10.5% of the variance.

The reliability of the Stroop test is deemed sound by Nelson, Yoash-Gantz, Pickett and Campbell (2009) and Strauss et al. (2006), and satisfactory by (Lezak et al., 2004). Test-retest reliability over a short interval of ($r = .68$) has been recorded by Ettenhofer et al., (2006). No gender effects were recorded by Pachana, Thomspon, Marcopulos and Yoash-Gantz (2004) or Troyer et al., (2006), while van der Elst and colleagues (2006) recorded an advantage for females, an advantage that was only minimal in the data of Klein et al., (1997).

Debate exists around the most appropriate version of the Stroop. Both Bryan and

Luszcz (2000a) and Lezak et al., (2004) suggests that longer version of the Stroop are most

sensitive, while Klein and colleagues (1997) postulate the opposite. Both Strauss et al.

(2006), and Troyer et al. (2006) take issue with the norms provided for the Golden Version,

and advocate use of the Victoria Version given its brevity, the existence of well-stratified

norms and by virtue of it being in the public domain. Overall it remains unknown the degree

to which the various versions of the Stroop are correlated with one another (Strauss et al.,

2006; van der Elst et al., 2006).

4.3 The Trail Making Test (TMT)

Trail Making tasks are variously suggested to reflect the ability to shift mental set, the

ability to exercise inhibition and interference control, and planning and sequencing ability

(Mitchell & Miller, 2008; Sanchez-Cubillo et al., 2009). The task has been considered

variously as an attentional measure and as one of executive function (Sanchez-Cubillo et al.,

2009; Strauss et al., 2006). The TMT is within the public domain (Lezak et al., 2004) and is

amongst the most popular measures within neuropsychology (Ettenhofer et al., 2006;

Tombaugh, 2003).

The TMT consists of two parts. In Part A, the stimulus page consists of consecutively

numbered circles, while for Part B, stimuli consists of circles with co-varying numbers and

letters. Part A serves as a control trial; the participant is required to connect the circles in

numerical order as rapidly impossible. For Part B, participants are to connect alternate circles

by number-letter-number in ascending order as rapidly as possible. Strauss et al., (2006) give

detailed instructions for administration.

It is common for many researchers to administer only Part B and record completion

time; errors and ratio scores are not commonly reported within the literature (Demakis,

2004). Sanchez-Cubillo et al., (2009) and Lezak et al., (2004) suggests that trial B time

minus trial A removes processing and motor speed components, making it the purest measure. However, Perianez et al., (2007), using both a mixed clinical (TBI and schizophrenia) and normal sample, found B-A to correlate with TMT-B score at $r = .9$, suggesting that B-A is redundant. This however threatens validity as the high degree of co-linearity suggests that cognitive flexibility is not the main determinant of performance (Lezak et al., 2004).

Tombaugh (2003) conducted a large norming study ($n = 911$ normal adults, age range 18-89 years). Age was much more highly correlated than education, with the two variables shown by regression analysis to account for 58% and 6% of the variance respectively. Upon further exploration of the impact of education, the variable was found to exert an influence only on those older than 54 years, and then it only accounted for between 3-7% of the variance. The work of Hester, Kinsella, Ong and McGregor (2005) also suggests that gender and education exert only a nominal influence. Tables of stratified norms provided by Tombaugh (2003) greatly extended those available previously, and Hester et al., (2005) provide further stratified Australian norms for use with older adults.

Reliability is noted by both Lezak et al., and Strauss et al., (2006) to be adequate, especially for Part-B. However, test-retest reliability for a ratio score over a short time period among older adults was poor at $r = .23$ in the study by Ettenhofer and colleagues (2006). The task is known to be sensitive to age (Hester et al., 2005; Tombaugh, 2003) and TBI (Sherrill-Pattison, Donders, & Thompson, 2000; Spikman, Deelman & van Zomeren, 2000). The TMT's utility for use with mTBI populations has been questioned by Strauss et al., while Lezak et al. argue that large standard deviations on Part-B may obscure true differences and thus contribute to such negative findings.

4.4 Dual-Tasks

Attention, the physiological process of selective apportionment of neuronal resources is often postulated as coming under executive control (Fuster, 2002; Shallice & Burgess, 1998). Thus, allocation of attention in demanding circumstances is often of interest to those studying executive function (Falconer, Geffen, Olsen & McFarland, 2006). Dual tasks require different cognitive operations to be conducted simultaneously allowing the assessment of divided attention. Dividing attention is contested to make demands on the central executive according to the theory of Supervisory Attentional System (Norman & Shallice, 1986; Shallice, 2002; Shallice & Burgess, 1998).

Divided attention and selective attention decrease more heavily with advanced age than the ability to sustain attention or concentrate (Bieliasuskas, 2001; Treitz, Heyder & Daum, 2007). These facets of attentional control are also negatively impacted by TBI (Chan, 2000; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994). A heterogeneous range of dual tasks are employed in the field of executive function and ageing (Fisk & Sharp, 2004; Treitz, et al., 2007), and the field of executive function and TBI (Chan, 2000; Mangels, Craik, Levine, Schwartz & Stuss, 2002; Mathias, Beall & Bilger, 2004). In terms of fractionating executive processes, dual tasks are typically independent of g and load separately from other executive measures (Bate, Mathias & Crawford, 2001; Chan, Hoosain & Lee, 2002; Fisk & Sharp, 2004; Miyake et al., 2000).

4.4.1 Telephone Search while Counting (TSC)

As a dual-task, the current investigation utilises the Telephone Search while Counting (TSC) subtest from the Test of Everyday Attention (TEA; Robertson et al., 1994). The TSC consists of two parts. In the first, participants merely look for key symbols while searching entries in a simulated telephone book under timed condition. In the second, participants again search in the telephone book, this time while being required to simultaneously count

audio tone strings, under timed conditions. The difference in time taken between the two conditions, corrected for accuracy, gives a measure of divided attention; a 'dual task decrement' (Robertson, et al.). This is effectively the 'cost' of dividing attention.

Robertson et al., (1994) do not provide data on internal reliability, which Strauss et al., (2006) speculate is due to the speeded nature of the task. Test-retest values are marginally acceptable to poor, with $r = .59$ being recorded by both Chan et al., (2002) and Robertson et al. in ethnically different samples. At face value, the task has ecological validity as it is designed to approximate everyday activity (Strauss et al.). In terms of divergent validity, the correlation of TSC with the National Adult Reading Test (NART; Nelson, & O'Connell, 1978); as a measure of g, is almost non-existent at $r = -.03$ (Robertson et al.). Chan et al., (2002) found that TSC did not correlate significantly with TMT-B, Digit-Symbol Coding, Digit Span, the Six Elements Test (SET; Shallice & Burges, 1991), Multiple Errands Task (MET; Shallice & Burgess, 1991), Stroop or Verbal and Figural Fluency tests, with correlation coefficients of r .06-.18 being recorded. In a study by Bate and colleagues (2001), correlations for the TSC with the Stroop, Paced Auditory Serial Addition Test (PASAT; Gronwall, 1977), digit symbol, digit span and a measure of selective attention ranged between r .24-.37   When factor analysis is used, TSC appears to load on a factor separate from other facets of attention and other measures from the TEA, suggesting that TSC is indeed a valid measure of divided attention (Bate et al., 2001; Chan et al., 2002).

Robertson et al., (1994) argue that despite the poor reliability of the TSC, the virtue of the task is its great sensitivity to central dysfunction. The TSC successfully discriminated stroke sufferers from aged matched controls in the 65-80 year age range, but not in the 50-64 year old age range (Robertson et al). The TSC also successfully discriminated moderate and severe TBI sufferers at a mean time of 14 months post-injury from controls (Robertson et al). Ziino and Ponsford (2006) however failed to demonstrate differences in a sample of mixed

TBI severity relative to controls, although great heterogeneity in time since injury and large SDs in the TBI group may have obscured such differences. Bate and colleagues (2001) did not detect differences between controls and severe TBI patients on the TSC, and suggest that Robertson et al. may have been able to do so due to the use of a small sample, by having a shorter post-injury interval and by failing to control for the influence of IQ. Conversely, Hennessy, Geffen, Pauley & Cutmore (2003) found that the TSC was the only measure of several employed which differentiated mTBI sufferers from orthopaedic controls at one month post-injury. Chan (2000) also detected differences in mild-to-moderate TBI cases relative to controls, although his patients were specifically selected as having attentional problems which would be expected to bias the results. Despite the purportedly high sensitivity of the TSC, this task does not appear to have been previously employed by published studies of normal ageing. Remaining untested among normal ageing groups, and having some sensitivity among TBI groups even at the milder end of the injury spectrum, the instrument is worthy of further study and an appropriate inclusion in the current study.

4.5 Wisconsin Card Sort Test (WCST)

The Wisconsin Card Sort Test (WCST) remains among the most thoroughly researched and most common measures of executive function (Burgess et al., 2006; Ord, Greve, Bianchini & Aguerrevere, 2010). It is variously suggested to assess concept and rule acquisition, maintenance and shift of set (Bryan, & Luszcz, 2000a; Strauss et al., 2006). Participants are given four cards with different stimulus properties, as depicted in Figure 4.1. After being dealt the stimulus cards, in the standard version, the participant is given two decks of 64 cards (Lezak et al., 2004; Rhodes, 2004). These cards have similar properties to the original four stimulus cards; that is these cards are geometric shapes, varying in both number of shapes per card and in colour. The cards can be sorted by shape, number of shapes

per card, matching the shapes (e.g. sorting stars with stars), or colour, again illustrated in Figure 4.1.
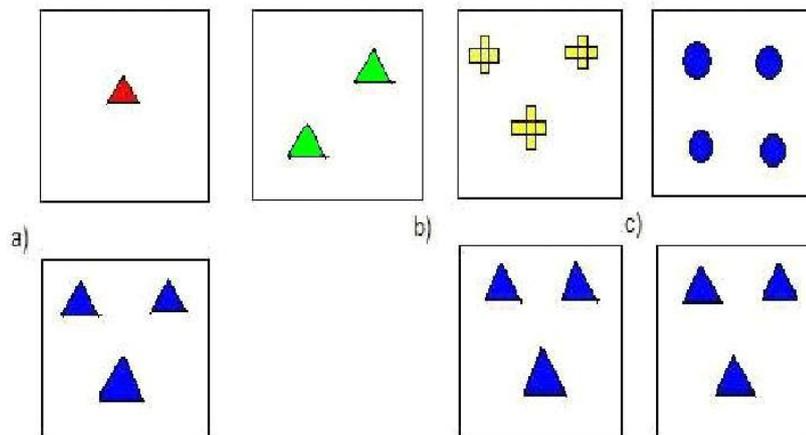
Figure 4.1. The WCST. Cards are sorted by either a) shape, b) number, or c), colour.

Participants are not given instructions as to the sorting rules, but merely given feedback in the form of 'yes' or 'no' as to whether a sort was correct by the examiner; the sorting rule changes without warning (Lezak et al., 2004; Rhodes, 2004). A perseverative response would be sorting by an old rule, even after being given negative feedback several times suggesting that the sorting rule has changed. Individuals suffering frontal lobe damage frequently respond perseveratively on this task (Banich, 2009).

The task is considered difficult due to the unannounced sorting rule changes and the task's length (15 to 30 minutes). As such many respondents find the task relatively unpleasant and this is identified as a barrier for work with older adults (Bryan & Luszcz, 2000a; Rhodes, 2004). Several versions and modifications exist. Scoring procedures vary but commonly include the number of categories achieved (maximum of 5), and the number of perseverative errors (Bryan, & Luszcz, 2001; Lezak et al., 2004). In a meta-analysis of age effects Rhodes (2004) found a similitude of effect sizes across these two indexes, with perseverative errors being marginally more sensitive. Many of the other scores than can be

calculated exhibit high inter-correlations between the two main scores and as such are deemed redundant (Strauss et al., 2006).

Age differences are well documented for the WCST, especially after 75 years of age (Rhodes, 2004). More difficult to establish is the mechanism underlying such a decline; whether the decrement represents an executive deficit, or alternatively either a decline in WM or generalised slowing (Rhodes, 2004; Lezak et al., 2004; Strauss et al., 2006). Miyake et al., (2000) and Fisk and Sharp (2004) provided good evidence for a unique executive deficit over and above the contribution WM and processing speed. Education is deemed to have only a small impact, while the impact of IQ is modest (Strauss et al.). Obonsawin and colleagues (2002) showed a Modified Card Sorting Task (MCST) to be independent of g.

Card Sorting Tasks are typically free from gender effects according to Strauss et al., (2006) and the postulate is supported by the results of Proctor and Zhang, (2008). The WCST has documented sensitivity to TBI (Goldstein, & Levin, 2001; Goldstein, Levin, Goldman, Clark, & Altonen, 2001; Leon-Carrion, et al., 1998). Mild patients are typically unimpaired outside of the acute phase, while a dose-severity relationship exists for moderate to severe cases (Ord et al., 2010).

Reliability for the WCST is typically poor (Strauss et al., 2006). This is unsurprising given that success is dependent on discovering the sort and shift principle, once this is achieved,the subject is unlikely to forget (Lezak et al., 2004). This highlights the issue of novelty discussed previously in Section 3.4, and as such the task may need to be regarded as 'one-shot' (Lezak et al.). As the impact of practice and repeat administration is significant, equations and tables correcting for repeat administration have been collected and reproduced in Strauss et al.

4.6 Tower of Hanoi (ToH) and Tower of London (ToL)

Multiple versions of Tower Tasks exist, with the most common versions being the Tower of Hanoi (ToH) and the Tower of London (ToL) (Lezak et al., 2004; Sullivan, Riccio & Castillo, 2009). The former is an oriental puzzle, of which the latter is a modification allowing task difficulty to be graduated for psychometric purposes (Bryan, & Luszcz, 2000b; Lezak et al.,). A Tower task is also included within the Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan & Kramer, 2001) battery.

Tower tasks require participants to arrange discs onto posts from a starting position, to a predetermined target positions, in as few moves as possible (Sullivan et al., 2009), as depicted in Figure 4.2. Sub-goals need to be met to achieve the final position, thus the task is said to measure planning and goal-management (Banich, 2009; Bryan & Luszcz, 2000a). Working memory and inhibition are also implicated (Lezak et al., 2004; Sullivan et al., 2009).
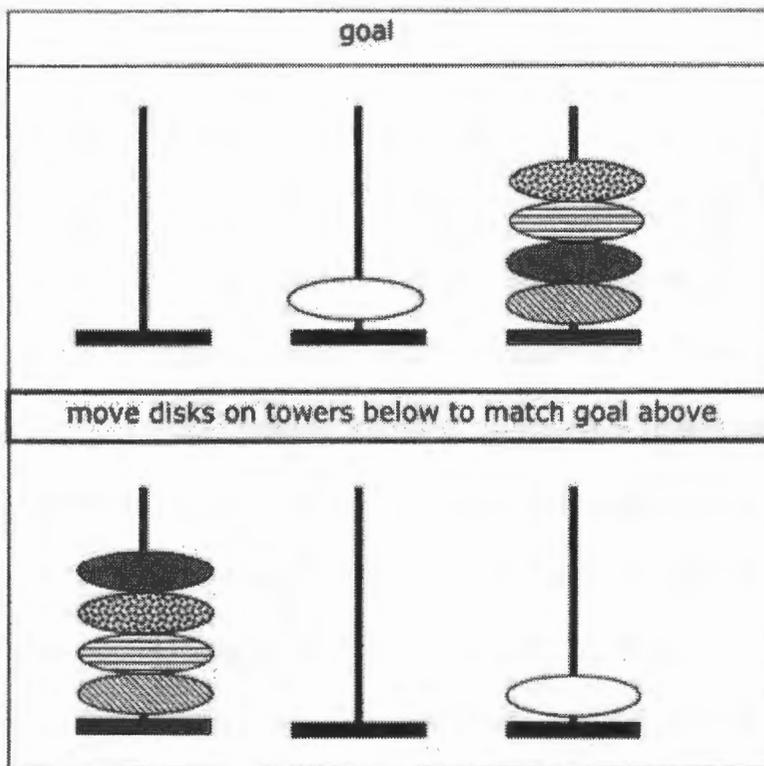
Figure 4.2. Example of a ToL trial. From "Mental Planning and the Tower of London Task" by L.H. Phillips, V.E. Wynn, S. McPherson and K.J. Gilhooly, 2001, *Quarterly Journal of Experimental Psychology, A, 54*, p. 580.

The score taken is typically the number of moves required to achieve the solution (Humes, Welsh, Retzlaff & Cookson, 1997; Sullivan et al., 2009). Some examiners take note of initiation time, completion time and rule violations (Sullivan et al.). In addition to face validity, Humes et al., and Sullivan et al., note good evidence from neuroimaging and electrophysiological studies implicating the neuroanatomical correlates of frontal and pre-frontal cortex activation. Tower tasks are sensitive to a wide range of neurodegenerative and psychopathological conditions in addition to focal lesions (Humes et al; Sullivan, et al.). In terms of ageing, Sullivan and colleagues conclude results are equivocal. Tower Tasks are also known to be sensitive to TBI (Chan, Chen, Cheung, Chen & Cheung, 2004; Leon-Carrion et al., 1998) although the evidence is far from voluminous.

4.7 The Cognitive Estimates Test (CET)

Cognitive estimation is an executive domain originally proposed by Shallice and Evans (1978) and thus the Cognitive Estimates Test (CET) was devised, emerging from the newer cognitive neuroscience tradition (Bryan, & Luszcz, 2000a). Participants are asked a series of questions and then required to provide approximate answers (Spencer & Johnson-Greene, 2009; Strauss et al., 2006). Multiple versions exist. The questions are designed so that they cannot be answered directly from crystallised knowledge, but require deductive reasoning and problems solving processes to arrive at a plausible answer (Bryan & Luszcz, 2000a; Spencer & Johnson-Greene, 2009). The task requires participants to generate reasonable estimates of quantifiable attributes of common object or familiar concepts. For example a participant might be asked "How long is the average necktie?," or "How fast do racehorses gallop?" Responses are then scored as falling within or outside the acceptable range based on normative data.

Due to the problem solving processes invoked by the CET, the task has been considered executive in nature. However, in review Strauss and colleagues (2006) raise

doubts as to the CET's construct validity, suggesting the task more taps *g* and knowledge retrieval, noting only a modest relationship to other executive measures. Spencer and Jonson-Greene (2009) have also taken a critical position after proffering data where the CET correlated non-differentially with both executive and non-executive tasks. Additionally, Spencer and Johnson-Greene noted the poor ability of the CET to differentiate between normal individuals and those in the acute stage of neuropsychological insult. Strauss and colleagues decree that the CET is far from valid or reliable, suggesting much more work is necessary to establish the task's theoretical and clinical relevance.

4.8 The Self-Ordered Pointing Task (SOPT)

The Self-Ordered Pointing Task (SOPT) also arises from a cognitive neuroscience framework (Bryan & Luszcz, 2000a). It is purported to be executive in nature by requiring behavioural regulation, and the use of plans, strategy and effective monitoring for successful performance (Ross et al., 2007; Hedden & Yoon, 2006). Participants are required to point to a single item from an array of abstract stimuli. Over successive trials the participant is required to continue to point to stimuli which have not been gestured to previously; successful performances requires the employment of strategy to keep track of designs not previously selected.

In review, Strauss et al., (2006) challenge the validity of the SOPT, noting processing speed and WM to be more likely determinants of successful performance than executive processes per se. This postulate is in agreement with the results of Schmitter-Edgecombe and Chaytor (2003) who found the poor performance of severe TBI patients to be attributable to memory rather than executive deficits. Bryan and Luszcz (2001) found a significant contribution of WM among the normal ageing and some unique variance attributable to executive function. Reliability is modest across trials at $r = .38$ (Bryan and Luszcz, 2001). The task has some age sensitivity (Bryan and Luszcz, 2001; Garden, Phillips & MacPherson,

2001), and is also sensitive to TBI (Schmitter-Edgecombe & Chaytor, 2003). As with the CET, Strauss et al., surmise that available psychometric data is scant and more research into the task's validity and utility is necessary.

4.9 The Multiple Errands Task (MET) and the Six Elements Test (SET)

The Six Elements Test (SET) and the Multiple Errands Task (MET) originate with Shallice and Burgess (1991). These two tasks were devised in an effort to develop measures that were ecologically valid and adequately sensitive to detect executive dysfunction among those who performed within the average range or above on more traditional measures (Knight, Alderman & Burgess, 2002). Both measures are theorised to tap planning and the monitoring of goal relevant behaviour (Garden et al., 2001). The SET gives participants six sub-tasks to allocate time to and perform within rule constraints. A version of this task is also included in BADS (Wilson et al., 1996).

The MET assesses similar functions to the SET but is conducted in a real world shopping setting, being reliant on field observation by the examiner for scoring (Garden, 2001). The MET has the greater ecological validity, while the SET is easier to administer and standardise in clinical practice (Knight et al., 2002; Wilson et al., 1996). The version of the SET included in the Behavioural Assessment of Dysexecutive Syndrome (BADS; Wilson et al. 1996) has test-retest reliability of $r = .33$ among normal controls with the low reliability attributable to the loss of novelty after the initial administration according to the developers. Knight and colleagues found a hospital version of the MET to have good internal consistency at $r = .77$, and inter-rater reliabilities of between $r. 81$-1.0. Neither of these paradigms receives coverage by either Lezak et al., (2004) or Strauss et al., (2006) as measures in their own right.

4.10 The Delis-Kaplan Executive Function System (D-KEFS)

The D-KEFS (Delis, Kaplan & Kramer, 2001) is a relatively recent nine test executive function battery. With regards to executive processes, the D-KEFS purports to measure cognitive flexibility, inhibition, problem solving, planning, impulse control, concept formation, abstract thinking and creativity (Homack & Riccio, 2005; Mitchell & Miller, 2008) although both Lezak et al., (2004) and Strauss et al., (2006) note the absence of a theoretical rationale for test selection. Extensively normed ($N = 1750$), the battery captures a large range of ages (8 -89 years) delineated into16 bands. The D-KEFS is predominantly comprised of adaptations of existing measures with extended floors and ceilings (Lezak et al., 2004; Mitchell and Miller, 2008). Administering the entire battery is said to take 90 minutes (Homack & Riccio, 2005).

Psychometrically, the core tests hold up well, with the optional procedures faring less so (Strauss et al., 2006). The test developers do not offer any reliability data for the optional tests and reliabilities remain problematic (Crawford, Sutherland & Garthwaite, 2008; although see Shunk, Davis & Dean, 2006 for a more generous view). Work by Mitchell and Miller (2008) provides a modest degree of support for the ecological validity of the D-KEFS, with selected subtests shown to have some utility in predicting activities of daily living among a community dwelling sample. Both Homack and Riccio (2005) and Strauss et al. (2006) concur that further work is needed to establish the instrument psychometrically.

4.11 The Behavioural Assessment of Dysexecutive Syndrome (BADS)

While the D-KEFS is extensively normed, the BADS (Wilson et al., 1996) concentrates on being ecologically valid. The BADS is comprised of six tests seeking to tap cognitive flexibility, problem solving, planning, judgement and behavioural regulation. Many of the BADS subtests are original, with the remainder being adaptations of newer measures. Administration takes less than an hour. The BADS also includes a supplementary 20 item inventory, the Dysexecutive Questionnaire (DEX).

Inter-rater reliability for the BADS subtests ranges from r .88-1.0, and test-rest

reliabilities among normal controls range from between r.33-.71, with the exception of the

Key Search subtest scoring poorly at $r = -.08$ (Wilson et al., 1996). These values highlight a

validity / reliability trade-off; novelty is lost after a repeat administration reflected in the

reduced reliability coefficients according to Wilson et al., although Strauss et al. (2006)

contest that this is yet to be quantified by research. Problems have been noted when using the

Temporal Judgements subtest with populations outside of the U.K.; the norms derived from

the original U.K sample do not seem to apply (Bennett, Ong and Ponsford, 2005a; Proctor &

Zhang, 2008). This proves troublesome when calculating the overall BADS executive score

and although imperfect, Bennett et al., (2005a) recommend excluding this subtest and

prorating the score as an average of the other five subtests. Bennett et al., (2005a) report

overall reliability of $r = .60$ for the executive score, which increases slightly to $r = .63$ if

Temporal Judgements is dropped.

In terms of validity of the various processes, the results of Bennett et al., (2005a) are

encouraging. Using factor analytic techniques they found a relationship between the Zoo Map

subtest from the BADS and TMT-B and the Porteus Maze Test, a relationship between the

BADS version of the SET and the WCST, and a relationship between the subtests Action

Program and Cognitive Estimation, and a relationship between Key Search and Rule Shift

from the BADS and Lezak's (1982) Tinker Toy Test. Bennett et al. (2005a) deem the SET

and Action Program subtests most sensitive to brain dysfunction using a mixed clinical

sample, consistent with Wilson et al.'s (1996) earlier finding with respect to TBI. The BADS

overall executive score correlates with its individual constituent parts at between r .49-.76,

with the exception of Temporal Judgements, coming in at a poorer $r =.28$ (Bennett et al.,

2000a). The individual subtests themselves are inter-correlated at values between r .21-.50,

excepting Temporal Judgements relating to the other subtest at between only r .01-.09 (Bennett, et al., 2000a).

In terms of predicative validity, in an Australian study, Norris and Tate (2000) found that the BADS performed comparably to more traditional measures in distinguishing between a control and neurologically compromised group, while being superior to traditional measures in predicting real world functioning. Normative data is based on a sample of only 216 normal adults, and from a mixed clinical sample of only 78 individuals (Wilson et al., 1996). Strauss et al. 2006 are critical of the poor description of the normative sample, particularly the lack of demographic data. The supplementary measure, the DEX, has been subject to considerable criticism, lacking both validity and reliability (Bennett, Ponsford & Ord, 2005b; Gerstorf, Siedlecki, Tucker-Drob & Salthouse, 2008; Norris & Tate; 2000).

4.12 Executive Measures - Summary

The more conventional tests of executive function such as Verbal Fluency measures, the WCST, the TMT and the Stroop remain the most popular and widely used. The availability of normative data is generally superior in contrast to newer measures developed from a cognitive neuroscience perspective such as the CET, the SOPT and Tower Tests. Batteries by Delis et al., (2001) and Wilson et al., (1996) are relatively recent additions to the field and their development indicates increasing neuropsychological interest in measuring executive function in a sophisticated and systematic fashion.

4.13 Non-Executive Measures of Interest

Several other cognitive measures of interest are given coverage forthwith. Most are commonly encountered within the literature. While instruments of interest within the field are far from limited to those reviewed subsequently, those selected merit the level of detail given herein, due to their employment by Studies 1 and 2.

4.14 Hopkins Verbal Learning Test-Revised (HVLT-R)

The Hopkins Verbal Learning Test-Revised (Brandt, & Benedict, 2001) is a measure of list learning originally devised for work with dementia populations. It also serves as a shorter alternative to measures such as the California Verbal Learning Test (CVLT; Delis, Kramer & Ober, 1987) and the Rey Auditory-Verbal Learning Test (RAVLT; Lezak et al., 2004). The HVLT-R improves upon the original by adding a delayed recognition trial (Benedict, Schretlen, Groninger & Brandt, 1998). Participants are presented with 12 words from 4 different semantic categories. Three learning trials are conducted to give an immediate memory score, followed by a 20-25 minute delayed free recall condition, in addition to a 24 item word recognition trial (Benedict et al., 1998). Multiple alternate forms are available for repeated measurement (Strauss et al. 2006).

The measure possesses face validity and convergent validity. Despite being shorter in number of items, the HVLT correlates with the CVLT at $r = .74$ (Lacritz & Cullum, 1998). Reliability coefficients among older subjects from the norming study by Benedict et al., (1998) were acceptably high for total recall ($r = .74$), delayed free recall ($r = .66$) and poorer with respect to recognition scores (between r .39- .46).

In terms of age sensitivity, age accounts for more (19%) of the variance than education (5%) according to the data of Brandt and Benedict (2001). Older adults in the study by Lacritz and Cullum (1998) produced scores within the range of younger subjects in the study Benedict et al., (1998). However, Lacritz and Cullum acknowledge the similitude may be an artefact of superior education level as older adults in their study had an average of 16.2 years of education. In a study by Vanderploeg et al. (2000), age effects were small at 3.7% of the variance and most pronounced after 80 years of age.

Hester et al. (2004) noted a contribution of education but an absence of gender effects, whereas for the data of Vanderploeg and colleagues (2000) the inverse applied; the effect of gender was larger, accounting for 8.5% of the variance, with a 3 point advantage being found

for females, while the contribution of education was surprisingly negligible. While Brandt

and Benedict (2001) did report significant gender effects, Strauss et al. (2006) note that in

that data gender accounted for only 1.7% of the variance and as such is of little clinical

significance. The HVLT-R has not been used widely in the field of TBI. Sensitivity to mTBI

has been demonstrated within only 2 days of injury or less (Bruce & Echemendia 2003;

Falconer, Geffen, Olsen & McFarland 2006).

4.15 The Rey-Osterrieth Complex Figure Test (ROCFT)

The Rey-Osterrieth Complex Figure Test (ROCFT) is a measure of visual memory

and perceptual organisation (Fastenau, Denburg & Hufford, 1999; Strauss et al., 2006).

Respondents are presented with the complex geometric figure and required to copy it without

warning that it will need to be reproduced either immediately and / or after a delay (Lezak et

al., 2004; Strauss et al., 2006). Alternate figures based on the same paradigm have been

devised by Taylor, as reproduced in Lezak et al. and Strauss et al. Scoring can be done in

accordance with a number of systems (for reviews see Lezak et al. and Strauss et al.) with

Taylor's 36 point scoring system the most conventional (Gallagher & Burke, 2007, Fastenau

et al., 1999; Strauss et al.2006). Care is needed in selecting appropriate norms given the

variability in administration procedures and the samples used (Gallagher & Burke, 2007;

Lezak et al., 2004).

The task is sometimes conceptualised as having an executive component although

Strauss et al., (2006) opine that the evidence is lacking. In agreement with this postulate are

the results of a study by Temple, Davis, Silverman and Tremont (2006) where executive

measures did not predict ROCFT scores in a large clinical sample.   The ROCFT is reliable,

as is the Taylor scoring method (Lezak et al., 2004; Strauss et al., 2006). Practice has an

effect, hence the availability of alternate forms and corrections for practice (see Strauss et

al.). The age sensitivity of the ROCFT is well established, especially after 70 years (Fastenau

et al., 1999; Gallagher & Burke, 2007; Rosselli & Ardila, 1991). Sensitivity to TBI and other

pathology is also well established (Bigler et al., 1996; Fernandez, Bartolomore & Ramos,

2002; Temple et al., 2006). Gender differences have proved controversial, and are at best

nominal (Fastenau et al., 1999; Gallagher & Burke, 2007; Lezak et al., 2004; Strauss et al.,

2006). While significant relationships between education and the ROCFT exist, the impact is

small, accounting for less than 3% of the variance in the norming study of Fastenau et al.

(1999). Review by Strauss et al., indicates that the impact of education is inconsistent across

studies.

4.16 Digit Span

Digit Span tasks require participants to recall random number strings of increasing

length, presented aurally in Forwards and Backwards conditions (Lezak et al., 2004; Strauss

et al., 2006). Aside from looking at total Digit Span scores, Digits Forwards and Backwards

are often examined separately as clinical lore postulates the two tasks capture separate

processes (Lezak et al., 2004; Myerson, Emery, White & Hale, 2003). The argument is that

for Digits Backwards, information must not only be held in working memory, but also

manipulated to reverse the string which is more complex and taxing thus implicating

executive processes (Bopp & Verhaegen, 2005; Bunce & MacReady, 2005). Therefore, any

dissociation between Digits Forward and Backwards is postulated to reflect executive

function, and as such should be greatest among older adults in comparison to their younger

counterparts (Hester et al., 2004; Myerson et al., 2003).

Lezak et al., (2004) firmly postulates the two indexes are highly different from one

while Strauss et al., (2006) take the opposite position. Strauss and colleagues actually argue

that by treating Digits Forward and Backwards as a single measure, little is obscured and

reliability is increased. In their meta-analysis, Bopp and Verhaegen (2005) found age

differences for Digits Forwards and Backwards, with Digits Backwards being the more

sensitive of the two tasks. This is in contrast to earlier meta-analysis by Verhaeghen,

Marcoen and Gossens (1993) where effect sizes for Digits Forward and Backwards were said

to be comparable. When analysing WAIS-III normative data both Hester et al., (2004) and

Myerson et al., (2003), found no differential rate of span decline for Digits Backwards versus

Forwards. Wilde, Strauss and Tulsky (2004) found no differential rate of span decline

between Forwards and Backwards conditions and the non-differential decline held for the

eldest groups. The correlations with age were remarkably similar, $r = -.24$ for Forwards and r

$= -.25$ for Backwards (Wilde et al., 2004). Hickman, Howieson, Dame, Sexton and Kaye

(2000) noted no differences between adults 65-74, in comparison to those aged 84-93, on

Digits Forward or Backwards either at baseline, or over four years longitudinally.

Digit Span is very reliable; average reliability for this index was $r = .90$, with a range

of r .93-.84 depending on age group, with test-retest reliability of $r = .80$ (Psychological

Corporation, 1997a). The task is stable in terms of age until the seventh decade (Lezak et al.,

2004; Myerson et al., 2003; Psychological Corporation, 1997a) and robust to the impact of

TBI (Aharon-Peretz et al., 1997; Blake Fichtenberg, & Abeare, 2009; Duncan, Johnson,

Sawles & Freer, 1997; Langeluddecke & Lucas, 2003). Education has some effect (Hester et

al., 2004; Ostrosky-Solis & Lozano, 2006) while gender does not (Hester et al., 2004;

Hickman et al., 2000).

4.17 Digit Symbol-Coding

The Digit-Symbol Coding subtest from the WAIS-III is a popular measure of

information processing speed (Lezak et al., 2004). The respondent is required to transpose

abstract symbols associated with a particular number onto the record form while consulting

the coding key. A similar non-Wechsler alternative is the digit-symbol coding is the Symbol-

Digit Modalities Test task by (Smith, 1982).

Digit-Symbol Coding is multifaceted test (Joy, Kaplan & Fein, 2004). Although the task captures information processing, graphomotorspeed and memory also contribute to performance (Lezak et al., 2004; Strauss et al., 2006). Nevertheless, information processing speed remains the primary determinant (Joy et al., 2004; Kennedy, Clement & Curtiss, 2003; Kreiner & Ryan, 2001). Incidental learning account for only 5-6% of the variance, and WMS-III index scores around 15% (Joy et al). Due to the speeded nature of digit symbol-coding, the test developers report test-retest reliabilities rather than split-half (Psychological Corporation, 1997a). The average reliability for this index was $r = .83$, with a range of r .79-.87 depending on the age group (Psychological Corporation, 1997a).

Digit symbol-coding is sensitive to age (Ardilia, 2007; Lezak et al., 2004). Age explained 50% of the variance when analysing data from the WAIS-III the standardisation sample, while the effect of education was only modest (Joy et al., 2004). There is often a gender advantage in favour of females (Lezak et al., 2004; Ryan, Kreiner & Tree, 2008) The processing speed index is the most sensitive to pathology of the WAIS indexes , a finding replicated among TBI sufferers (Axelrod, Fichtenberg, Liethen, Czarnota & Stucky, 2001; Blake et al., 2009).

4.18 Summary – Non Executive Measures

To study executive function with sufficient rigour to test rival hypotheses, it is necessary to use measures from other domains. While the non-executive measures reviewed herein represent by no means an exhaustive list, they warranted coverage due to their use in the current investigation. Non-executive measures typically have better established construct validity than executive ones.

CHAPTER 5

Literature Review of the Process Fractionation of Executive Function

As discussed previously in Chapter 2, earlier models of executive function had a unitary flavour. There is now however a growing consensus towards, and emphasis on, the fractionability of executive processes (Banich, 2009; Fisk & Sharp, 2004, Kennedy et. al, 2008; Lezak, Howieson & Loring, 2004; Stuss & Levine, 2002). Process fractionation models seek to delineate the actual processes occurring when a task postulated to require executive function is performed. Such models have application for investigations considering the stability of the organisation of executive function throughout the ageing process (Hull, Martin, Beier, Lane, Lane and Hamilton, 2008; Miyake et al., 2000). Studies utilising a process fractionation approach are reviewed forthwith.

A study by Duncan, Johnson, Sawles and Freer (1997) was concerned not only with the fractionability of executive function, but also as to whether executive function could be separated from *g*. Duncan and colleagues recruited a heterogeneous TBI sample. They found that executive and non-executive measures correlated with one another to a similar magnitude (*r* .26-.29), arguing that executive function was not distinct from *g*. A caveat is warranted however.

In the larger of Duncan et al.'s (1997) two studies, issue can be taken with the purportedly executive measures chosen: the Wisconsin Card Sorting Test (WCST); Semantic Fluency; the Rey Auditory-Verbal Learning Test (RAVLT) and a block-type puzzle. It is contestable that only the WCST and the Semantic Fluency task are tests of executive function. The block design task may certainly involve executive function, particularly planning ability, but is not traditional classed as such a measure. One also fails to see how the RAVLT can be considered primarily executive in nature rather than a test of memory.

Better operationalisation of the construct executive function would engender greater confidence in the results of Duncan et al.

Wood and Liossi (2007) also investigated the fractionability of executive function and the issue of *g*. Earlier efforts (Duncan et al., 1997; Obonsawin et al., 2002) relied on the WAIS-R, while Wood and Liossi used the WAIS-III. Wood and Liossi predicted that measures of *g* with higher contributions from *gf* would be even less distinguishable from executive function. They recruited a sample of *n* = 188 severe TBI sufferers, at an average of 2.9 years since injury. In addition to the WAIS-III, measures of executive function from two broad classes were given. In the ecologically valid domain, patients were administered the Hayling-Brixton Tests (Burgess & Shallice, 1997) and the Zoo Maps and Key Search subtests from the Behavioural Assessment of Dysexecutive Syndrome (BADS; Wilson, Alderman, Burgess, Emslie, & Evans, 1996). The conventional executive domain comprised the Phonemic Fluency task and the TMT-B.

Factor analysis yielded two factors, accounting for 52.9% of the variance (Wood & Liossi, 2007). Scores from the Hayling-Brixton tests loaded on the first factor, while Zoo Maps, Key Search and TMT-B loaded on the second. Phonemic Fluency was said to load almost evenly between the two factors. The first factor correlated strongly with FSIQ, PIQ and VIQ, with the second being considered more executive. All measures correlated with FSIQ and PIQ. Perplexingly, Wood & Liossi fail to report the proportion of the variance explained by each factor. They do however handle the limitations of the study well, acknowledging heterogeneity of age and injury severity, and the lack of a control group. Wood & Liossi conclude their paper by calling for taxonomies of both executive function and intelligence to be made clearer.

The most influential paper concerning the separability of executive functions was authored by Miyake et al., (2000) and had two aims. One aim was to examine the degree of

separateness or relatedness of three hypothesised executive sub-processes; Shifting, Updating and Inhibition. The second was attempting to elucidate how each of the three target executive functions maps on to more complex, traditional tasks of executive function, namely the WCST and Tower of Hanoi (ToH), in addition to a random number generation task and a dual-task.

Shifting was defined as the process of focusing attention between sub-tasks and different elements of the same task (Miyake et al., 2000). Updating was defined as the process of evaluating incoming information, revising the contents of working memory and deleting what is no longer relevant. Miyake and colleagues make a distinction between Updating and Working Memory, with the distinction being the process of Updating requires active manipulation, whereas storage in Working Memory is said to be more passive. Inhibiting was defined as the process of deliberately inhibiting a prepotent response when necessary. The authors do not claim that the three tested constructs are exhaustive, and offer the example of Planning which was deemed too difficult to define.

Selecting newer tests was seen by Miyake and colleagues (2000) as a way addressing task-impurity, and the employment of multiple measures was an attempt to deal with the reliability problem. The measures choosen to represent the three processes are listed in Figure 5.1., and are described by Miyake et al. A sample of 137 young college students (age was not reported) was employed and confirmatory factor analysis was used to test various models of executive function ranging from the three factor model (Updating, Shifting and Inhibiting), through to a unitary model. Structural equation modelling was used to examine the contribution of the three constructs to the more complex measures (WCST, ToH, random number generation and dual-task). The hypothesised three factor model provided the best fit for the data. While the factors Updating, Shifting and Inhibiting were distinct, there was also a fair degree of inter-relatedness with correlations reported ranging from r .42 - .63.
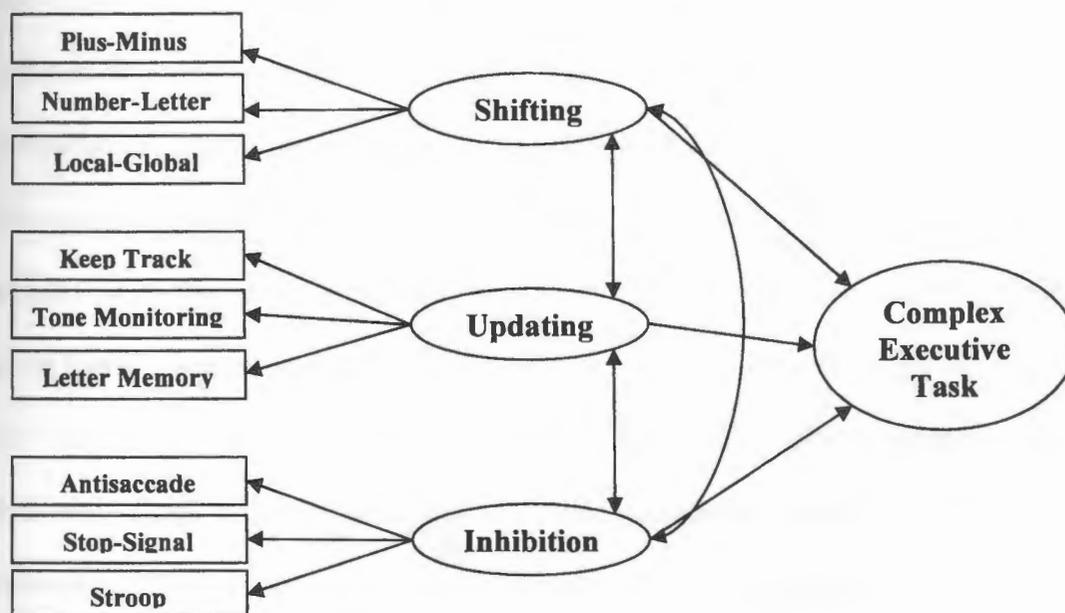
Figure 5.1. The process fractionation model of Executive Function as proposed by Miyake et al. The direction of the relationships indicates that the constructs Shifting, Updating and Inhibition are separable but related. Adapted from "The Unity and Diversity of Executive Functions and their Contributions to Complex "Frontal Lobe" Tasks: A Latent Variable Analysis" by A. Miyake et al., 2000, *Cognitive Psychology, 41*, p.70

In relation to the more traditional tasks, the WCST was most associated with Shifting. The ToH was argued to be related to Inhibition and random number generation implicated both Inhibition and Updating. Against expectation, the dual-task was independent of the three factors, including switching. Miyake and colleagues concluded that there is both diversity and unity within executive function. Processing speed was not investigated and the authors acknowledge the need to further test their factor structure in different age groups.

To that end Fisk and Sharp (2004) set out to replicate and extend the work of Miyake et al., (2000). Testing the fractionability of executive function, Fisk and Sharp retained the factors Updating, Shifting and Inhibiting. They did however add a measure of Verbal Fluency, utilise a broader age range ($N = 95$, M age = 41.89 years, with a range of 20-81 years) and examine the influence of processing speed.

The verbal fluency task was the rarely-used Chicago Word Fluency Test (CWFT), and it is unclear why this measure was adopted by Fisk and Sharp (2004) over the more common Phonemic, Semantic or Excluded Letter Fluency procedures which would allow comparison with the considerable body of existing literature. The CWFT as described by Fisk and Sharp comprises two trials. For the first participants have five minutes to generate as many words as possible beginning with the letter 'S.' For the second, participants are given four minutes to generate as many four letter words as they can beginning with the letter 'C.' Other executive measures included the WCST, a random number generation task and a dual-task. There were various measures of visual and auditory working memory, and processing speed. Performance on most cognitive measures declined with age, including executive functions, with the effect being less pronounced for verbal fluency and non-significant for the dual-task.

Factor analysis was performed, with age differences investigated through hierarchical regression. A four factor structure was reported, with individual factors accounting for between 32.2 % - 9.8% of the variance. The factors were interpreted as being consistent with Miyake et al., (2000), namely Updating, Shifting and Inhibition. A fourth factor, with word fluency and random letter generation loadings, was postulated to reflect the efficiency of accessing long-term memory. The results provided additional support for the position that executive functions are fractionable. However, after controlling for age-related decrements in processing speed, the variance accounted for by Updating and Inhibition was non-significant, leaving only Shifting significant from the model of Miyake et al. Consistent with the results of Miyake et al., the dual-task did not relate significantly to any other factor, and there was no evidence of an age-related decline in verbal fluency performance.

Hull and colleagues (2008) also endeavoured to extend Miyake et al.'s (2000) study by replicating it in a sample of older adults between the ages of 51 and 74 years (*M* age =

60.2 years). Vocabulary and Picture Completion from the WAIS-III were also administered given the additional aim of investigating any differential relationships between verbal or non-verbal modalities: however, the results did not show modality effects. A dual-task was not part of the battery. The resultant data revealed larger inter-correlations between tasks within a proposed factor than between. There was no correlation of note between age and executive function although the Hull and colleagues advocated caution when interpreting this finding given the restricted age range sampled. A two-factor solution retaining Updating and Shifting provided the best fit for the data, with Inhibition being dropped. Updating had the strongest relationship with WAIS subtest scores suggesting that this factor was more reliant on IQ than Shifting. Updating performance best predicted ToH and WCST performance, while Shifting did not significantly predict performance on either. The result is in contrast with that of Miyake et al. (2000) who found the WCST to relate to Shifting and the ToH to Inhibiting.

Hedden and Yoon (2006) examined executive function as a predictor of interference susceptibility for verbal working memory. The research is of particular interest due to the use of an older sample ($n = 121$, M age = 72.2 years, range 63-82 years). With performance on a directed list-learning task as the dependent measure, Hedden and Yoon used structural equation modelling to examine the contribution of executive function, and fractionated sub-processes with reference to Miyake et al., (2000). The purported executive sub-processes of Shifting, Updating and Inhibition were examined. However, the authors split Inhibition itself into two further sub-processes; Prepotent Response Inhibition, and Resistance to Proactive Interference.

Shifting was indexed with three measures: performance on a Plus-Minus Task, the TMT and perseverative errors on the WCST. Updating was measured with a letter memory task, Digit-Span Backwards and the Self-Ordered Pointing Test (SOPT). Prepotent Response

Inhibition was measured by performance on an antisaccade task and the Stroop task.

Resistance to Proactive Interference was measured by Excluded Letter Fluency and Semantic

Fluency. In addition to the executive measures, verbal and visual memory tasks were

administered. The results and interpretation of Hedden and Yoon (2006) suggest that in this

population that executive function is comprised of two distinct but related processes. Shifting

and Updating represent one function, with the second being Resistance to Proactive

Interference.

Although Hedden and Yoon (2006) found only two factors, whereas Miyake et al.

(2000) identified three, Hedden and Yoon view their results as being in-line with Miyake et

al. and even Salthouse (2005) in that the factors had similar magnitudes and loadings as those

recorded previously. In regard to the failure of Inhibition to stand as a factor in it own right,

Hedden and Yoon (2006) suggest that Inhibition may be so central to executive function as to

not be discernible when fractionated. However, Hull and colleagues (2008) disagree,

suggesting that Hedden and Yoon employed more complex and less process pure measures

such as the TMT and WCST, in contrast to those chosen by Miyake et al., and thus "may

have reduced the unique variance associated with the Shifting factor" (p. 509). Hull et al.,

also indentifies a lack of control for processing speed within the Inhibition factor as a

limitation of the work of Hedden and Yoon.

Friedman et al. (2006) further examined the relationship between intelligence and

executive function using Miyake et al.'s (2000) process fractionation model. Participants

were 234 individuals from a study of twins, aged between 16 and 18 years. Fluid

intelligence, crystallised intelligence and WAIS FSIQ were all considered. Confirmatory

factor analysis was consistent with the earlier model of Miyake et. al., with the executive

functions of Inhibition, Updating and Shifting said to be related but separable (Freidman et

al., 2006). There was great similitude in how the three intelligence constructs related to

executive function. The factor of Updating was strongly related to intelligence, sharing 41%-48% of the variance, whereas the relationship with Inhibition and Shifting to intelligence was weak. Friedman et al. (2006) further suggest that the latter findings might be accounted for by shared variance between Updating and these executive constructs. They suggest that Updating may largely be reliant upon working memory, and thus quite related to intelligence while positing the other executive constructs of Inhibition and Shifting to be separable.

Freidman et al. (2008) added data from an extra 114 participants to those from the Friedman et al. (2006) study to examine the contribution of genetics to individual differences in executive function. Latent variable analysis was used to contrast the pattern of relationships between pairs of monozygotic and dizygotic twins (Freidman et al., 2008). Freidman and colleagues were surprised to find that differences in executive function were almost exclusively genetic. The factor structure of Miyake et al. (2000) was again supported, with Updating and Shifting having greater heritability than Inhibiting (Freidman et al., 2008). For non-executive factors, perceptual speed was related to executive function, whereas IQ related strongly to Updating and weakly to Shifting. The heritability of executive function was reported to go beyond that of both perceptual speed and IQ.

Jester et al. (2009) were also interested in the question of heritability of executive function, and whether the construct was distinct from g. Jester and colleagues studied families, focusing on intergenerational transmission, rather than the relative contributions of nature and nurture. A large number of children ($n = 434$, 12-17 years) and their parents ($n = 376$) were recruited. Intelligence quotients were derived from WAIS or WISC short-forms and executive tasks were the TMT, ToH and WCST. Jester and colleagues found that overall, the executive measures correlated with IQ, although the inter-correlations among the IQ measures were larger than those between IQ measures and executive function. A two factor model (IQ and Executive Function) provided the best fit for the data, supporting the

validity of executive function as a construct distinct from *g*. Executive function was transmitted moderately by family (between *r* .34-.51), while IQ was more heritable.

5.1 Summary

The evidence to date regarding the fractionability of executive function is mixed. Miyake et al. (2000) proposed and identified a three-factor model comprising separable but related factors of Shifting, Updating and Inhibition. This model has been replicated by Fisk and Sharp (2004), Friedman et al. (2006; 2008), but not by Hedden and Yoon (2006) and Hull et al. (2008). Data from the latter two research teams support a two-factor solution only, although the factor structure is not consistent across these studies. Hull and colleagues found only Shifting and Updating to constitute a valid fractionable executive factor within an older adult population, in contrast, Hedden and Yoon found that Shifting and Updating overlapped and comprise a single factor, with a conceptualisation of Inhibition representing the other.

There is evidence to suggest that executive function in these models is distinct from intelligence (Friedman et al. 2006, 2008; Hull et al. 2008). There is mixed but greater support for Shifting and Inhibition to be distinct constructs overall, while Updating appears related to both Working Memory and intelligence. Burgess (1997) advocates caution before trying to fractionate executive function. He draws a parallel between fractionating executive function and dissecting an insect; noting that by doing the latter, one does not necessarily learn how it flies.

CHAPTER 6

Normal Ageing

There is no escaping the physical changes that take place within our bodies as part of the normal ageing process; muscle tone is lost, the respiratory and circulatory systems are not as efficient as they once were and vision declines after one's 30s, followed soon after by hearing (Bieliasuskas, 2001; Kail & Cavanaugh 2000). All organs are impacted by the process senescence, that of gradual cell death with the impact on the central nervous system being particularly great (Raz, 2004).

6.1 Physical Changes that Occur within the Brain during Normal Ageing

There is global change across the brain associated with ageing; cerebral atrophy, the loss of grey matter, ventricular enlargement, a decrease in synaptic densities and reduced efficiency of neurotransmitter function (Buckner, 2004; Graham, & McLachlan, 2004; Hedden & Gabrieli, 2004; Park, Polk, Mikels, Taylor & Marshuetz, 2001; Raz, 2004). The rate of grey mater decline is fairly even between one's 20's and 50's while white matter volume follows a less linear path, decreasing rapidly in the 5th decade of life (Raz, 2004). These physical changes are posited to produce the cognitive decline associated with ageing.

The loss of cortical tissue is most marked in the frontal lobes, followed by the medio-temporal areas, while the occipital lobe remains fairly impervious to ageing (Lowe & Rabbitt, 1997; Park et al., 2001). The disproportionately strong loss of tissue in the frontal regions and in regions that have the strongest connections to the frontal lobes has given rise to the frontal ageing hypothesis of West (1996), central to this thesis, and as reported in Section 6.4.

6.2 Cognitive Ageing

Cognitive decline begins in ones 20's, but does not typically become apparent until later. This may be due to decline prior to the 20's being quite minimal, or because younger

adults function at a level far higher than is necessary for survival (Park et al., 2001; Raz, 2004; Verhaeghen, Marcoen & Gossens, 1993). Increased experience may also mask the ageing process; an increase in life skills and expertise can 'off-set' the decline so that it does not become apparent until a critical point is reached (Park et al., 2001). The influence of education and intelligence may provide a buffering effect, and account for the wide inter-individual variability observed in normal ageing (Buckner, 2004). Multiple mechanisms are theorised to contribute to what is known as cognitive reserve - the degree to which an individual can withstand cognitive insult without demonstrating clinically significant behavioural impairment (Mangels, Craik, Levine, Schwartz & Stuss, 2002). It is also important to note that cognitive decline does not impact all capacities, nor occur at a uniform across the capacities that are impacted (Hedden & Gabrieli, 2004). Further, some areas of cognition, such as semantic knowledge and wisdom actually improve with advanced age (Hedden & Gabrieli, 2004; Helmuth, 2003; Hughes & Bryan 2002). Verhaeghen, Marcoen and Gossens (1993) caution that decline should not be confused with decay.

Nonetheless, a substantial body of evidence documents advanced ageing being accompanied by cognitive decline. Older adults may have difficulty with memory and recall, experience greater difficulty in learning new information and exhibit slower information-processing speed and cognitive response times in comparison to their younger counterparts (Bieliasuskas, 2001; Craik, 2000; Lowe & Rabbitt, 1997). And while memory declines are very broad and well established, not all areas are impacted, with autobiographical and recognition memory proving robust to ageing (Hedden & Gabrieli 2004). Where decline does occur decrements are particularly dramatic after 75 years of age (Bieliasuskas, 2001; Rabbitt, 1997) although see (Helmuth, 2003, Hess, 2005, and Verhaeghen et al., 1993, for more optimistic views).

While the existence of cognitive decline has been clearly documented, the mechanisms underlying the decline are not so clear. Although neuroscience and cognitive aging research have increasingly converged, several competing explanations are offered within the literature.

6.3 Global Accounts of Cognitive Ageing

A 'global' account, or an undifferentiated single mechanism view, suggests that brain changes are diffuse and thus affect all cognitive abilities to the same proportional extent (Craik, 2000; Lowe & Rabbit, 1997). Global or single mechanism accounts are also termed 'the common cause hypothesis' within the literature. Single-factor models attribute cognitive decline to the neurophysiological changes impacting the central nervous system, rather than to brain changes which occur earlier and proceed more quickly across different regions. The most well known proponents of a global account are Salthouse and his colleagues (Salthouse, 1996; Salthouse, Atkinson, & Berish, 2003; Salthouse, 2005; Tucker-Drob & Salthouse, 2008) who have long attested that decrements in general processing speed account for much of the age-related variance in memory and other cognitive domains. Such a position however is not without opposition.

In review Park and colleagues (2001) note that no clear neural substrate accounts for the processing speed deficit. Although single-factor models are attractive in their simplicity (Bieliasuskas, 2001), if global changes do actually underpin slowed information processing, the position is difficult to reconcile given the resistance of the sensory cortex to age-related decrease in volume in comparison to other brain regions (Park et al., 2001). Hedden and Gabrieli (2004), and van Hooren, Valentuin, Ponds and van Boxtel's (2007), conclude that when examining the literature it is unclear whether different cognitive functions decline at a differential or common rate. Phillips (1999) voiced frustration that the processing speed hypothesis had been a pre-occupation of ageing literature over the preceding fifteen years.

Bieliasuskas (2001) raised concern regrading the type of analysis used in the work of Salthouse and colleagues. The concern is with spurious relationships. Bieliasuskas argues that if reaction time, a highly age-related variable, is covaried with performance on another task, say the Stroop for example, then the portion of variance accounted for on the Stroop will be inherently high. Yet statistically significant but theoretically nonsensical results could also be returned by using an equally heavily age related measure, greying of the hair. If hair greying was covaried with performance on a memory task, Bieliasuskas asks "can it then be concluded that greyness of the hair is a fundamental part of the cognitive architecture" (p. 95)?

6.4 Specific Mechanism Accounts of Cognitive Ageing and the Frontal Ageing Hypothesis

Reviews by Bieliasuskas (2001), Park et al., (2001), Hedden and Gabrieli (2004), Raz (2004), and others indicate that age associated cognitive decline does not occur at a uniform rate. Attentional control typically declines with advanced age, whereas the ability to employ habitual processes and use representational knowledge is much more robust (Bialystok, Craik, Klein & Viswanathan, 2004; Hedden & Gabrieli, 2004). One only has to look at performance on the 'hold' versus 'don't hold' tests on WAIS for examples of differential cognitive decline associated with advanced ageing (Bieliasuskas, 2001).

Given the weakness of simplistic common cause models, there is merit in studying specific mechanisms in detail, to gain a better account of the different factors which contribute to cognitive ageing. The domain of memory and its physical architecture has received the most attention, especially the temporal system, given both its importance to memory function and the clear problems demonstrated from structural damage to this region (Park et al., 2001; Raz, 2004). Therefore, detailed discussion of memory systems is largely redundant here and beyond the scope of this thesis. The specific mechanism account most

relevant to this thesis, the frontal ageing hypothesis, was proposed by West (1996). Because tissue loss is disproportionately greater in the frontal regions and regions with the strongest connections to the frontal lobes, and as anatomically the frontal lobes are known to be the seat of executive function, such an account predicts that executive functions would be impacted both earlier, and eventually more severely, by normal ageing than other cognitive processes (Daniels et al., 2006; Friedman et al., 2006; Hedden & Yoon, 2006; Span, Ridderinkhof & van der Molen, 2004).

6.5 Summary

There are both general and specific physical changes that occur within the brain during physical ageing. Thus, it is no surprise that cognition suffers with advancing age. There are overall reductions in cognitive abilities, and some individual domains that are particular impacted. There is evidence for global factors, most notably age-related declines in processing speed (Salthouse, 1996; 2005), accounting for many of the cognitive deficits incurred throughout the normal ageing process. However, there is also good evidence for decline in specific regions and functions over and above a unitary account. To quote Park and colleagues (2001) "*one problem with the behavioural literature in cognitive ageing is that hypothesis about the mechanisms of age-related decline on cognitive tasks have frequently been presented as though evidence for age-sensitivity in one mechanism is evidence against another. This type of thinking is naïve. It is likely that all the different executive processes, as well as speed of processing, decline with age and collectively contribute to difficulties in reasoning, memory, and together higher ordered cognitive functions*" (p.153). The influence of global factors not withstanding, the study of specific mechanisms is also meritorious. Executive function over the course of normal ageing represents one such worthy area of enquiry.

CHAPTER 7

Executive Function and Normal Ageing

Despite an increase in research activity examining executive function and ageing (Alvarez & Emory, 2006; Phillips, 1999) a paucity remains. Normative data is essential for the purposes of advancing research and theory, and to provide a baseline in clinical practice (Banich, 2009; Clark et al., 2004; Ettenhofer, Hambrick, & Abeles, 2006). The issue of adequate normative or baseline data is critical as neuropsychologists are increasingly asked to distinguish between normal ageing and pathological ageing (Hickman, Howieson, Dame, Sexton & Kaye, 2000). Such data is lacking for older adults, particular after 75 years of age (Ivnik, Malec, Smith, Tangalos & Petersen, 1996; Richardson & Marottoli, 1996). The matter is exigent given that the 'old-old' are the most rapidly growing segment of the population (Goldstein, Levin, Goldman, Clark, & Altonen, 2001; Hickman et al., 2000). Garden, Phillips and MacPherson (2001) note a paucity of research examining executive function among 40-60 year olds, as do Hedden and Gabrieli (2004) among 30-60 year olds. Bryan and Luszcz (2000a) identify a need overall for work establishing the validity of tests of executive function for use with older adults.

Further examination of the fractionability of executive processes is useful to shed light on whether the organisation of executive function remains the same or differs with advancing age (Hull, Martin, Beier, Lane, Lane and Hamilton, 2008; Miyake et al., 2000). The utility assessment of executive function may hold in predicting functional independence of older adults (Cahn-Wiener et al., 2000; Garden et al., 2001), and in the neuropsychological assessment of driving competence (Bieliasuskas, 2005) are other avenues relevant of enquiry within the field of normal ageing. The current research principally sets out to contribute by

examining executive function over a stratified normal ageing cohort. Before it does so, it is important to consider the research that has gone before. This review concentrates on literature from the past ten years although selected older papers are also included.

7.1 Research using Extreme Age Group Designs

When studying executive function among normal ageing cohorts, extreme age group designs are often used. That is, the performance of younger adults is compared to that of older adults believed to be experiencing non-pathological ageing. Such designs typically yield significant differences.

Investigating the relationship between 'frontal' function and memory, Parkin and Lawrence (1994) demonstrated several age differences. A group of older adults ($n = 22$, M age = 71.9 years) were compared with younger controls on measures of recall, recognition, the Wisconsin Card Sort Test (WCST), Phonemic Fluency and the Ideational Fluency measure, the Alternate Uses (AU) test (Guilford, Christensen, Merrifield & Wilson, 1978). A substantial negative effect of age on Phonemic Fluency performance was recorded, with older adults scoring approximately 21 words less than younger adults. This finding is of note as most studies reviewed subsequently do not detect age differences on this measure. Older adults also exhibited inferior AU and WCST performance. Younger adults performed better on all the memory measures in comparison to older adults.

Levine et al., (1998) compared performance of older adults ($n =20$, M age =71.8 years) to that of younger controls on a task of strategy implementation, not dissimilar to the Six Elements Test (SET; Shallice & Burgess, 1991). Older adults showed subtle but statistically significant decrements in performance in comparison to younger controls. Troyer (2000) studied the Phonemic and Semantic Fluency performance of younger (18-35 years, $n = 41$, M age = 22.3 years) and older adults (60-89 years, $n = 54$, M age =73.6 years). For Phonemic Fluency, there were no significant age effects while there was an age effect for

Semantic Fluency, in favour of the young. Regression analysis revealed no unique predictive effect of education or sex on fluency performance.

Wecker, Kramer, Wisniewski, Delis and Kaplan (2000) aimed to examine the impact of age on executive function, specific to the ability to maintain mental set. A sample between 20 and 79 years of age (n = 112, M age =50.4 years) were tested on California versions of the Stroop and the Trail Making Test (TMT). Regression analysis was the mode of analysis. After partialling out component skills embedded in the multi-factorial tasks, age accounted for a unique portion of the variance on the Stroop task, but not for the TMT. A weakness of the study was the failure to exclude individuals on the basis of neurological status or serious illness.

West, Murphy, Armilio, Craik and Stuss (2002) examined performance curves on multiple trials of executive tasks, and measures of memory and attention. Older adults (M age =73.8 years) performed worse than younger adults (M age =23.9 years) in both executive and non-executive conditions, with the deficits being greater on the executively-loaded task. Allain et al., (2005) demonstrated that older adults (n = 18, M age =80.3 years) performed worse on planning, as measured by the Zoo Map Test from the Behavioural Assessment of Dysexecutive Syndrome (BADS; Wilson, Alderman, Burgess, Emslie, & Evans, 1996), than their younger counter parts (n = 16, M age = 28.6 years).

Taconnat et al., (2006) examined the role of executive function in influencing encoding and thus memory performance for younger (M age = 28 years) and older adults (M age = 64 years). Executive function was measured with the WCST, the Stroop and Excluded Letter Fluency. Age effects were recorded for executive and non-executive measures. Factor analysis showed a clear distinction between executive and memory measures, and the factor structure was consistent for both age groups. As far as encoding (rhyme generation) was concerned, the index correlated more strongly with executive function than the mnemonic

index. This finding suggests that the age related decline in rhyme generation was related to an age related decline in executive function. The authors posit that inferior executive function prevents the older group from achieving strategic encoding as compared to the younger group.

More sophisticated studies not only look for differences between younger and older adults in executive function, but also test rival explanations in some capacity. These rival explanations are typically either that processing speed or intelligence accounts for any significant differences recorded. Levine, Stuss and Milberg (1995) examined executive function in a normal ageing cohort when developing a shorter alternative to the WCST. Sampling adults in three different age bands (18-39 years, $n = 20$, M age = 26.4 years; 40 -64 years, $n = 20$, M age = 54.6 years, and 65-79 years, $n = 20$, M age = 72.1 years), an age related decrease was found on all card-sort indexes, with the difference between the youngest and oldest groups being statistically significant. The results did not indicate a relationship between g (as measured by NART score) and test performance. Measures of processing speed were not included.

Parkin and Java (1999) compared the cognitive performance of younger adults ($n = 20$, M age =25.3 years) with the 'young-old' ($n = 20$, $M = 68.9$ years) and the 'old-old' ($n = 20$, $M = 78.8$ years). Phonemic, Semantic and Ideational Fluency (AU test) and the WCST were utilised from the executive domain. Processing-speed was measured with a digit symbol substitution task and a simpler digit-cancellation task. A measure of fluid intelligence and NART score were also included. Consistent with most research, and in contrast to the earlier study by Parkin and Lawrence (1994), no age-related differences were recorded for Phonemic Fluency performance. On the Semantic Fluency task, the younger group out performed both older groups (Parkin & Java, 1999). The young-old exhibited superior Semantic Fluency relative to the oldest-old. For AU performance, there were no

significant differences in appropriate uses generated, although both older groups produced more inappropriate uses (errors) than younger adults. Younger adults committed fewer errors than both of the older groups on the WCST. For WCST categories achieved, younger adults performed better than both groups of older adults and the performance of the young-old was superior to the old-old. Significant age related declines were recorded across all three age groups on processing speed measures.

A large study Crawford, Bryan, Luszcz, Obonsawin and Stewart (2000), subsequently reanalysed by Ferrer-Caja, Crawford and Bryan (2002), compares executive function within a younger and older cohort, testing whether executive decline accounts for age related cognitive deficits, or whether there is simply a non-differential decline in g. Originally Crawford et al., (2000) conceded that both executive function and g contributed to variance in memory performance, but claimed a decline in processing speed accounted for age-related memory decline. A serious design flaw of the study was the use of different measures of executive function between the older and younger adult groups which of course confounds interpretation. That is, the degree to which the differences are an artefact of age, or simply differences in underlying constructs tapped by the different executive function batteries was unclear. Upon reanalysis employing structural equation modelling and demarking verbal and performance tests, Ferrer-Caja et al., (2002) found age to be negatively associated with executive function in the younger and older samples, a negative relationship which was stronger for older individuals. The reanalysis gave a global decline in processing speed as an explanation less credence.

With age differences on Self-Ordered Pointing Task (SOPT) performance recorded previously, Bryan and Luszcz (2001) set out to explore the mechanism underlying such findings. While the SOPT is theorised to be executive in nature (requiring regulation of behaviour and the use of plans and strategy) it was also expected to place demands upon

working memory (for effective monitoring). Executive function, working memory and processing speed were investigated as predictors of performance across two age groups (17-48 years, $n = 60$, M age = 23.8, and 65-88 years, $n = 60$, M age = 73.8). Working memory was assessed using span tasks and information processing speed was measured using Digit Symbol-Coding. In addition to the SOPT, other executive measures employed were the WCST, the Stroop, Phonemic Fluency and Excluded Letter Fluency. All measures were found to be age-sensitive, excepting perseverative errors on the Excluded Letter Fluency task. Although younger adults committed fewer errors on the SOPT, the two groups did not differ in terms of strategy use. Contrary to predictions, SOPT performance was relatively independent of working memory performance. Differences in processing speed appeared to account for most of the age-related variance on SOPT although perseverations on executive measures made a small unique contribution.

Hughes and Bryan (2002) appears to represent a further analysis of data of Bryan and Luszcz (2001) as means, standard deviations and sample sizes for the age groups are identical between the two studies although the paper is not identified as such. Hughes and Bryan examine strategy use for Phonemic and Excluded Letter Fluency, scoring 'Clusters' and 'Switches' in fluency performance, as per Troyer, Moscovitch and Winocur (1997). Measures of Verbal ability, processing speed and executive measures the Stroop, WCST and SOPT were also administered. Younger adults exhibited superior performance on all the measures of processing speed and the non-fluency measures of executive function. No age differences were recorded for Phonemic Fluency performance. This null result, discordant with that of Bryan and Luszcz (2001), appears to be explained by education being covaried by Hughes and Bryan (2002). Younger adults showed superior Excluded Letter Fluency performance. There were no significant differences in Clustering and Switching between the

two groups. Fluency performance was related to SOPT errors in the younger cohort, and to Stroop and SOPT performance in the older group.

Bunce and MacReady (2005) explored age related differences in list learning, exploring the contribution of processing speed and executive function, testing younger ($n =$ 52, $M = 23.27$ years, range 18-36 years) and older adults ($n = 52$, $M = 68.62$ years, range 61-78 years). Executive function was measured in a very limited fashion, by performance on Phonemic Fluency and Digits Backwards. Processing speed was measured with Digit Symbol-Coding and a choice reaction time task. Processing speed accounted for age differences in memory while executive function did not. The authors concede that the executive measures employed may not have tapped the processes involved with sufficient rigor.

Also concerned with age, memory performance and executive function were Rhodes and Kelley (2005), examining the performance of younger ($n = 50$, M age = 19.6 years) and older ($n = 50$, M age =7 1.8 years) adults. In addition to the memory measures, processing speed was included as measured by a digit-symbol substitution task, a number comparison task and the differences score calculated from TMT parts A and B. While the TMT is one of the most commonly used measures of executive function (Ettenhofer et al., 2006), and was initially selected as such by Rhodes and Kelley, it was relegated to a processing speed measure by these researchers as it "loaded on the speed measure" (p. 582). This left only the WCST and Phonemic Fluency performance as measures of executive function. Younger adults performed better on all tasks, with the exception of Phonemic Fluency, where no age differences were apparent. The processing speed / TMT factor was reported to account for 32% of the variance, with the executive measures contributing an additional 26%. Disappointingly, any differential variance on these factors between age groups is not explored.

Span, Ridderinkhof & van der Molen, 2004 conducted an ambitious, innovative and well designed study to concurrently evaluate the global slowing and frontal ageing hypotheses. Data was taken across the lifespan from children ($n = 22$, age $M = 9.2$ years), adolescents ($n = 17$, age $M = 15.4$ years), adults ($n = 21$, age $M = 24.1$ years) and seniors ($n = 19$, age $M = 68.7$ years). Tasks were grouped as executive (e.g. involving inhibition, adaptive control), or non-executive (measuring simple reaction time, stimulus discrimination etc). A strength of the study was that all tasks used the same stimulus materials (schematic faces in a 4 x 4 grid), and shared a similar task format whether in the executive or non-executive condition reducing random error. A main effect for age was recorded, showing seniors to be slower than all other age groups. Executive function contributed significantly to response latencies in the senior group, but for none of the other age groups. The contribution of executive function in the senior group was over and above that of processing speed. Unfortunately the authors failed to discuss the magnitude of the contribution of executive function.

Salthouse, Atkinson and Berish (2003) investigated executive function as a mediator of cognitive ageing, using a raft of executive and non-executive measures to test convergent and divergent validity. Structural equation modelling and factor analysis were the modes of analysis. Although executive measures loaded moderately on the sub-processes they were attested to represent, there were very strong relationships between executive measures and *gf* leading Salthouse et al. to suggest that executive function is not distinct from the constructs of processing speed, memory, *gf* and vocabulary. They also speculate that the negative relationship between age and cognitive variables from executive and non-executive domains is more indicative of general decline in integrity of the neuronal system, rather than a product of frontal ageing. Hedden and Yoon (2006) however are critical of Salthouse et al.'s (2003)

interpretation of data, suggesting that executive measures were actually more closely related than the other cognitive measures.

Salthouse (2005) continued to investigate the construct validity of executive function by presenting one new study, and by aggregating data from multiple studies for a second. In the first, 382 adults between the ages of 18 and 93 years were sampled. Executive measures were the WCST, Phonemic fluency, Semantic Fluency, and Alternating Fluency (a more complex variant of Semantic Fluency), a clock drawing task and the 'Connections Test' (Salthouse's variant of the TMT). Executive function was examined against vocabulary, reasoning ability, visuospatial ability, episodic memory and processing speed. Salthouse found that most of the cognitive measures show a negative relationship with age, influenced heavily by reasoning ability and processing speed.

For Study 2, Salthouse (2005) aggregated34 studies from his laboratory (giving an $n = 6,959$). However, the greatest n for any one measure is 2,417 (for the 'Digit Reaction Time' measure) and second greatest n is 1,520 for a TMT type task. The smallest is $n = 150$. Out of the 56 cognitive variables listed, 'Digit Reaction Time' appears most frequently, being employed in only 14 of the studies, followed by 'Connections' used in only eight instances. Thus, the bulk of the seemingly impressive volume of data is actually estimated using statistical techniques. The Stroop was said to show no unique age variance in the incongruent condition. This finding is odd in relation to age effects on the measure recorded by many others (Bugg, DeLosh, Davalos and Davis, 2007; Bryan, & Luszcz, 2001; Ettenhofer et al., 2006; Lowe and Rabbitt, 1997; Hughes and Bryan, 2002; Klein, Ponds, Houx & Jellemer, 1997; Taconnat et al., 2006; Troyer, Leach & Strauss, 2006; van der Elst, van Boxtel, van Breukelen & Jolles, 2006; Wecker et al., 2000). Overall, Salthouse (2005) claims the pattern of results is inconsistent with executive function representing a distinct construct. One is

advised against drawing strong conclusions from the Salthouse (2005) study given the dubious methodology employed with respect to data estimation.

Reviewing the existing literature, Bugg et al., (2007) noted that while processing speed exerts a large influence on Stroop performance, there appeared to be an independent age-related effect. A large sample ($n = 938$, range 20-89 years) was stratified into 10 year bands and tested on the Stroop and reaction time (congruent colour naming on the Stroop). A subset, ($n = 281$) also completed the WCST and measures of simple and choice reaction time. Linear-regression was used to detect an age-related decline on all Stoop trials. The decline was greatest in the incongruent colour naming condition, explaining 74% of the variance after neutral colour naming latency was accounted for. Age exerted an influence on WCST perseverative errors (also requiring inhibition), with 80-50% of the age-related variance remaining after the various processing measures were accounted for.

7.2 Research using Narrower Age Ranges

As age related differences in executive function are often demonstrated, and are not unequivocally explained away by rival hypotheses, it is logical to test for such differences within a narrower age range. Lowe and Rabbitt (1997) employed regression analysis to study older adults ($n = 123$, M age = 68.1 years, range 60–83 years), finding age to be most deleterious on Stroop and switching tasks, when contrasted against measures of cognitive speed. Lowe and Rabbitt concluded that old age slows performance more on 'frontal' than 'non-frontal' measures. These findings are in direct competition to a global slowing or single factor account.

Bryan and Luszcz (2000b) investigated the influence of fluency performance (Phonemic, Excluded Letter, AU) on incidental memory performance among older adults ($n = 565$, M age = 76.9, ranged 72-95). Measures of verbal ability (NART score) and processing speed (modified WAIS digit symbol substitution test) were also included to test rival

hypotheses. The lack of age stratification is puzzling given the impressive sample size, especially as it can difficult to capture a sufficient number of participants in the 80 years and over range. Bryan and Luszcz (2000b) found all fluency measures were correlated with age, with relationships strongest for Excluded Letter Fluency and AU results. Better fluency scores predicted better incidental recall although the contribution of processing speed was greater. The AU test was the only fluency measure to make a unique contribution to memory performance after processing speed and verbal knowledge were controlled for.

Garden et al., (2001) aimed to address the paucity of studies of executive function in the 40-60 year old age band, and sought to employ measures they considered more ecologically valid. The performance of 'younger' adults ($n = 20$, $M = 38.2$ years, range 31-46 years) was compared with 'older' adults ($n = 20$, $M = 59.6$ years, range 53-64 years) on the Six Elements Test (SET) and Multiple Errand Test (MET). Both measures were described previously in Section 4.9. No differences of note were detected between the two age groups. Due to a possible ceiling effect, the authors devised an additional study with a similar sample employing the WCST, the SOPT. Younger adults exhibited superior performance on both measures leading Garden et al. to postulate that early ageing is sensitive to standard rather than "more realistic" (p. 479) planning tasks. Bialystok et al., (2004) investigated executive control, as measured by the 'Simon Task' (one of inhibitory control, not dissimilar to the Stroop), between younger (30-60 years) and older (60-80years) adults. Response latencies were significantly greater in the older group.

Ettenhofer et al., (2006) wished to explore Phillips' (1997) contention that due to the need for novelty, tests of executive function are invalidated after as little as a single administration. Older adults ($n = 118$, M age = 68.9 years, range 54-87 years) were tested twice on the five of the most commonly used measures of executive function (the WCST, the TMT, the Stroop, Phonemic Fluency and Semantic Fluency), between four and eight weeks

apart. Performance on Semantic Fluency (but not Phonemic fluency), and the Stroop and WCST showed significant correlations with age in the predicted direction. WCST and Phonemic Fluency showed significant improvement between testing time one and two; however the improvement was small and the standard deviations relatively large.

Treitz, Heyder and Daum (2007) endeavoured to further elucidate the course of executive function across adulthood, comparing small groups of adults aged 20-30 years, 31-45 years, 46-60 years and 61-75 years. The sample size within each age group was small, being between n= 13-17. Results for the Semantic Fluency task and a self-report measure of executive dysfunction were null, while for inhibition and dual-task performance the two elder groups were inferior to the two youngest groups. Older adults showed the largest dual-task decrement and performed significantly worse than the other three groups.

Just as the more sophisticated studies using extreme age group designs consider rival hypotheses, so too does an even smaller body of work using narrower age bands. Phillips (1999) attempted to explain the processes underlying age-related declines in fluency performance. Adults between the ages of 56-81 years ($n = 66$, M age = 67.6 years) completed a Phonemic Fluency task, a measure of IQ and crude measures of 'speed' (handwriting and choice reaction time). However, age did not actually impact fluency performance. Troyer et al., (2000) conducted a large norming study of Phonemic and Semantic Fluency tasks ($n = 411$, M age = 59.8 years), exploring the impact of age and other demographic variables through regression analysis. Consistent with Ettenhofer et al., (2006), Rhodes and Kelley (2005), Troyer et al., (1997) and Tombaugh et al., (1999), age had a minimal effect on Phonemic Fluency performance and a greater effect on Semantic Fluency performance. Higher levels of education were associated with better fluency performance and gender effects were minimal. There was similitude of performance across alternate forms of the Phonemic and Semantic tests.

van Hooren et al., (2007) explored the impact of age across the cognitive domains of processing speed, executive function, and verbal memory. Participants were subjects from the Maastricht Ageing Study (n = 578, age range = 64-81 years). Age had a negative impact on all cognitive measures, with the age differences being most pronounced on tasks with an inhibitory component, such as the Stroop, and less so on a TMT type task and for Semantic Fluency performance. Education had a positive impact on cognition, in that those with medium and high levels performed significantly better than their lower educated counterparts on all measures. The only influence of gender was in favour of females for verbal memory performance. In discussion of the education effects recorded, the authors speculate that higher education may have afforded participants greater cognitive reserve.

7.3 Summary

When extreme age groups designs are used (young vs. old), it is relatively a consistent finding that performance on tests of executive function declines with age (Allain et al., 2005; Bryan, & Luszcz, 2001; Bugg et al., 2007; Ferrer-Caja, et. al., 2002; Fisk and Sharp, 2004; Hughes and Bryan, 2002; Levine et al., 1995; Parkin, & Java, 1999; Rhodes and Kelley, 2005; Salthouse, 2005; Span et al., 2004; Taconnat et al., 2006; Troyer, 2000; Wecker, 2000; West et al., 2002). Performance on one test of executive function, Phonemic Fluency, is the exception.

Phonemic Fluency tasks are thought to be executive in nature as strategic retrieval of information is required; inefficient executive function should lead to employment of poorer strategy and thus production of fewer words (Phillips, 1997). However, the validity of Phonemic Fluency as a measure of executive function has been questioned. Many researchers argue the task primarily involves simple lexical access and is therefore executively undemanding (Fisk & Sharp, 2004; Ross, Hanouskova, Giarla, Calhoun & Tucker, 2007; Shores, Carstairs & Crawford, 2006). This is a position that the author is

inclined to agree with, given the relative invariance of the Phonemic Fluency task to age in contrast to the positive age results recorded for the Semantic Fluency task within the literature reviewed. When exploring alternate explanations for the age invariance of the Phonemic Fluency task, Hughes and Bryan (2002) suggest that the superior word knowledge of older adults assists their performance when compared with their younger counterparts, masking differences which may otherwise be apparent. However, this age-related advantage in vocabulary does not mask differences on the Semantic Fluency task, rendering the explanation less tenable. Further, if anything, the Phonemic Fluency task, with a greater number of trials, should have a reliability and thus sensitivity advantage (Strauss, et al., 2006).

In research that examines age related decline on measures of executive function across less extreme age ranges (contrasting the 'young-old' with the 'old'), the differences, as one would expect, are attenuated. They are also more test specific and variable. This finding is consistent with a broader review of age and cognition by Hedden and Gabrieli (2004). Phillips (1999) returned an age-related Figural but not Phonemic Fluency decrement. Parkin and Java (1999) found age differences for Semantic Fluency performance only. Levine et al., (1995) found no age differences for WCST performance. Bialystok et al., (2004) recorded age differences on an inhibition task, and Garden and colleagues (2001) found age related differences on traditional, but not more ecological valid measures of executive function. When factor analytic techniques are used, age related declines are typically detected (Bryan, & Luszcz, 2000b; Ettenhofer et al., 2006; Lowe & Rabbitt, 1997; van Hooren et al., 2007).

When rival hypotheses are considered, that either differences in executive function are better explained by differences in g, or by an age-related decline in processing speed, results are less compelling. Researchers such as Salthouse (2005) and Crawford et al., (2000) question whether executive function is actually a valid construct distinct from other cognitive

domains. Nevertheless, older adults have shown greater executive than non-executive deficits, and deficits independent of both g and processing speed (Lowe & Rabbitt, 1997). Levine et al., (1995) found no relationship between g and WCST performance while Phillips (1999) did find a relationship between g and strategy usage for a Semantic Fluency task.

Whether age related declines in executive functions are accounted for by processing speed alone is contentious. The data of Crawford and colleagues (2000) with subsequent re-analysis by Ferrer-Caja e al. (2002) demonstrated a unique but small variance from executive function remained after processing speed was accounted for, as did Span et al., (2004) and Bryan and Luszcz (2001) for the SOPT, and Lowe and Rabbitt (1997) for the Stroop. Conversely, Salthouse (1996; et al., 2003; 2005) did not find executive function to be distinct from processing speed, nor did Bunce and MacReady (2005). However, the author has raised methodological concerns with the work of Salthouse (2005), and Hedden and Yoon (2006) were critical of conclusion drawn by Salthouse et al., (2003). Bunce and Macready acknowledged their own limitations with respect to a narrow method of indexing executive function.

Overall, when examining the literature, age effects are typically recorded for commonly used executive measures. The effects are most obvious when using extreme age group designs, yet age effects also exist when contrasting more stratified samples (e.g. young-old vs. older-old), albeit more equivocally. The measures most typically sensitive to such effects are the Stroop, the WCST and Semantic Fluency. There is fair support for the construct of executive function being distinct from g. The debate as to whether executive deficits among this population can be accounted for by decrements in processing speed, or 'global slowing,' is more lively and the data more conflicting. The influence of processing speed appears considerable, and certainly greater than that of executive function. Nevertheless, the majority of papers reviewed that endeavour to investigate this question

document a small but unique age-related variance attributed to executive function, even after

the influence of processing speed has been accounted for.

CHAPTER 8

Older Adults, TBI and Executive Function

This review concentrates on literature from the past ten years although selected older papers are also included. As per the normal ageing literature review, the social and emotional aspects of executive function are considered largely beyond the scope of this review. With respect to severity of injury, this review concentrates on the mild-to-moderate spectrum as these are the injuries most common in older adults, and as injury course within this range is more of a challenge to quantify. Nevertheless, studies of severe TBI are by no means excluded, particularly if they deal specifically with the domain of executive function.

The literature within this field proved at times quite disparate. Aside from the pathophysiology and epidemiology of TBI; the mTBI literature, the literature dealing with the cognitive outcome of older TBI patient, and the literature regarding TBI and executive function all warranted coverage. A summary and a synthesis is given at the end of the chapter in an effort to avoid repetition, rather than summarise each individual section in turn, especially given the over lap between the older adult TBI literature and the mTBI literature. And while they do overlap, there is not a sufficient body of literature to have an older adult mTBI section in its own right, and the same applies regarding the executive function of older adults post TBI.

8.1 Traumatic Brain Injury (TBI)

Traumatic brain injury involves either a direct blow to the head or the application of other forces, resulting in damage to the brain or alteration in function (Helps, Henley & Harrison, 2008). For the purposes of this thesis, TBI will be considered to exclude other aetiologies, such as stroke or anoxia, in accordance with the definition provided by Lezak et al., (2004). Traumatic brain injury is a major health, social and economic problem (Hillier,

Hillier & Metzer, 1997; Hukkelhoven et al., 2003; Myburgh, et al., 2008). It is estimated that in Australia between 2004 and 2005, that there were 22,710 hospitalisations due to TBI, at a direct cost of $184 million (Helps et al., 2008). Traumatic brain injury is the most common form of brain damage (Henry & Crawford, 2004) and injuries can have a deleterious impact on emotional stability, personality, and activities of daily living in addition to impaired cognitive functioning (Goldstein et al., 1999; Lezak et al., 2004; Schretlen & Shapiro, 2003). Motor, sensory and cognitive deficits commonly ensue (Gennarelli & Graham, 1998) and insight into changed function and overall self-awareness often suffers (Brenner, Homaifar & Schultheis, 2008; Hart, Whyte, Kim & Vaccaro, 2005). Executive deficits are common (Proctor & Zhang, 2008; McDonald, Flashman & Saykin, 2002, Wood & Liossi, 2007) and TBI remains underfunded and under studied (Hillier et al., 1997).

8.2 The Pathophysiology of Traumatic Brain Injury

Traumatic Brain injury can either be penetrating or closed. A penetrating head injury involves an object penetrating the skull whereas blunt-force trauma is commonly known as Closed Head Injury (CHI) (Strauss et al., 2006). In excess of 90% of TBI cases are of the non-penetrating type (Henry & Crawford, 2004; Lezak et al., 2004). Blunt trauma normally results in diffuse injuries, with the frontal and temporal regions particularly impacted (Draper & Ponsford, 2008; Schonenberger, Ponsford, Reutens, Beare & O'Sullivan, 2009). The typical TBI involves the moving head stopping suddenly; injury involves acceleration-deceleration forces (Gennarelli & Graham, 1998). Often, but not necessarily, the head stops because of impact with another object (Gennarelli & Graham, 1998; McDonald et al., 2002).

Traumatic brain injury can be further classified along other dimensions. Injuries can be either focal or diffuse, and deemed as either primary or secondary (Flanagan, Hibbard, Riordan & Gordon, 2006; Gennarelli & Graham, 1998). Primary injuries occur at the time of impact, while secondary injuries emerge distally; minutes, hours and even days after the

event, arising due to hypoxia, oedema and increased intracranial pressure (Flanagan et al., 2006; McDonald et al., 2002; Schonenberger, 2009 et al.). Due to the delayed onset of secondary injuries it is useful to think of brain injury as being more of a process than a discrete event; the structural abnormalities that typically follow do not occur instantaneously (Gennarelli & Graham, 1998).

Focal injuries relate to a specific region or area of the brain, and can include contusions, lacerations, localised haemorrhages and focal ischemic lesions. The architecture of the skull renders the frontal lobe and temporal lobes particularly vulnerable to damage arising from contusions, especially those regions close to the skull base bony prominences (Bamdad, Ryan & Warden, 2003; Flanagan et al., 2006; McDonald et al., 2002). Trauma can also occur away from the trauma site due to lesions of the coup-countercoup type where the head is struck on one side, and the brain subsequently rebounds and strikes the opposite side of the skull (Flanagan et al., 2006; Gennarelli & Graham, 1998). As aforementioned, the frontal and temporal regions are particularly impacted by TBI (Draper & Ponsford, 2008; Schonenberger et al., 2009) while the occipital lobes, parietal lobes and cerebellum are frequently spared (Flanagan et al., 2006, Gennarelli & Graham, 1998). Given the richness of connections, both afferent and efferent, between frontal structures and other areas, it is not surprising that executive dysfunction is often the result of such preferential injury (Bamdad et al., 2003; McDonald et al., 2002; Proctor & Zhang, 2008). Lacerations result from depressed skull fractures or penetrating objects. Focal ischemic lesions occur when blood flow is interrupted. These can be due to vasospasm (sharp and sometimes persistent constriction of blood vessels), which follows subarachnoid haemorrhage and renders the cerebral arteries particular vulnerable (Flanagan et al., 2006). The other main mechanism for focal ischemia is via physical compression of the arteries which often results from post-injury brain swelling (Flanagan et al., 2006).

Diffuse axonal injury is the result of stretch and torque forces, or 'shear and strain' (Gennarelli & Graham, 1998; McDonald et al., 2002). As tissues of the brain withstand stretch better if deformed in a slow, rather than abrupt fashion the sudden impact or abrupt acceleration / deceleration often associated with TBI is deleterious (Gennarelli & Graham, 1998). Diffuse axonal injury produces widespread cerebral damage, impacting the brain at the level of individual neurons (Gennarelli & Graham, 1998). Diffuse axonal injury is also the most likely cause of loss of consciousness (LOC) and a direct relationship exists between injury severity and DAI (Flanagan et al., 2006). As DAI is a microscopic process the results are often not visible in standard CT scan or MRI (Flanagan et al., 2006; Gennarelli & Graham, 1998). For further review of the proposed mechanisms for individual cellular death resulting from DAI see Gennarelli and Graham (1998). Diffuse axonal injury is disruptive to executive function (Henry & Crawford, 2004).

Subdural haemorrhages occur due to 'shearing' of the bridging veins (Flanagan et al., 2006). Older adults are particularly susceptible to this type of haemorrhage not only due to the occurrence of age-related atrophy, but also due to the hardening and loss of elasticity of the blood vessels within the brain associated with ageing (Albert & Knoefel, 1994; Flanagan et al., 2006). Therefore, the effect of subdural haemorrhages may not be immediately detected within the older patient as an age-related expansion in the volume of subdural space increases the time before compression becomes clinically significant (Flanagan et al., 2006; Goldstein & Levin, 2001). Further, the atrophy process makes veins vulnerable to tear even in the event of relatively minor trauma (Goleburn & Golden, 2001). Thompson, McCormick and Kagan (2006) also suggest that an age-related increased adherence of the dura to the skull, and high rates of the use of anti-coagulant medications contribute adversely to the pathophysiology of TBI incurred by older adults. Schonenberger et al., (2009) speculate that the older brain may not only be more vulnerable, but also less able to repair itself.

8.3 Why study TBI and Executive Function?

As reported in Chapter 2, it is widely accepted that the frontal lobes are the seat of executive functioning, and review of the pathophysiology of TBI has shown that these are the same areas that are likely to be injured during blunt trauma (Bamdad et al., 2003; McDonald, et al., 2002). Executive deficits are frequently the sequelae of TBI (Draper & Ponsford, 2008; Proctor & Zhang, 2008; Mangels, Craik, Levine, Schwartz & Stuss, 2002). Understanding the neuropsychological sequelae of TBI is important, and executive function is a logical foci given that these functions are argued to be crucial for such a wide range of cognitive and social activities (Bamdad et al., 2003; Burgess, 1997; Kennedy et. al, 2008; McDonald et al., 2002).

In studies of cognitive outcome post TBI, Draper and Ponsford (2008) note that executive function has been largely neglected in favour of memory and information processing. This disproportionate emphasis is reminiscent of the situation within the normal ageing literature, where memory has received much attention at the expense of other domains (Ferrer-Caja et al., 2002; Lowe & Rabbitt, 1997). It is also important that executive function and dysfunction can be studied sufficiently well so that rehabilitation interventions can be better evaluated and developed (Banich, 2009; Helps et al., 2008; Kennedy et. al. 2008). As the rationale for studying TBI in an older adult population stems in part from the high prevalence of amongst this group, it is useful to now turn attention to the epidemiology of TBI.

8.4 Epidemiology of TBI

8.4.1 Age and Gender

Traumatic brain injury occurs most frequently in young adult males, and at double the rate of females (Hillier et al., 1997; Tate, McDonald & Lulham, 1998). While the young are the biggest group represented, there is a second peak in the incidence of head injury in older

adulthood rendering older TBI patients a logical group to study (Goldstein & Levin, 2001; Goleburn & Golden, 2001; Helps et al., 2008). Figure 8.1, taken from Helps et al., illustrates how older adults represent quite a sizeable proportion of TBI cases.
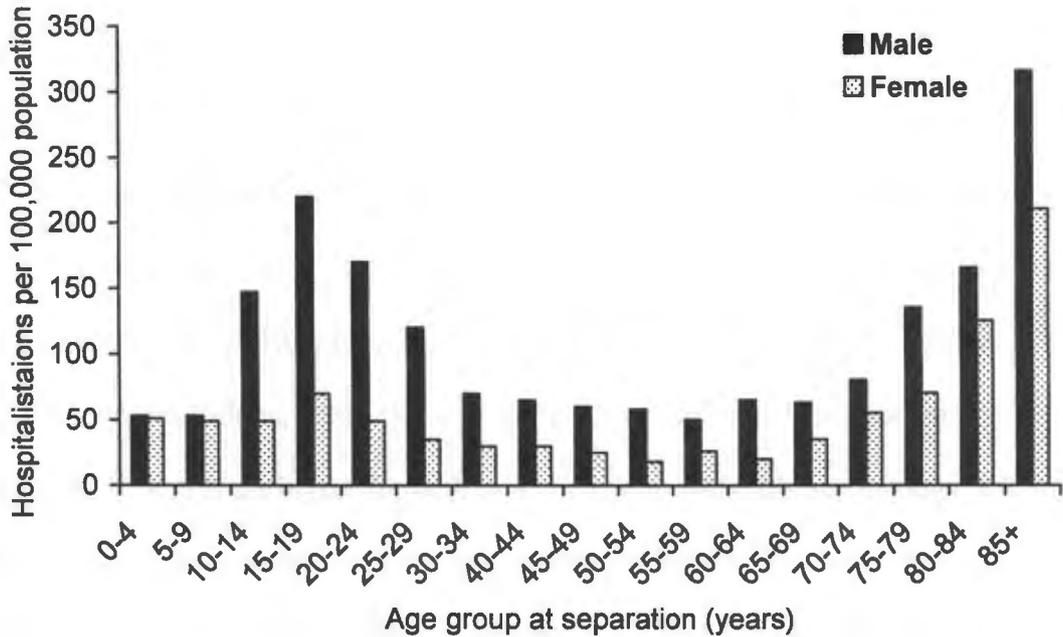
Figure 8.1. TBI as principal diagnosis, cases by sex and age group from Australia 2004-2005. Adapted from "Hospital Separations due to Traumatic Brain Injury, Australia 2004-05" by Y. Helps, G. Henley, and J.E. Harrison, 2008, *Injury Research and Statistics Series Number 45*, p.16.

8.4.2 Severity

Determining the overall prevalence of TBI cases of varying severities is difficult as many mild cases do not present for treatment, or may present at out patient settings (Binder, 1997). Ponsford et al., (2000) report that 80% of all head injuries can be classified as mild which is consistent with the results of separate Australian studies data reported by Hillier et al., (1997) and by Langley, Johnson, Slatyer, Skilbeck and Thomas (2010). The current investigation's TBI patients were recruited from the latter. Only 60% of the cases in a large Australian study by Helps et al., (2008) could be classified as mild, as were 62.2% cases in another Australian study by Tate et al., (1998). Hospital admissions procedure and other

biases can also represent differences between sites impacting the proportion of mTBI cases recorded across studies (Langley et al., 2010). Once mTBI cases are accounted for, Hillier et al., (1997) noted an even split in the proportion of cases that were moderate and severe.

8.4.3 Mechanism of Injury

Motor vehicle accident (MVA) is the most common mechanism of injury for younger adults (Flanagan et al., 2006; Hillier et al., 1997; Tate et al.,1998), while for older adults it is typically falls, followed by MVA (Coronado, Thomas, Sattin & Johnson, 2005; Goleburn & Golden, 2001; Helps et al., 2008). Motor vehicle accidents are associated with greater injury severity (Tate, et al., 1998). Thompson et al., (2006) report that 51% of TBI cases are caused by falls for older adults, with MVAs accounting for 9%, while Coronado and colleagues' (2005) figures are higher for both types of injury, with falls accounting for 67% of cases and MVAs 16% of cases. A smaller percentage of injuries accounted are accounted for by criminal assault and abuse by carers (Goleburn & Golden, 2001). Those aged between 65 and 74 years, are three times more likely to be hospitalised with fall related TBI than those younger, and the risk increase exponentially after 70 years of age (Coronado et al., 2005; Flanagan et al., 2006; Tate et al., 1998). In review, Rubenstein and Josephson (2002) estimate an incidence of between 0.2 and 1.6 falls per annum for community dwelling older adults, with the rate being higher in institutional settings. However, only one in ten falls experienced by an older adult will result in injury (Thompson et al., 2006). Falls risk may be an area where preventative efforts can be made (Flanagan et al., 2006; Goleburn & Golden, 2001) and as such, identifying the factors that make serious injury likely is a critical issue (Rubenstein & Josephson, 2002).

8.5 Why study TBI in Older Adults?

As was apparent from the coverage of the epidemiology of TBI, older adults have the second highest incidence of TBI, and issues surrounding TBI in older adulthood will become

increasingly exigent as our population ages rapidly (Goldstein, & Levin, 2001). While TBI during older adulthood predisposes the elderly to a premature death (Flanagan et al., 2006; McDonald et al., 2002), the bulk of this segment of the population enjoy a substantial survival rate (Coronado et al., 2005). This survival rate has improved greatly since the 1990's (Flanagan et al., 2006) and increased the demand for periods of post-acute care and family supervision (Goldstein et al., 1999).

Age related structural and cognitive changes, coupled with the co-occurrence of TBI, have the potential for producing pronounced deficits (Goldstein, & Levin, 2001; Schonenberger et al., 2009). Thus it follows that, given the high incidence of TBI in this age group, and the presumably poorer outcomes which result, that older adults are a logical population to study (Goleburn & Golden, 2001; Hukkelhoven et al., 2003; Myburgh et al., 2008). Despite increasing effort since the mid 1980s, the study of TBI among older adults is still relatively neglected (Goleburn & Golden, 2001). Much of the existent research is typified by problems with small samples, heterogeneity of outcome measures, a failure to control for injury severity, and in longitudinal work, poor follow-up (Goleburn & Golden, 2001; Rapoport et al., 2006).

It continues to remain unclear whether the pattern of cognitive impairment that typically follows TBI is expressed uniformly across the life span (Ashman et al., 2008), making the study of older adults with TBI meritorious. The practical applications of research into the cognitive sequelae of age and TBI are varied and include improving rehabilitation interventions (Banich, 2009; Helps et al., 2008) and preventative efforts around road safety (Hillier et al.,1997) and falls risk (Rubenstein & Josephson, 2002; Thompson et al., 2006). Prior to turning attention to a review of the literature concerning the cognitive outcome of TBI sustained by older adults, it useful to give consideration to diagnostic and methodological issues, relevant to this field.

8.6 Diagnostic Issues

Particular challenges exist in the diagnosis of TBI in older adults. Mild injuries often go unreported, yet such injuries in the elderly can result in significant problems (Flanagan et al., 2006). The diagnostic picture is further complicated by the capacity for both insidious and delayed onset post mTBI in this age group (Flanagan et al., 2006; Goldstein & Levin, 2001). This age group's injuries arise predominantly from low velocity falls which inturn lead to delays in presenting at treatment cites, and concomitant difficulties in accurately reporting Post-Traumatic Amnesia (PTA) and LOC (Goldstein & Levin, 2001; Helps et al., 2008). Older adults may not even remember the event that caused a mTBI, leading to difficulties in making differential diagnosis between TBI and the cognitive and behavioural changes associated with the dementing conditions (Flanagan et al., 2006; Thompson et al., 2006). The diagnostic picture is further complicated by the potential impact of subclinical conditions such as Mild Cognitive Impairment (MCI) and hypertension (Lezak et al., 2004).

8.7 Rating TBI Severity

There is no universally accepted severity measure for classifying TBI. The two most frequently employed methods are to use the Glasgow Coma Scale (GCS; Teasdale & Jennet, 1974), or to derive a rating using duration of PTA (Sherer, Struchen, Yablon, Wang & Nick, 2008). The duration of LOC is also used for indicating severity (Lezak et al., 2004; van Baalen et al., 2003).

The GCS is a short rating scale, near universally accepted, for ranking both TBI severity and outcome in medical facilities and research (Lezak et al., 2004; Saatman et al., 2008). Glasgow Coma Scale scores are based on depth of coma or altered consciousness and the examiner rates the ability to respond to commands. While the GCS has good predictive and inter- and intra-rater reliability, it is not free of limitations (Lezak et al., 2004; van Baalen et al., 2003). Scores on the GCS are subject to change depending on the time they are taken;

for example scores may worsen over time in some cases as secondary injuries emerge (Lezak et al.,2004; Saatman et al., 2008). Sedation and the effects of alcohol intoxication can artificially inflate severity ratings (Lezak et al.; Saatman et al.). Thus, there is debate as to which score to use, with candidates being variously that made by emergency services, the worst score, that taken 1 day post injury or 6 hours post injury etc. (Sherer et al., 2008; van Baalen, 2003).

Post-traumatic amnesia (PTA) is described as the inability to recall recent events (Goleburn & Golden, 2001). Post-traumatic amnesia has good predictive utility (Binder et al., 1997; Lezak et al., 2004; Sherer et al. 2008). Good evidence for the validity of PTA as a severity marker comes from a neuroimaging study by Schonenberger et al., (2009), where PTA, but not GCS, predicted white and grey matter integrity. Reliability problems do exist however as the measure is reliant on the patient or their family's retrospective account (Goleburn & Golden, 2001; Lezak et al., 2004). Duration of LOC is the other main method for rating injury severity. As with PTA, the limitations of self-report also apply to LOC, where the patient (or any others present) estimate the period of time where consciousness was lost (Helps et al., 2008). Not only are there problems with deficient recall or poor insight on the part of the patient, but when other ratings are used there may be a tendency to idealise the pre-morbid function of the patient (Milders, Fuchs & Crawford, 2003). The correlation between PTA and LOC was $r = .67$ in a large study by Sherer et al., (2008). While self-report is a limitation of both PTA and LOC, in most cases there is no practical alternative for obtaining the data of interest (Thomas, Skilbeck & Slatyer, 2009). Table 8.1 gives the accepted ranges for rating injury severity using the three methods discussed. The current study uses PTA as the severity index within the parameters set by Lezak et al., (2004) and Stein (1996).

Table 8.1

Levels of TBI severity by measure

	GCS	PTA	LOC
Mild	13–15	<1day	<30 minutes
Moderate	9–12	>1 to <7 days	>30 min to <24 hours
Severe	3–8	>7 days	>24 hours

Adapted from Stein (1996).

8.8 Methodological Issues in TBI research

As with other lines of research enquiry, the area of TBI has its own specific challenges and issues. Age cohort differences have been found to be more pronounced within TBI populations, differences over and above those found in work on normal ageing (Goleburn & Golden, 2001). Because of this, Schretlen and Shapiro (2003) suggest conducting more longitudinal research, while Dikmen et al., (2001) voice concern around the potential for practice effects in longitudinal work to mask deficits over time within mTBI populations. Christensen et al. (2008) caution that longitudinal efforts should include data from at least three time points, so that recover trajectories that may be non-linear can be detected.

Debate also exists around the choice of appropriate control subjects and recruiting methods. It is suggested that the use of normal rather than medical controls may artificially inflate differences due to the absence of injury, trauma and the effects of hospitalisation (Goleburn & Golden, 2001; Larrabee, 2005; Mathias, Beall & Bilger, 2004; Ponsford et al., 2000). Aharon-Peretz et al., (1997) detected differences between TBI patients and normal controls, but not between orthopaedic controls and TBI patients. However there are multiple methodological issues with that study, as evident in the review conducted forthwith in Section 8.10. Conversely, results of meta-analysis by Schretlen and Shapiro (2003) exploring

the issue, with respect to cognition at least, suggested that choice of control type was not significant.

Clinical vs. prospective recruitment of TBI samples has also proved contentious. It is widely agreed that optimally, selection into studies should be based prospectively on the occurrence of head-injury, as opposed to the occurrence of symptoms, especially in the area of mTBI (Binder et al., 1997; Dikmen et al., 2001; Larrabee, 2005; Schretlen & Shapiro, 2003). Clinical or retrospective recruitment may prove to be non-representative, especially of mTBI cases, as only those with persistent deficits are typically seen in clinical neuropsychological practice (Dikmen et al., 2001). When recruiting prospectively, careful inspection of medical records is necessary to accurately capture cases. The difficulty is that TBI does not enter the rubric of ICD classification codes, making it necessary for the researcher to determine that injuries involve the brain as opposed to merely involving the head (Helps et al., 2008; Tate et al 1998). Litigation status is also controversial with respect to sampling TBI patients (Larrabee, 2005; Mathias et al., 2004)

Overall inconsistency in measuring the severity of TBI, and with the interval between time of injury and data collection, makes cross study comparisons difficult (Christensen et al., 2008; Henry & Crawford, 2004; Sherer et al., 2008). Thus the mixed findings apparent in the literature may in part result from differing methods of classification and sampling (Christensen et al., 2008; Dikmen et al., 2001; Sherer et al., 2008). The same concerns around the ecological validity of neuropsychological tests that exists in ageing apply to the field of TBI (Goleburn & Golden, 2001).

8.9 Review of the Literature concerning mTBI and Cognition

As aforementioned, it is well established that TBI alters cognitive function and can produce lasting deficits at the moderate to severe end of the injury spectrum (Christensen et al., 2008; Ponsford, Draper & Schonberger, 2008; Schretlen & Shapiro, 2003; Sigurdardottir,

Andelic, Roe & Schanke, 2009). The mTBI area is less researched and the findings more mixed. The area is worthy of consideration forthwith, not only because it is a controversial one, but also as the bulk of the current investigations population of interest suffer mild injuries. It is often argued that litigants are motivated to 'fake bad' or approach testing with sub-optimal effort due to the potential financial gains of demonstrating injury related deficits (Larrabee, 2005). As such, some researchers control for, or examine, the impact of litigation status. Several key papers from the literature regarding cognitive function post-mTBI are covered forthwith.

Ponsford et al., (2000) compared an mTBI group ($n = 83$, M age = 26.4 years) with injury controls recruited from the same medical facility, tested at one week and three months post injury. The test battery included memory measures while being biased towards processing speed. One week post injury the mTBI group performed more poorly on processing speed measures than control subjects. At three month post-injury there were no differences in neuropsychological test performance between mTBI sufferers and controls although 24% of the head inured sample continued to self-report difficulties. In exploring the findings of the subset with persisting difficulties, the authors explain that it is unclear whether MVA resulted in greater brain injury, added more complicating physical injuries, or if MVA was simply more psychologically traumatising.

Mathias et al., (2004) were interested in the sensitivity of measures of processing speed to mTBI. A sample of 40 mTBI sufferers (M age = 32.4 years) were prospectively recruited and compared with well matched controls. Only 28% of the clinical sample were involved in litigation at the time of testing. Testing occurred at around one month post injury. Information processing was measured using choice reaction time tasks while measures from the Test of Everyday Attention (TEA; Robertson et al., 1994) were used to test selective and divided attention. An executive domain was comprised of Phonemic

Fluency and the Ruff Figural Fluency Test (RFFT; Ruff, Evans & Marshall, 1986). Memory performance was captured using the RAVLT. Results showed mTBI sufferers to be slower than controls on the TEA Telephone Search Task control condition, but not on the Telephone Search while Counting (TSC) condition (the dual-task divided attention trial). The mTBI sufferers performed worse than controls on the selective attention task (Visual Elevator from the TEA), on the RAVLT and on the RFFT, but not on the Phonemic Fluency task. There was also evidence of slowed information processing for mTBI sufferers. The authors suggest that the effects size for the speed measures were at least medium, and of a similitude to that of the other domains.

Binder et al., (1997) conducted a meta-analysis of studies of mTBI sufferers, 3 months post injury and beyond. The rationale for doing so was to investigate the critical issue, the chronicity of deficits. Executive function as a domain in its own right was not studied although TMT parts A and B, and the Stroop test were included among the measures of attention, and the WCST and Phonemic Fluency were assigned the domain 'mental flexibility.' Severity of injury accounted for a greater proportion of the variance than any particular cognitive domain. Attentional measures were most sensitive to mTBI. A small percentage of mild TBI cases continue to exhibit small deficits 3 months post injury, and Binder et al. concluded by calling for more research into the nature of this phenomenon.

Belanger et al., (2005) also conducted meta-analysis into outcome post mTBI, investigating cognitive domain and litigation status as potential moderating factors. Thirty-nine studies met entry criteria. Cognitive domains included general cognition, attention, memory acquisition, delayed memory, language, visuospatial ability and motor ability. Fluency was categorised as a domain in its own right, additional to executive function. Time since injury was demarcated into greater or less than 90 days. The largest effects were evident in the fluency and delayed memory domains, and the smallest were for motor

functions and executive function. Unfortunately, the authors do not discuss the relationship (or lack thereof) between fluency and executive function. Belanger et al. suggest that by three months post injury, that the cognitive sequelae of mTBI are resolved. Effect sizes were similar irrespective of litigation status for those examined within 90 days post injury. At the more distal time-point however, mTBI non-litigants and controls were not differentiated on the basis of performance, whereas deficits experienced by mTBI litigants remained or worsened. In exploring this finding Belanger et al. do not comment on the potential for those with persisting deficits to be potentially more motivated to participate in research as suggested by Binder et al., (1997) and Ponsford et al., (2000). A weakness of Belanger et al.'s (2005) design is the inclusion of studies using both prospective and clinical recruitment.

Studies of mTBI are not confined to this section of the literature review. Cases among older adult TBI populations, and studies including data from mTBI sufferers that explore executive function in greater detail, are examined within subsequent Sections. Attention is now turned to the literature that focuses on the cognitive impact of TBI for the older patient.

8.10 Review of the Literature concerning TBI, Age and Cognition

Goleburn and Golden (2001) reviewed 18 outcome studies investigating TBI sustained by older adults, conducted predominately during the 1980s and 1990's. They noted that prior to 1986, no work had concentrated on adults 65 years and older. Until 1991 all outcome studies were said to have utilised retrospective rather than prospective recruitment, and in these earlier studies it was more common for those with pre-existing disease and dysfunction to be included in samples, whereas such individuals have been more commonly screened out by later ones. When injury severity was taken into account, adults 65 years and older had poorer outcomes in comparison to their younger counterparts. Mortality rates were also higher and unsurprisingly related to injury severity. Cognitive deficits had been

recorded globally, and in various domains including attention, verbal fluency and memory. While interest was deemed to be increasing at the time of their review, Goleburn and Golden postulate the study of older TBI patients was neglected.

Meta-analysis by Hukkelhoven et al. (2003) professed to be principally concerned with the impact of age on outcome following TBI; however 96% of the sample was less than 65 years old. Data was aggregated from four different sites in addition to that from eleven prior studies, at the time point of six months post injury. Hukkelhoven et al., (2003) found that age was associated with a dramatically higher incidence of mortality and poorer outcome, especially after 39 years of age.

Raskin et al., (1998) investigated the impact of mTBI on cognitive function. While not focusing specifically on older adults, Raskin and colleagues did give consideration to the impact of age, splitting the sample ($n = 148$), into two age bands for some analyses, 39 years and younger ($n = 86$, minimum 17 years) and 40 years and over ($n = 53$, maximum 71 years). Participants completed the WAIS-R, WMS-R, California Verbal Learning Test (CVLT), the Rey-Osterrieth Complex Figure Test (ROCFT), various measures of attention, the WCST, the Stroop and Phonemic Fluency. Average time since injury was under two years, although the range (1-214 months) was very large. Participants had all been referred for neuropsychological assessment and were thus recruited selectively. Traumatic brain injury influenced cognitive performance, with deficits being most apparent on measures of attention, memory and for the TMT. The only age sensitive domain was that of memory; with the younger group exhibiting superior performance.

Mazzucchi et al., (1992) conducted one of the earliest studies into the cognitive sequelae of TBI sustained by older adults. Individuals between the ages of 50 and 75 years ($n = 70$, M age = 59.3 years) were tested, with variability in time since injury ($M = 10.4$ months, range 6-36 months) and heterogeneity of injury severity (63% suffered mild injures, 26%

severe injuries, 11% moderate) being features of the sample. Cognitive measures included the WAIS, an extensive group of memory tests and a smaller number of other tasks. Outcome was ranked at five levels, ranging from unimpaired through to severe deterioration and even dementia, based on cognitive performance. Fifty percent of the sample experienced a poor outcome (either severe deterioration or dementia), and 25.7% experienced moderate decline. Chi square analysis showed mTBI cases to be no different in outcome in comparison to the other classes. However, normal outcome was associated with PTA of less than one week, and dementia was associated with PTA duration in excess of one week. Age was not correlated with severity or outcome within this older cohort.

Aharon-Peretz et al., (1997) investigated the acute cognitive sequelae (six weeks post injury) of TBI among 22 older adults (*M* age = 75 years) in comparison with 10 normal controls (*M* age = 75 years), and 10 orthopaedic control (*M* age = 79 years). The TBI cohort were within the mild-to-moderate range. Measures employed were Digit Span and Similarities from the WAIS, verbal and visual memory tasks, and Semantic Fluency. The TBI group performed more poorly than normal controls on all tasks except Digit Span, while no differences were apparent between the performance of the TBI group and orthopaedic controls. The authors interpret the later result to suggest that cognitive decline predated injury and may have actually predisposed older adults to falls. However, Aharon-Peretz et al. offer no caveats around random error given the very small cell sizes employed, or the possibility that the orthopaedic controls, being almost on average 4 years older than the TBI group, may have masked true differences.

Goldstein et al., (1999) examined ratings made by significant others of the cognitive, emotional and social functioning of 17 older TBI patients and 10 control subjects. Twelve TBI cases were of moderate severity while the remainder were mild. Motor Vehicle Accident was the most common mechanism of injury. Data was taken at four months and

one year post injury, and a pre-injury estimate was also made. The collateral reports suggest that cognition was impaired initially in TBI cases, but not by the one year follow-up point.

Goldstein et al., (2001) contrasted the cognitive performance of mild and moderate TBI cases in a population aged 50 years and older, examining cognition with greater rigour. The sample consisted of 18 mTBI patients, 17 moderate TBI sufferers and 14 well matched controls (*M* ages = 62.3, 65.2 and 65.3 years respectively), assessed at 1 month post injury. Tests of attention, memory, language and executive function were administered. The authors acknowledge the absence of measures of information processing as a limitation. Despite the improved test selection over Goldstein et al. (1999), the composition of the executive function domain by Goldstein et al. (2001) is not without issue, consisting of similarities from the WAIS (which could be argued to be more valid as a test of language) coupled with the WCST, while Phonemic Fluency was relegated to the language domain and the TMT to attention. With respect to mechanism of injury, moderate cases suffered more MVAs, while the mTBI group suffered more falls and pedestrian accidents (Goldstein et al., 2001). Moderate cases performed more poorly than controls and mTBI patients in all domains. Phonemic fluency performance was the only cognitive measure where the performance of mTBI sufferers was significantly worse than that of controls.

The Goldstein et al., (2001) study was extended further by Goldstein and Levin (2001). Fifteen extra cases were added, and elucidating the relationships between cognitive outcome and the severity indices of GCS, PTA and impaired consciousness was a focus. The presence or absence of intra-cranial pathology, GCS score and intracranial complications related most frequently to the cognitive tests. Post-traumatic amnesia correlated significantly with the executive construct only, while a trend for impaired consciousness to correlate with executive function existed at an alpha level of .06. Injury severity was further demarcated into complicated-mild (intra cranial complications present), and uncomplicated –mild

(absence of intra-cranial complications), in addition to moderate. Such an analysis showed uncomplicated mTBI cases to have superior performance for both Phonemic Fluency and the modified WCST, relative to complicated mTBI and moderate cases. Complicated mTBI sufferers outperformed moderate patients on the TMT only. It should be noted that there were only six moderate cases which reduces confidence in the results, a limitation that Goldstein and Levin fail to acknowledge.

Rapoport et al., (2006) examined cognition in an older adult TBI population 50 years and older ($n = 49$, M age = 67 years), at twelve months post-injury. The most common mechanism of injury was falls for 50.7% of the sample, followed by 'other' (29%) and MVA (20.3%). Measures employed included Digit Span and Digit Symbol-Coding, Logical Memory subtests from the WMS, the CVLT and delayed copy of the ROCFT. The Boston Naming Test (BNT; Kaplan, Goodglass & Weintraub, 1983) was included as a measure of language, and Semantic Fluency and WCST indexed executive function. Sixty-five percent of moderate TBI cases reported subjective complaint of cognitive impairment, while the rate was 41.4% for mTBI and 17.3% for control subjects. The TBI sufferers performed significantly worse on the processing speed measures, the BNT and on Semantic Fluency than controls. Srivastava et al. (2006) conducted further analysis of the same data which showed the MMSE to have little utility in detecting mild and moderate TBI at 12 months post injury. Rapoport et al. (2008) presented data from a two year follow-up point, where at that time point no persisting cognitive or functional deficits were recorded.

Ashman et al. (2008) examined cognition among TBI sufferers 55 years and older ($n = 54$). Time since injury was actually very distal; only 44% of the sample had sustained their injury within the past 4 years, with a total range of 1-58 years post injury. Sixty-three percent of TBI patients were in the mild range, with the remainder falling in the moderate-to-severe range. The CVLT, and Logical Memory and Visual Reproduction from the WMS-III

captured the domain of memory. Processing speed was assessed with relevant Woodcock-Johnson tasks and a pegboard task. Executive function was tapped with the WCST and TMT-B, while the authors choose to group a Verbal Fluency task with the Vocabulary subtest from the WAIS, and the BNT, to represent the combined domain of verbal ability and fluency. Trail Making Test Part A was the sole measure assigned to the domain of attention. Overall, there were significant differences between TBI sufferers and controls on Logical Memory performance, the CVLT and the TMT-A only. The lack of differences on other measures is not entirely unexpected given the poor control over injury severity, and in particular, time since injury.

8.11 Traumatic Brain Injury and Executive Function

Having covered the literature dealing with the impact of mTBI on cognition, and the literature concerned with the cognitive sequelae of TBI for older adults, it is now time to review the work conducted with TBI sufferers that either examines the domain of executive function specifically, or at least features tests of executive function. Attention is given first however to a meta-analysis by Schretlen and Shapiro (2003).

Schretlen and Shapiro (2003) conducted the first review of the impact of TBI upon cognition across the full severity spectrum, conducting a meta-analysis of 39 studies. As expected, patients fared worse than controls, and injuries that were within the moderate-to-severe range produced greater and longer lasting cognitive disruption. Schretlen and Shapiro did not report the age range covered or any age-related trends. Recovery for moderate-to-mild patients was greatest within 6 months post injury and appeared maximal by two years. Schretlen and Shapiro also investigating the influence of control group chosen; being either 'normal' or orthopaedic / other injury. They found slightly smaller effect sizes in studies using orthopaedic controls, but these differences were not significant. This finding bodes well for the validity of studies using normal controls. Schretlen and Shapiro deemed separate

coverage of the various domains of cognition, including executive function, to be beyond the scope of the review, while indicating that such data was being analysed for presentation elsewhere. The promised review however is yet to appear.

Raskin and Rearick (1996) took a sample of mTBI sufferers ($n = 19$, M age $= 42.3$ years), and compared their Phonemic and Semantic Fluency performance with that of normal controls. Recruitment was not prospective as patients had been referred for neuropsychological assessment. All had MVA as the mechanism of injury and none were involved in litigation. Participants were at least 12 months post injury ($M = 38.87$ months). The Phonemic Fluency task was the standard FAS, while for the Semantic Fluency task participants were given a 90 second trial and prompted by the examiner as to potential sub-categories. Patients were also administered the CVLT, the WCST and the Paced Auditory Serial Addition Test (PASAT; Gronwall, 1977) in an attempt to examine the relationship between verbal fluency, memory and executive function. The mTBI group generated fewer words on both fluency tasks than controls. Semantic but not Phonemic Fluency performance showed a strong relationship with CVLT performance. No other relationships of note were found between fluency performance and the other measures.

Leon-Carrion et al., (1998) took a sample of TBI patients (M age $= 32.4$ years), and delineated them into those who had undergone neurosurgical intervention (evacuation of haematoma, $n = 13$), and those who had not ($n = 35$). All TBI patients were in the severe range as measured by GCS, with the exception of three moderate cases in the non-surgery group, and all patients were said to be within 2 years post-injury. No further data is given regarding the temporal course of recovery for the TBI group. Patients were administered the Tower of Hanoi (ToH) and the WCST. Data was not taken from a control group although results were compared to norms derived from earlier work by Leon-Carrion and colleagues. Irrespective of surgery status, TBI patients demonstrated impaired performance on both the

WCST and the ToH. A relationship existed in the expected direction between severity of injury and poverty of performance.

Levine et al., (1998) conducted a validation study of a strategy application test, similar in structure and demands to the Six Elements Test (SET). Levine and colleagues tested a variety of groups, including a lesion group ($n = 16$), a TBI group ($n = 42$ of varying severity, tested between 1 - 2.5 years post-injury) matched controls, and a normal ageing group (who's data was reported in Section 7.1). In addition to the SET-type task, participants also completed convergent measures of executive function, such as Phonemic and Semantic Fluency, the WCST, the TMT, and the Stroop, and also divergent measures such as an IQ estimate, the WMS-R and the BNT.

The results for the strategy application test showed the lesion group to fare worst, followed by the TBI group and then the normal ageing group (Levine et al., 1998). Older adults showed subtle but statistically significant decrements in performance in comparison to younger controls. The strategy usage task correlated moderately (r .25-.35), with both executive and non-executive measures. In those from all groups whose performance was deemed non-strategic, after education and IQ was corrected for, a significant relationship remained between the strategy application task and the WCST, the TMT-B, the Stroop and one of the recall measures. Levine et al. argue that the pattern of results suggested that integrity of executive function was important for successful performance on the strategy task, in addition to the contribution of memory and information processing. That is, a differential deficit was identified.

Brooks, Fos, Greve & Hammond (1999) investigated executive function in a small ($n = 11$) non-ageing mTBI sample. When compared with controls, mTBI sufferers within 3 days of injury, performed worse on the TMT parts A and B, Phonemic Fluency and the

PASAT. There were no significant differences on WISC-R Mazes, which the authors posit may have been not sufficiently difficult, or on naming and language tasks.

Chan (2000) studied attention in TBI sufferers in Hong Kong using the TEA and measures of executive function. The sample ($n = 21$, M age = 37.3 years) were recruited from a neurosurgical ward. Severity classification is not made explicit, although patients appear to be primarily within the mild-to-moderate range, and were said to be 3 months post injury ($M = 41$ months). The TEA differentiated TBI sufferers from controls on the majority of the instrument's subtests. Within the executive domain, TBI sufferers performed worse on the Stroop, Digits Backwards and on the TMT-A, but not TMT-B. There was also a strong trend for inferior SET performance, falling just short of statistical significance. Chan and Manly (2002) tested a mild-to-moderate TBI cohort ($n= 30$, M age = 38 years) at between 3 and 15 months post-injury on the executive tasks ToH and the SET. Performance on the ToH was not significantly different between TBI sufferers and controls, while performance on the SET was.

An Australian study of executive function conducted by Hennessy, Geffen, Pauley and Cutmore (2003), took a sample of individuals with mTBI ($n = 22$, M age = 23.7 years) at one month post injury, comparing them to 15 matched orthopaedic controls. Measures administered were various subtests from the TEA and Phonemic Fluency, Design Fluency, the Stroop, TMT-B, the ToL and Self-Ordered Pointing Task (SOPT). The only measure to demonstrate a difference between TBI patients and controls was the dual-task measure TSC from the TEA. The authors acknowledged that a lack of statistical power precludes drawing strong conclusions from their data.

Henry and Crawford (2004) conducted a meta-analysis of verbal fluency performance among TBI sufferers, particularly seeking to establish whether executive function was differentially sensitive to the effect of TBI in comparison to other domains such as processing

speed and memory. Thirty papers meet inclusion criteria. Average severity and time since injury were not reported. The effect sizes for impaired Phonemic and Semantic Fluency performance by TBI sufferers were almost uniformly large. Too few studies used the Semantic Fluency paradigm for it to be compared with other cognitive domains, so Phonemic fluency performance only was examined against processing speed (as captured by TMT-A), memory (by way of list learning performance) and WCST performance. Phonemic Fluency was the most sensitive of all the measures to TBI, although the difference was only statistically significant in comparison to WCST performance. Nevertheless, Phonemic Fluency accounted for an additional 6.5% of the variance in comparison to processing speed, leading the authors to conclude that executive function suffers more than processing speed post TBI, and that executive function suffers to a degree at least comparable to that of memory. The pattern of results was not accounted for by premorbid IQ differences or by differences in current VIQ. Given the large amount of data analysed, it is disappointing that any age-related trends, or lack thereof, were not commented upon.

Hart et al. (2005) investigated the relationship between executive function and self-awareness of cognitive deficits. The TBI cohort ($n = 36$ M age = 34.4 years) were selected on the basis of subjective attentional complaint, and were typically tested several years post-injury ($M = 2.5$ years). Injuries are described as being moderate-to-severe although only 6% of the sample recorded PTA of less than two weeks; in actuality the sample was quite severely injured. Executive function was measured as a single composite score derived from 8 measures. Real world function and attention were assessed entirely on the basis of self-report. As predicted, TBI patients performed worse than controls in the domain of executive function and demonstrated greater impairments in self-awareness.

In a related study, Kim et al., (2005) examined the contribution of executive function to inattentive behaviour. Attention was measured by multiple observer ratings in a quasi-

naturalistic setting, while a research confederate created various pre-orchestrated naturalistic distractions. On and off task behaviour was calculated to derive an index of inattentive behaviour. A choice reaction time task was also administered as a measure of processing speed. The executive composite score accounted for 19% of the variance in inattentive behaviour. This score was a better predictor of inattentive behaviour than age or injury severity. Age did not correlate with the executive composite, while there was a moderate correlation between injury severity and the executive composite. Post-hoc tests showed that the choice reaction time task did not mediate executive function, and analysis revealed that a significant proportion of the overall variance remained when only non-speeded executive measures were included. When interpreting these results it should be kept in mind that choice reaction time is a very simple way of indexing information processing. Given the superficial manner in which processing speed was indexed by Kim and colleagues, a degree of caution is warranted regarding the conlcusivenesss of their findings with regard to the relationship between processing speed and executive function.

Kennedy et al., (2008) conducted a meta-analysis 15 studies of rehabilitation interventions that aimed to improve executive function post-TBI. Individual rather than group treatments were the norm (86.67%), although this figure may have been inflated by the inclusion of several studies using single N designs, as noted by Kennedy et. al. A similitude of intervention efforts is noted despite the varied target behaviours. Most studies indicated immediate gains, while longer term gains were maintained less frequently although Kennedy and colleagues do not indicate over what length of time. Gains in executive function were more likely to be identified when measures of daily living were used, as opposed to standardised cognitive tests. None of the studies reviewed by Kennedy et al. included older adults as participants.

One of the few studies to specifically examine TBI and executive function among older adults was conducted by Kliegel, Eschen and Thone-Otto (2004). They sought to elucidate the relationship of executive function to prospective memory performance, and to also test the frontal ageing hypothesis. The performance of young healthy controls ($n = 19$, M age = 24.3 years) were contrasted with two separate groups, a young TBI group ($n = 7$, M age = 37.9 years), selected on the basis of normal memory performance (as measured by the WMS-R) but with impaired executive functioning (as per BADS results), and a group of older healthy controls ($n = 21$, M age = 70.1 years). Kliegel et al. hypothesised that the younger group would fare best, predicting a lack of differences between the older adults and TBI participants. Perplexingly, they do not give any rationale for predicting a similitude of performance between the older adults and a group specifically selected to have executive deficits. This is especially curious given that executive decrements within normal ageing cohorts are often sub-clinical and difficult to detect (Bryan, & Luszcz, 2000a). The TBI group had all sustained severe injuries (PTA duration 1.5-34.5 weeks), and were between 27 and 55 months post-injury (Kliegel et al., 2004). The WCST was administered in addition to prospective memory measures.

Younger adults out performed both groups on all measures, with the sole exception being the first phase of the prospective memory task (Kliegel et al., 2004). On the later three phases of the task, and for the WCST, young controls out performed the other two groups, with a lack of significant differences recorded between the older adults and the TBI group. Little is made of the lack of differences between the older group and the TBI patients, although it is acknowledged that another age-related factor such as diminished processing speed may have been operant. Nevertheless, given both the severity of injuries suffered by the TBI patients and their pre-selection on the basis of executive difficulties, it seems almost incredulous that they would perform at similar level to normal ageing older adults. Such a

finding also runs counter to a major issue concerning this thesis, that the cognitive sequealae of TBI are quantitatively and qualitatively different to the normal ageing process.

8.12 Summary

The existence of cognitive deficits post TBI at the moderate to severe end of the injury spectrum is well established (Christensen et al., 2008; Ponsford et al., 2008; Sigurdardottir et al., 2009). The area of mTBI is much more controversial and of particular relevance to this endeavour as most older adults will experience injuries classified as mild (Coronado et al., 2005; Goleburn & Golden. 2001). In reviewing studies of mTBI sufferers using non-ageing samples, it was evident that impairment was generally detected within the first month post injury (Brooks et al., 1999; Mathias et al., 2004; Ponsford, et al., 2000) and largely absent from studies measuring cognition beyond three months post-injury (Belanger et al., 2005; Ponsford, et al., 2000). Nevertheless, Binder et al., (1997) produced data that suggests that a small subset of mTBI cases exhibited cognitive problems beyond this time point, while Ponsford et al., (2000) recorded persisting deficits among this population on psychosocial measures only.

Studies using non-ageing samples do not demonstrate any clear finding as to whether any one particular cognitive domain is particularly sensitive to mTBI. Binder et al., (1997) indicate that attention is most sensitive, while Belanger et al., (2005) suggest that verbal fluency and memory were most vulnerable. The lack of agreement is unsurprising given the heterogeneity of research designs and measures employed. In terms of litigation status, both Ponsford et al. (2000) and Belanger and colleagues (2005) found no effect within three months post-injury, although after three months post-injury Belanger et al. reported that deficits for non-litigants were largely resolved in contrast to their litigant counterparts.

Given that a deleterious impact on cognitive function within the general population had been widely demonstrated as being among the sequelae of TBI, it is not surprising that

the same holds true for older adult samples (Ashman et al., 2008; Goleburn & Golden, 2001; Goldstein, 1999; Goldstein et al., 2001; Hukkelhoven et al., 2003; Mazzucchi et al., 1992; Rapoport et al., 2006; Raskin et al., 1998). A more vexing question however, is whether the cognitive sequelae of TBI for older adults is qualitatively and quantitatively different from that of their younger counterparts, and which, if any, factors mitigate the impact?

Earlier review by Goleburn and Golden (2001) found that adults 65 years and older suffering TBI had poorer cognitive and psychosocial outcomes in comparison to their younger counterparts, exhibited higher mortality rates, and unexpectedly, an absence of a strong relationship between mortality and injury severity. A lack of a relationship between injury severity and outcome, and age being associated with poorer outcomes, was also recorded in the pioneering earlier work by Mazzucchi et al., (1992), while Goldstein (et al. 1999, et al., 2001) report more of a dose-injury relationship with cognition, and a high degree of variability in psychosocial sequelae, consistent with the non-ageing research of Ponsford et al., (2000).

Regarding the impact of time since injury for older adults, cognitive deficits have been detected within three months of injury, even in mTBI cases (Goldstein, et al., 1999; Goldstein & Levin 2001; Goldstein et al., 2001). By twelve months post-injury few cognitive deficits were revealed. Goldstein and Levin (2001), Goldstein et al., (2001) and Rapoport et al., (2006) all documented such deficits at 12 months post-injury, predominantly in moderate cases. By the 24 month post-injury mark, the deficits originally recorded by Rapoport et al., (2006) at 12 months were largely resolved (Rapoport, et al., 2008). Studies that included severe cases recorded deficits more distally (Ashman et al., 2008; Mazzucchi et al., 1992).

It is not uncommon for the domain of executive function, to suffer post TBI (Hart et al., 2005; Kim et al., 2005; Kliegel et al., 2004; Levine et al., 1998). In terms of severity and temporal course, during the acute phase Brooks et al., (1999) detected executive impairments

within a mTBI group three days post injury, while Hennessy et al., (2003) did not at one month post-injury. Chan (2000) documented impaired executive performance on multiple measures in a mild-to-moderate cohort around three months post injury, although the sample was recruited selectively on the basis of subjective attentional complaint. As logic would suggest, it appears that more severe injuries are associated with longer lasting executive deficits (Leon-Carrion et al.,1998) and such a dose / deficit relationships is consistent with results of a meta-analysis of the impact of TBI on general cognitive function performed by Schretlen and Shapiro (2003). Poor reporting of both TBI severity and time since injury makes integrating the findings of other studies with an executive bent difficult (Henry & Crawford, 2004; Levine et al., 1998). The generalisability of the results of research by Kim et al., (2005), Kliegel et al., (2004) and Hart et al., (2005) is complicated by the issue of selective recruitment.

In terms of particular measures of executive function as being most sensitive or more likely to show an impact post TBI, tasks of verbal fluency seem to show the most consistent decrements (Aharon-Peretz et al., 1997; Brooks et al., 1999; Goldstein et al., 2001; Henry & Crawford, 2004; Rapoport et al., 2006; Raskin, & Rearick, 1996). Henry and Crawford (2004) found the Phonemic Fluency task to be the most sensitive of all cognitive measures in their meta-analysis and Goldstein et al., (2001) found that Phonemic Fluency performance was the only measure that distinguished older mTBI cases from controls. Raskin and Rearick (1996) recorded deficits 12 months post injury in a mTBI cohort for both Phonemic and Semantic Fluency performance although their sample was not recruited prospectively. Aharon-Peretz et al., (1997) found Phonemic Fluency to be sensitive to mTBI in an older sample while Mathias et al., (2004) and Hennessy et al., (2003), both using non-ageing mTBI samples, recorded rare null results for the paradigm.

The WCST showed impairment in severe cases in the study by Leon-Carrion et al., (1998). The results of Goldstein et al., (2001) showed a composite score which included the WCST to differentiate moderate TBI cases from mTBI cases at one month post injury, but not between mTBI cases and controls. Rapoport et al., (2006) noted poorer performance in older moderate cases at twelve months post injury, but not at the two year mark (Rapoport et al., 2008). Thus, the WCST appeared to be sensitive to TBI in cases of moderate severity and greater. Results for the TMT were less consistent. Brooks et al., (1999) found poor performance in mTBI patients relative to controls three days post injury, and Raskin et al., (1998) also recorded deficits in a selectively recruited mTBI sample for TMT-B. Hennessy et al., (2003) did not find such deficits for mTBI cases at one month post-injury, while Chan (2000) documented poorer performance in mild-to-moderate TBI patients on the TMT-A only. Strauss et al., (2006) have deemed the TMT to have questionable utility for assessing mTBI populations.

Other measures were employed even less frequently making general comment difficult. On the Stroop, poorer performance was demonstrated by mild-to-moderate TBI patients by Chan (2000), while Hennessy et al., (2003) detected no such effect for mTBI cases at one month post-injury. Mathias et al., (2004) recorded inferior Figural Fluency performance for mTBI sufferers at one month post injury. Leon-Carrion et al., (1998) detected impairment on the ToH in severe cases, while Chan and Manly (2002) found that the measure did not differentiate mild-to-moderate TBI patients from controls. Regarding the SET, Chan (2000) noted a trend towards impaired performance in mild-to-moderate TBI patients, and impairment in a further study of patients within the same severity range was documented by Chan and Manly (2002). The superior sensitivity of the Phonemic Fluency paradigm to TBI is in direct contrast to the relative invariance of the same task among normal ageing studies (see Section 7.3). Conversely, it is also somewhat surprising that results for

the WCST from the TBI literature suggested sensitivity in more moderate and severe cases only, given that the instrument is sensitive to normal ageing (see Section 4.5).

As discussed earlier, debate exists as to whether executive function is even a valid construct in its own right distinct from *g,* and whether executive impairment shown in normal ageing studies is not merely the product of global slowing (see Section 7.3). From the non-ageing mTBI literature, while conducting meta-analysis, Binder et al., (1997) determined that injury severity was more influential than any one cognitive domain. Mathias et al., (2004) found that their domain of interest, processing speed, had effect sizes similar in magnitude to that of other domains, including executive function. In their meta-analysis, Henry and Crawford (2004) found that fluency measures made a unique contribution to the variance, over and above processing speed. Kim et al., (2005), using a more severely injured and selectively recruited sample, found that executive function made a unique contribution to inattentive behaviour, a contribution which again was not explained away by processing speed.

Work by Mathias et al., (2004), and Binder et al. (1997) within mTBI populations showed a similitude between cognitive domains of impact of injury, while within the same body of literature, Belanger et al., (2005) found memory and fluency to be most sensitive. With respect to specific cognitive domains impacted by TBI among older adults, no clear picture emerged. There is a need for research into the impact of TBI on executive function overall, and for studies to investigate the executive function of older TBI cohorts. This thesis represents an effort to reduce this paucity.

CHAPTER 9

Study 1 - The Impact of Age on Executive Function

9.1 Aims and Hypotheses

The aim of the current study is to further elucidate the impact of normal ageing on executive function by comparing the performance of older adults aged 50-59 years, 60-69 years and 70-79 years. As was established within Chapter 7, extreme age-group designs predominate research that investigates the influence of age on executive function. Therefore, the current investigation makes an important contribution as further delineating cognitive performance in older adulthood is necessary to contribute to a fuller account of cognitive ageing throughout the lifespan. Hedden and Gabrieli (2004) identify a need for investigations that can examine whether any observed cognitive decline is gradual, or sharper after a critical period is reached. A research paucity is well identified (Alvarez & Emory, 2006; Ivnik, Malec, Smith, Tangalos & Petersen, 1996; Phillips, 1999; Richardson & Marottoli, 1996). The 50-59 year old age bracket, sampled by the current study, represents a group that is particularly understudied (Garden, Phillips & MacPherson, 2001).

The Semantic Fluency task (Strauss et al., 2006) was an important inclusion in the current study. Semantic Fluency is often omitted in studies of age and executive function in favour of the Phonemic Fluency paradigm (Bryan &Luszcz, 2000b, 2001; Fisk & Sharp, 2004; Hughes & Bryan, 2002; Parkin & Lawrence, 1994; Rhodes & Kelley, 2005). However, this can be problematic as the Phonemic Fluency task itself is often, but not universally, age invariant (see Section 7.3), and has been contested to be more a measure of lexical access than executive function (Fisk & Sharp, 2004; Shores, Carstairs & Crawford, 2006). Thus both measures are used herein. The inclusion of divided attention measure Telephone Search while Counting (TEA; Robertson et al., 1994) also represents a

contribution. There are no available published studies where the TSC has been employed with ageing cohorts, despite the purportedly high sensitivity of the measure (Hennessy, Geffen, Pauley & Cutmore 2003; Robertson et al., 1994) and interest in studying divided attention among older adults (Bieliasuskas, 2001; Brenner, Homaifar & Schultheis, 2008; Fisk & Sharp, 2004; Treitz et al., 2007).

The normal ageing data collected is also intended to serve as a baseline in Study 2, allowing the performance of Study 1's participants to be contrasted with older adults who have suffered TBI. A secondary aim of this thesis is to further explore the utility of the Alternate Uses (AU) test (Guilford, Christensen, Merrifield & Wilson, 1978). The task has been suggested as a potentially valid and sensitive measure of executive function, and particularly suited to studying older adults (Bryan & Luszcz, 2000a). The need for measures to be both sensitive and ecologically valid have been challenges within this field (Burgess, 1997; Ettenhofer, Hambrick, & Abeles, 2006) and the AU test has been identified as showing promise in both respects (Bryan, & Luszcz 2000a; Butler, Rorsman, Hill & Rogerio, 1993). To this end the measure was an important inclusion in the current Study. While not being designed as a specific norming and validation study, the current investigation seeks to shed light on the issue of utility by testing sensitivity to age, and by considering the effect size of any positive results relative to other measures.

West (1996) suggests the frontal ageing hypothesis can account for many of the changes that are observed throughout the normal ageing processes. Conversely, proponents of global accounts of cognitive ageing suggest that brain changes are diffuse and impact all cognitive abilities to the same proportional extent (Craik, 2000; Salthouse, 1996). In line with the frontal-ageing hypothesis, it is predicted that executive measures will be impacted to a greater degree than non-executive measures. It is necessary to also include non-executive measures of memory and processing speed so that competing global accounts can be tested as

rival hypotheses. While age is predicted to exercise the biggest influence over cognitive performance, the literature reviewed previously also suggested that gender and education may impact some measures (Hester et al. 2004; Lacritz & Cullum, 1998; Ostrosky-Solis & Lozano, 2006; Ryan, Kreiner & Tree, 2008; Tombaugh et al., 1999; van der Elst et al., 2006; Vanderploeg et al., 2000). While no specific predictions are made with regard to gender and education, their effects will be tested for.

1. Based on previous research (Bryan, & Luszcz, 2001; Ferrer-Caja et al., 2002; Levine, Stuss & Milberg, 1995), the frontal ageing hypothesis (West, 1996) will provide a better account for the pattern of results than a global factors account (Craik, 2000; Salthouse, 2005).

2. Age will have a deleterious impact on performance for the following executive measures; the Semantic Fluency task (Ettenhofer et al., 2006; Tombaugh et al., 1999; Troyer, 2000), the Stroop task (Strauss, et al. 2006, as per Ettenhofer et al., 2006; Lowe & Rabbitt, 1997), the dual-task TSC (Robertson et al., 1994), and the AU task (Bryan & Luszcz, 2000b; Parkin & Java, 1999).

3. Age will have a deleterious impact on Hopkins Verbal Learning Test-Revised (HVLT-R; Brandt & Benedict, 2001) Immediate and Delayed recall performance (Hester, Kinsella, Ong & Turner 2004; Vanderploeg et al., 2000).

4. Age will have a deleterious impact on the Rey-Osterrieth Complex Figure Test (ROCFT; Strauss et al., 2006, as per Fastenau, Denburg & Hufford, 1999; Gallagher & Burke, 2007).

5. Age will have a deleterious impact on the information processing speed
   measure, Digit Symbol-Coding (Psychological Corporation, 1997b, as per
   Joy, Kaplan & Fein, 2004; Span, Ridderinkhof & van der Molen, 2004).

In addition, it is not expected that Phonemic Fluency (Strauss et al., 2006) will show group differences based on previous work (Bryan, & Luszcz, 2000b; Troyer et al., 1997; Parkin, & Java, 1999; Phillips, 1999; Rhodes, & Kelley, 2005; Troyer et al., 1997; 2000). It is not expected that HVLT-R recognition memory will show group differences based on the robustness of recognition memory in normal ageing (see Lezak et al. 2004, Strauss et al. 2006) and the results of Hester et al., (2004). It is not expected that any of the Digit Span Indexes (Psychological Corporation, 1997b) will show group differences based on Hickman, Howieson, Dame, Sexton and Kaye (2000) and Myerson, Emery, White & Hale (2003). Also with respect to Digit Span, as best can be deduced with the modes of data analysis available to the current investigation, it is expected that Digits Forward and Digits Backwards will reflect a similar function (Strauss et al. 2006), rather than there being evidence for Digits Backwards to be inherently more executive in nature (Lezak et al., 2004) as covered previously in Section 4.16.

9.2 Participants

The sample size recruited is expected to provide adequate power, based on Kirk (1995), as reported subsequently in Section 9.7.

9.2.1 60 to 79 year olds

All participants from Study 1 between the ages of 60 and 79 years were recruited from the Tasmanian Study of Cognition and Gait (TASCOG). The TASCOG project is an investigation conducted by the Menzies Research Institute, a centre for epidemiological research in Hobart, Tasmania, Australia. The TASCOG project is a population based study,

focusing on the effect of subclinical cerebrovascular disease on brain function in older people.

Participants were recruited to TASCOG from a random sample of the electoral roll of community dwelling Southern Tasmanians, 60 years and older. Participants were invited into the TASCOG study by a letter in conjunction with a follow-up phone call and the response rate was 55% (Martin et al., 2009). Prospective participants were excluded from TASCOG if they were unable to walk without a gait aid, or if MRI scan was contraindicated (pacemakers, other metallic devices or severe claustrophobia). Participants included in Study 1 of this thesis were tested at the Menzies Research Institute, Hobart, between December 2004 and December 2005. In an effort to reduce any demand characteristics around driving ability and other transport related barriers, taxi vouchers were provided to TASCOG participants where necessary. Data was taken from 100 individuals.

In addition to meeting TASCOG criteria, individuals were excluded from Study 1 if any of the following applied: a history of brain injury or other neurological disorder, serious medical problems impacting cognition, past inpatient psychiatric treatment, current major mental illness, a history of substance abuse, if they had inadequate vision or audition to complete experimental tasks, or an existing diagnosis of dementia. All participants had English as their primary language and had normal or corrected-to-normal vision. Twenty three individuals were excluded, leaving a final sample of $n = 77$. Ten participants were excluded due to neurological conditions, six due to sensory deficits, five due to their psychiatric or substance history, and two due to missing data. No incentives were offered for participation and all participants were appropriately debriefed post testing. Ethics approval (H7947) was granted by the Southern Tasmania Health and Medical Ethics Committee.

9.2.2 50 to 59 year olds

A cohort of 50 to 59 year olds (*n* = 23) was recruited independently of the TASCOG project. These participants were predominantly recruited via advertisement in Hobart's major daily newspaper The Mercury (*n* = 14), with the remainder being mature age students recruited from the University of Tasmania's Counselling Program on the Sandy Bay campus or through flyers posted on notice boards of the same campus *(n* = 7), and via word of mouth (*n* = 2). These subjects were recruited between June and August 2009. The majority of this group were tested at the University of Tasmania's Sandy Bay campus, while for convenience two individuals opted to be tested in their own homes. As per screening of the 60 to 79 year olds, individuals were ineligible for entry into Study 1 if any of the following applied: a history of brain injury or other neurological disorders, serious medical problems impacting cognition, past inpatient psychiatric treatment, current major mental illness, having inadequate vision or audition to complete experimental tasks, a history of substance abuse or an existing diagnosis of dementia. This group had English as their primary language and had normal or corrected-to-normal vision. No incentives were offered for participation, with the exception of one student from this group who was eligible for nominal course credit through research participation. All participants were appropriately debriefed post testing. Ethics approval (H8650) was granted by the Tasmania Social Sciences Human Research Ethics Committee.

9.3 Procedure

A general questionnaire collecting demographic data, medical history, and health information (see Appendix A1), and the Geriatric Depressions Scale (GDS; Brink et al., 1982) were administered, followed by the cognitive battery, described in the following Sections 9.4 and 9.5. Administration of the cognitive battery typically took less than an hour. All participants completed testing in a single session and test order was held as constant as

possible, but adjusted as necessary to allow the appropriate interval for delayed recall

measures. Participants from the TASCOG study also had their gait and falls risk assessed by

medical personnel as part of that wider study. All participants were tested individually.

9.4 Tests Administered - Executive Measures

Measures of Executive Function were chosen carefully. As stated previously within

this thesis, an important secondary aim was to further examine the promising yet

understudied AU test (Bryan, & Luszcz, 2000a; Butler et al., 1993). Semantic Fluency and

the dual-task TSC were important inclusions given the neglect of both measures within the

existent literature, as reported earlier in Section 9.1. Despite the often reported age

invariance of the Phonemic fluency task (Bryan & Luszcz, 2000b; Fisk & Sharp, 2004;

Turner, 1999), the measure was included for comparison purposes with both the Semantic

Fluency and the AU tests, and also to provide a baseline for the clinical TBI study, where

differences are often recorded (Goldstein& Levin, 2001; Henry & Crawford, 2004; Rapoport

et al., 2006).   The Stroop was included as an interference paradigm. In all research,

judiciousness is warranted in test selection and this endeavour was not any different in that

respect. Given the size of the battery, brevity and suitability for use with older adults were

important criterion.

While the Wisconsin Card Sorting Test (WCST) may strike some readers as an

omission, the measure was not included as it did not meet the above two criterion (Bryan &

Luszcz, 2000a; Rhodes, 2004). As discussed previously in Chapter 3, older adults reportedly

find the WCST lengthy and unpleasant (Bryan, & Luszcz, 2000a; Rhodes, 2004). Both

factors represents a barrier to using the test in ageing studies (Bryan, & Luszcz, 2000a;

Rhodes, 2004). Bryan and Luszcz (2000a) note that the ambiguous and abrupt sorting

changes can be experienced as stressful and confusing by older adults,, while modified

version lack sensitivity. Adding the WCST to the battery would have increased overall

assessment time by between 20 and 30 minutes. Such an increase in assessment time would have also been quite disproportionate in comparison to the other measures employed. Further, age differences have already been well documented (see Rhodes, 2004 for review). Thus the WCST was not employed. Ideally, a measure of Figural Fluency (see Section 4.1.5) would also have been included. Again however such an inclusion was incompatible with the desire to reduce demands made of participants.

9.4.1 Phonemic Fluency

Participants were given the FAS version of this task, administered as per the standard instructions detailed by Strauss et al., (2006). The measure taken was the total number of correct responses.

9.4.2 Semantic Fluency

Participants were administered this task, as per the standard instructions detailed by Strauss et al., (2006) with the semantic category of 'animals' used. The measure taken was the number of correct responses.

9.4.3 Ideational Fluency – The Alternate Uses (AU) Test

As a measure of ideational fluency, the AU test (Guilford et al., 1978) was administered. Participants were given the following instructions:- *"I am going to tell you the name of an object, and then I am going ask you to tell me as many uses for the object as you can think of. There are no limits on the type of answer you give me, as long as it is a use for the object. For example, if I gave you the object 'brick,' one use for a brick might be to build a wall, and another might be as a door-stop. I'll tell you when to start and when to stop. We will do this three times, and I will give you a different object each time."* Participants were then given the opportunity to ask any questions or clarify the instructions.

Participants were given one minute per object to generate uses for the objects 'bottle,' 'paper-clip,' and 'hat.' Responses were written down verbatim and were then scored as correct if the respondent gave a use for the object. A response was deemed an error if the response given was not a use for the object (e.g. the object was merely described), if it was a repetition of a previous response or only a slight variation (e.g. for the object bottle "store water, store cordial, store beer"). The measures taken were the total number of correct responses and total number of errors across all trials.

9.4.4 The Stroop Test

Participants were given the Victoria version of this task, with stimulus material and administration procedures as detailed by Strauss et al., (2006). The measure taken was the time on the incongruent trial (Part C) divided by time taken on the colour naming trial (Part D), as per Strauss et al. This particular version was chosen for brevity and by virtue of being within the public domain (Strauss et al., 2006; Troyer et al., 2006, and see Section 4.2 discussing the relative merits of various versions of the Stroop test).

9.4.5 Dual-task; Telephone Search While Counting (TSC)

As a dual-task, participants were administered the TSC subtest of the Test of Everyday Attention (TEA; Robertson et al., 1994). The task was administered and scored as per the procedures detailed in the test manual (Robertson et al.). The score derived is a dual-task decrement weighted for accuracy.

9.5 Tests Administered – Non-Executive Measures

As with the Executive Measures selected, Non-Executive measures were chosen for brevity and suitability for use with older adults.

9.5.1 Hopkins Verbal Learning Test-Revised (HVLT-R)

As a measure of list learning, participants were administered the Hopkins Verbal

Learning Test-Revised (Brandt & Benedict, 2001). Form 1 of the test was used and

administered in accordance with the standard procedures detailed in the manual (Brandt, &

Benedict, 2001). The measures taken were Immediate Recall, Delayed Recall and

Recognition. The total number of word correctly recalled in Trials 1 through 3 (maximum 36)

provides the Immediate Recall score. The total number of words correctly recalled in a single

trial after a 20 minute delay provides the Delayed Recall score (maximum 12). The score for

the Recognition trial was the number of targets and foils correctly discriminated (maximum

24).

9.5.2 The Rey-Osterrieth Complex Figure Test (ROCFT)

The Rey-Osterrieth Complex Figure Test (ROCFT; Strauss et al., 2006) was used as a

measure of visual perception and visual memory. Copy and delayed recall (25-30 minutes)

trials were given as in accordance with "Administration A," as described by Strauss et al.

(2006). The figure was scored using Taylor's 36 point scoring system, as reproduced in

Lezak et al. (2004) and Strauss et al., (2006).

9.5.3 Digit Span

Digit Span from the WAIS-III (Psychological Corporation, 1997b) was administered

as per the standard procedure, with participants given two minutes to complete the trial.

Measures taken were the total raw score (sum of Digits Forwards and Backwards correct,

uncorrected for age), total correct score in the Digits Forwards condition, and total correct

score in the Digits Backwards condition.

9.5.4 Digit Symbol-Coding

As a measure of processing speed, participants were administered digit symbol-coding from the WAIS-III (Psychological Corporation, 1997b), as per the standard procedure.   This measure was chosen by virtue of its sound validity and sensitivity (Joy, Kaplan & Fein, 2004; Kreiner & Ryan, 2001; Lezak et al., 2004; see Section 4.17). The measure taken was the raw score uncorrected for age.

9.6 Results

A Series of 3 x 2 between subjects ANOVAs was conducted, with Age as a three level factor (50-59 years, 60-69 years, 70-79 years) and either Education (<12 years, 12 years +) or Gender as two level factors. It was inappropriate to analyse the data in series of 3 X 2 X 2 ANOVAs (Age x Education x Gender) as there was no theoretical reason to expect three way interactions. Further, such analysis would have been limited in terms of power (Kirk, 1995), with too few subjects in some cells (e.g. very few males in the 50-59 year old cohort with education <12 years).

Despite contrasts being planned in advance, Howell (1997) advises that in most instances it is acceptable and common practice to use post-hoc procedures, which have the virtue of being generally more powerful. Of the post-hoc procedures available, HSD was employed herein given the superior control over family wise errors rate (Howell, 1997). For ANOVAs where there were no violations of assumptions the alpha level was set to .05. Although ANOVA is very robust to violations of its assumptions (Howell, 1997), in cases where the Levene's statistic was significant, the alpha level was set to the more stringent .025, as suggested by Tabachnick and Fidell (2001). This approach was adopted as it was desirable to retain the natural scores of the data set rather than performing any data modification (Cahn-Wiener, Malloy, Boyle, Marran & Salloway, 2000; Rapoport et al.,

2008). While there was natural variability, there was no reason to believe that the scores were subject to any artificial measurement artefact thus they were retained. No outliers were identified during data screening using the criteria of Kirk (1995). For analysis using Pearson product-moment correlations, the alpha level was set to .01 due to the large number calculated. Complete ANOVA tables, correlation matrices and other SPSS output for all analyses from Study 1 can be found in Appendix B, including instances where statistical values are not reported due to an absence of significant results.

9.7 Demographic Data

The sample size recruited is expected to provide adequate power. This was calclualted using tables provided by Kirk (1995), following the usual practice of having an 80% probability of detecting a distance of one standard deviation between groups, with an alpha level of .05. With three levels of independent variable (Age), according to Kirk, a minimum n of 21 per group would be required. All age cohorts within this study exceed this figure as can be seen below in Table 9.1. Table 9.1shows the number of participants, and the age and gender balance within each age band, and for the sample overall. Generally, the sample was fairly evenly balanced, with the exception of there being a smaller number of subjects in the 50-59 year band, and a gender imbalance within this same group (65% female).

Table 9.1

Age and Gender across the Groups

| | Male | | Female | | Overall | |
Group	n	M (SD)	n	M (SD)	n	M (SD)
50-59	8	56.4 (3.0)	15	54.1 (3.4)	23	54.9 (3.4)
60-69	19	65.0 (2.5)	19	64.7 (2.6)	38	64.9 (2.5)
70-79	20	74.3 (2.9)	19	75.1 (3.0)	39	74.7 (2.9)
Total	47	67.5 (7.2)	53	65.4 (8.9)	100	66.4 (8.2)

The education levels within the various age bands and between genders are proffered in Table 9.2. The youngest group was more educated than their older counterparts, while there is a similitude of education between the genders that is maintained within each of the three age bands.

Table 9.2

Education by Age and by Gender

| | Male | | Female | | Overall | |
Group	n	M (SD)	n	M (SD)	n	M (SD)
50-59	8	15.0 (2.5)	15	14.7 (1.9)	23	14.8 (2.0)
60-69	19	11.4 (3.2)	19	11.1 (2.3)	38	11.3 (2.7)
70-79	20	11.6 (3.1)	19	10.1 (2.5)	39	10.9 (2.9)
Total	47	12.1 (3.2)	53	11.8 (2.9)	100	11.9 (3.1)

For the purposes of conducting analyses examining Education effects, the sample was divided into two groups based on median split of the variable Years of Education. The groups were either <12 years or 12 years +, with the break-down by age cohorts proffered in Table 9.3. As shown, there are few 50-59 year olds with education <12 years, and fewer 70-

79 year olds with 12+ years education than their same age counterparts. Otherwise the sample is well balanced.

Table 9.3

Education Group by Age

		< 12 years		12 years +		Overall
Group	*n*	*M (SD)*	*n*	*M (SD)*	*n*	*M (SD)*
50-59	3	56.0 (4.4)	20	54.8 (3.3)	23	54.9 (3.4)
60-69	20	65.0 (2.3)	18	64.8 (2.5)	38	64.9 (2.6)
70-79	29	74.5 (2.8)	10	75.2 (3.5)	39	74.7 (2.9)
Total	52	69.8 (6.4)	48	62.8 (8.4)	100	66.4 (8.2)

9.8 Effects of Age, Education and Gender on Executive Function

Before proceeding to the results of the analyses for Age and Executive Function, means, standard deviation and η^2 values for each of the Executive measures are displayed in Table 9.4.

Table 9.4

Performance on Executive Measures by Age Group

	Age Group			η^2 for sig differences	
	50-59	60-69	70-79		
	M (SD)	*M (SD)*	*M (SD)*	Age & Education	Age & Gender
Phonemic Fluency	45.4 (13.1)	36.1 (12.1)	38.1 (11.1)	*ns*	*ns*
Category Fluency	21.1 (5.1)	18.6 (4.9)	16.3 (4.3)	.068*	.121***
AU correct	20.1 (5.6)	10.5 (5.3)	9.3 (4.3)	.198***	.440***
AU errors [a]	4.3 (3.6)	9.1 (7.2)	6.5 (4.1)	.84*	.144**
Stroop [a]	1.7 (.4)	2.3 (.6)	2.4. (.6)	.094**	.155***
Dual-Task [a]	1.5 (1.8)	1.2 (1.2)	1.5 (2.4)	*ns*	*ns*

* = significant at p<.05, ** = significant at p<.01, *** = significant at *p*<.001.
[a] note. Low scores represent better performance.

There was no significant main effect for Age on Phonemic Fluency performance when testing Age & Education $F(5, 95) = 2.14$, $p = .123$, $\eta^2 = .044$, although there was a stronger trend for an Age effect when testing Age & Gender, $F(5, 95) = 2.73$, $p = .070$, $\eta^2 = .055$. There was no significant main effect for Education, while there was a significant main effect for Gender, $F(5, 95) = 7.28$, $p = .008$, $\eta^2 = .072$, favouring females. There were no significant interactions. Despite the absence of a significant main effect for Age on Phonemic Fluency performance, post-hoc tests indicated that the youngest group performed better than the 60-69 year olds, but not the 70-79 year olds, as shown in Table 9.5. This is somewhat contrary to the expectation of age invariance stated in Section 9.1.

Table 9.5

Post-hoc results for Age and Phonemic Fluency

		Group	
		60-69 years	70-79 years
Analysis		*p*	*p*
Age & Education	50-59 years	.010	*ns*
Age & Gender		.009	*ns*
Age & Education	60-69 years	-	*ns*
Age & Gender		-	*ns*

There was support for the hypothesis that Age would have a deleterious impact on Semantic Fluency performance. A significant main effect was recorded when calculating either Age & Education $F(5, 95) = 3.43$, $p = .037$, $\eta^2 = .068$, or Age & Gender, $F(5, 95) = 6.47$, $p = .002$, $\eta^2 = .121$. There were no significant main effects for either Education or Gender, and no interaction effects. The results of the post-hoc tests are proffered in Table 9.6, showing that the youngest group performed significantly better than the oldest group.

Table 9.6

Post-hoc results for Age and Semantic Fluency

Analysis		Group	
		60-69 years	70-79 years
		p	*p*
Age & Education	50-59 years	*ns*	<.001
Age & Gender		*ns*	.001
Age & Education	60-69 years	-	*ns*
Age & Gender		-	*ns*

There was support for the hypothesis that Age would have a deleterious impact on Ideational Fluency performance. A significant main effect for Age on Alternate Uses Correct $F(5, 93) = 11.38$, $p<.001$, $\eta^2 = .198$ (Age & Education) or $F(5, 93) = 36.2$, $p<.001$, $\eta^2 = .440$ (Age & Gender) was recorded. Although the Levene's test was significant for Age & Gender, this is not an issue at $p< .001$ (Tabachnick & Fidell, 2001). There was a main effect for Years of Education, $F(5, 93) = 6.65$, $p = .011$, $\eta^2 = .067$, in favour of the group 12+ years, and no significant main effect for Gender. There were no significant interaction effects. Post-hoc tests revealed that the youngest group performed significantly better than the two older groups, as shown in Table 9.7.

Table 9.7

Post-hoc results for Age and Alternate Uses Correct

Analysis		Group	
		60-69 years	70-79 years
		p	*p*
Age & Education	50-59 years	<.001	<.001
Age & Gender		<.001	<.001
Age & Education	60-69 years	-	*ns*
Age & Gender		-	*ns*

When analysing Alternate Uses Error data, there was a significant main effect for Age, $F(5, 93) = 4.22$, $p = .018$, $\eta^2 = .084$ (Age & Education) or $F(5, 93) = 5.94$, $p = .004$, $\eta^2 = .144$ (Age & Gender), but no significant effect for either Years of Education or Gender. The Levene's test was significant for both Age & Education and Age & Gender, however both results maintained their significance by being $< p$ .025. There were no significant interaction effects. Post-hoc tests revealed that the 60-69 year olds made significantly more errors than the 50-59 year olds, as shown in Table 9.8.

Table 9.8

Post-hoc results for Age and Alternate Uses Errors

| | | Group | |
| | | 60-69 years | 70-79 years |
Analysis		*p*	*p*
Age & Education	50-59 years	.004	*ns*
Age & Gender		.001	*ns*
Age & Education	60-69 years	-	*ns*
Age & Gender		-	.047

The results however does not provide direct support for the hypothesis that Age would have a deleterious impact on Ideational Fluency performance, given that the data with respect to AU errors and age is curvilinear, as depicted in Figure 9.1.
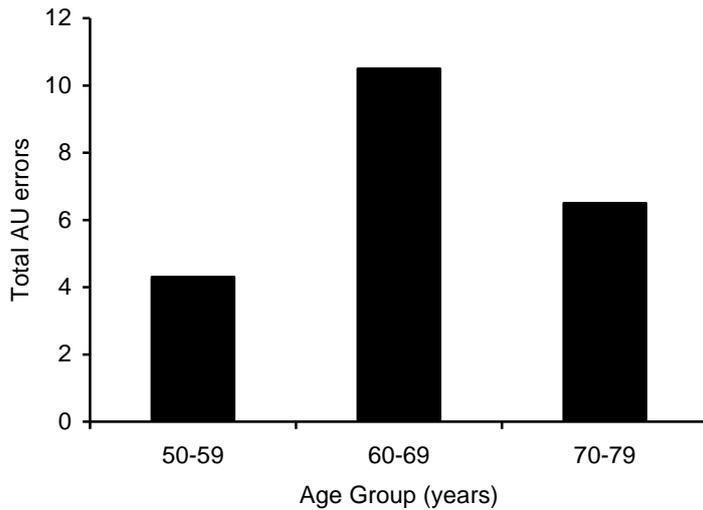
Figure 9.1. Alternate Uses Errors by Age Group.

There was support for the hypothesis that Age would have a deleterious impact on Stroop performance, with a main effect being demonstrated for Age $F(5, 94) = 4.81$, $p = .010$, $\eta^2 = .094$ (Age & Education), or $F(5, 94) = 8.53$, $p < .001$, $\eta^2 = .155$ (Age & Gender), but not for Education or Gender. There were no significant interaction effects. Post-hoc tests revealed that the youngest group performed significantly better than the two older groups, as shown in Table 9.9.

Table 9.9

Post-hoc results for Age and Stroop Performance

		Group	
		60-69 years	70-79 years
Analysis		*p*	*p*
Age & Education	50-59 years	<.001	<.001
Age & Gender		<.001	<.001
Age & Education	60-69 years	-	*ns*
Age & Gender		-	*ns*

There was not support for the hypothesis that Age will have a deleterious impact on Dual-Task performance. There were no significant main effects for the variables Age,

Education and Gender. There was however, a significant interaction effect for Age x Gender $F(5, 87) = 4.72$, $p = .011$, $\eta^2 = .099$, as shown in Figure 9.2, which suggests that males in the youngest group experienced the greatest dual task decrement. Although the Levene's test was significant, the interaction remains significant being $< p$ .025.
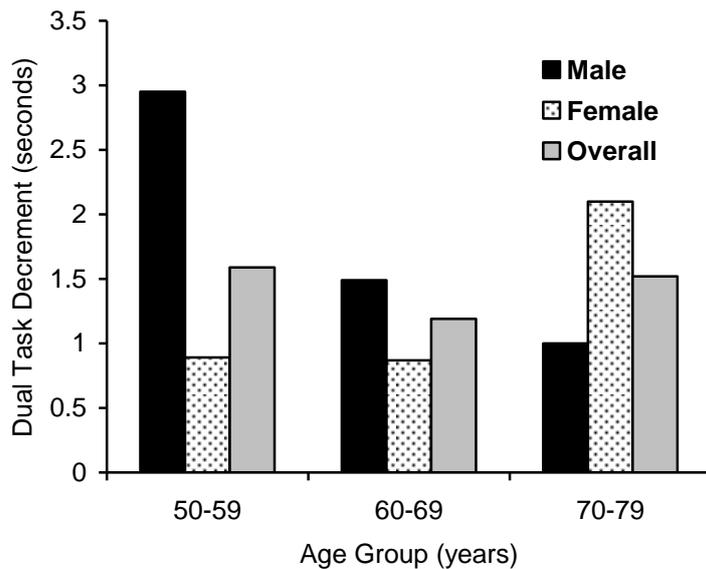
Figure 9.2. Dual-Task performance by Age and Gender.

9.9 Effects of Age, Education and Gender on other Cognitive Variables

Before proceeding to the results of the analyses for cognitive measure outside of the executive domain, the means, standard deviations and η^2 values for the divergent cognitive measures by age group are presented in Table 9.10.

Table 9.10

Performance on Non-Executive Measures by Age Group

	Age Group			η^2 for sig differences	
	50-59				
	M (SD)	M (SD)	M (SD)	Age & Education	Age & Gender
HVLT-R Immed.	27.2 (4.3)	20.1 (5.1)	19.1 (5.7)	.140**	.255***
HVLT-R Delay	9.6 (2.1)	7.7 (2.6)	6.3 (3.0)	.063*	.165**
HVLT-R Recog.	22.7 (1.5)	22.3 (1.2)	20.2 (5.6)	.084*	ns
ROCFT Delay	22.8 (5.1)	18.2 (7.2)	15.4 (6.1)	ns	.163***
Digits Raw	20.6 (4.0)	16.1 (4.2)	15.6 (3.7)	.174***	.170***
Digits Forward	7.4 (1.2)	6.4 (1.2)	6.2 (1.2)	.114**	.138**
Digits Backward	5.9 (1.1)	4.5 (1.2)	4.5 (1.1)	.156***	.182***
Coding	79.6 (15.5)	58.1 (14.2)	48.6 (14.1)	.324***	.328***

* = significant at p<.05, ** = significant at p<.01, *** = significant at *p*<.001.

There was support for the hypothesis that Age would have a deleterious impact on HVLT-R Immediate Recall performance. There was a significant main effect for Age $F(5, 95) = 7.64$, $p = .001$, $\eta^2 = .140$, (Age & Education), or $F(5, 95) = 15.58$, $p < .001$, $\eta^2 = .256$ (Age & Gender), and a significant main effect for Gender in favour of females $F(5, 95) = 15.58$, $p < .001$, $\eta^2 = .142$. The Levene's test was significant for both Age & Gender and Age & Education, although this is not problematic given that the *p* values for each calculation are well below .025 (Tabachnick & Fidell, 2001). The effect of Years of Education was not significant. There were no significant interaction effects. Post-hoc tests revealed that the youngest group performed significantly better than the two older groups, as can be seen in Table 9.11.

Table 9.11

Post-hoc results for Age and HVLT-R Immediate Recall

		Group	
		60-69 years	70-79 years
Analysis		*p*	*p*
Age & Education	50-59 years	<.001	<.001
Age & Gender		<.001	<.001
Age & Education	60-69 years	-	*ns*
Age & Gender		-	*ns*

There was also support for the hypothesis that Age would have a deleterious impact on HVLT-R Delayed Recall performance, with a significant main effect demonstrated for Age $F(5, 95) = 3.14$, $p = .048$, $\eta^2 = .063$ (Age & Education), or $F(5, 95) = 7.71$, $p = .007$, $\eta^2 = .165$ (Age & Gender), and a significant main effect for Education in favour of those with 12 years + of education, $F(5, 95) = 4.12$, $p = .045$, $\eta^2 = .042$, and a significant main effect for Gender in favour of females $F(5, 95) = 7.70$, $p = .007$, $\eta^2 = .076$. Post-hoc tests revealed that the youngest group performed significantly better than the two older groups as shown in Table 9.12.

Table 9.12

Post-hoc results for Age and HVLT-R Delayed Recall

		Group	
		60-69 years	70-79 years
Analysis		*p*	*p*
Age & Education	50-59 years	.022	< .001
Age & Gender		.019	< .001
Age & Education	60-69 years	-	*ns*
Age & Gender		-	*ns*

Contrary to expectations reported in Section 9.1, there was a significant main effect for Age on HVLT-R Recognition performance, $F(5, 95) = 4.23$, $p = .017$, $\eta^2 = .084$, using

the Age & Gender analysis. This effect is rendered a non-significant trend if the Age & Education analysis is used $F(5, 95) = 2.83$, $p = .066$, $\eta^2 = .057$.   The Levene's test was significant for Age & Gender although this is not problematic as the p value is less than .025. There were no significant main effects for either Education or Gender, and no significant interaction effects. Post-hoc test results, as proffered in Table 9.13, showed that the oldest group performed significantly worse than the two younger ones.

Table 9.13

Post-hoc results for Age and HVLT-R Recognition

		Group	
		60-69 years	70-79 years
Analysis		*p*	*p*
Age & Education	50-59 years	*ns*	.029
Age & Gender		*ns*	.027
Age & Education	60-69 years	-	.039
Age & Gender		-	.037

There was support for the hypothesis that Age would have a deleterious impact on Delayed Recall of the ROCFT. A significant main effect was demonstrated using Age & Gender , $F(5, 91) = 8.77$, $p < .001$, $\eta^2 = .163$, $F(5, 95) = 4.23$, $p = .017$, $\eta^2 = .084$. The effect however is only close to statistical significance if the Age & Education calculation is used, $F(5, 91) = 2.99$, $p = .055$, $\eta^2 = .062$. There were no significant main effects or interactions for either Age x Education or Age x Gender. Post-hoc test results, as shown in Table 9.14, showed that the youngest group performed significantly better than the two other groups.

Table 9.14

Post-hoc results for Age and ROCFT Delayed Recall

		Group	
		60-69 years	70-79 years
Analysis		*p*	*p*
Age & Education	50-59 years	.021	<.001
Age & Gender		.019	<.001
Age & Education	60-69 years	-	*ns*
Age & Gender		-	*ns*

Contrary to expectations, there was a significant main effect for Age on Digit Span performance, $F(5, 95) = 9.91$, $p <.001$, $\eta^2 = .174$ (Age & Education) or $F(5, 95) = 9.62$, $p <.001$, $\eta^2 = .170$ (Age & Gender). There were no significant main effects for either Education or Gender. The Levene's test was significant for Age & Gender although this is not problematic given that the *p* value is well below .025. There were no significant interaction effects. Post-hoc tests revealed that the younger group performed significantly better than the older two groups, as shown in Table 9.15.

Table 9.15

Post-hoc results for Age and Digit Span

		Group	
		60-69 years	70-79 years
Analysis		*p*	*p*
Age & Education	50-59 years	<.001	<.001
Age & Gender		<.001	<.001
Age & Education	60-69 years	-	*ns*
Age & Gender		-	*ns*

Contrary to expectations, there was a significant main effect of Age for Digits Forward $F(5, 95) = 6.06$, $p = .003$, $\eta^2 = .114$ (Age & Education), or $F(5, 95) = 7.53$, $p = .001$ $\eta^2 = .138$ (Age & Gender). There were no significant main effects for Education or

Gender. There were no significant interaction effects. Post-hoc test results, as presented in
Table 9.16, revealed that the younger group performed significantly better than the older two
groups.

Table 9.16

Post-hoc results for Age and Digits Forward

		Group	
		60-69 years	70-79 years
Analysis		*p*	*p*
Age & Education	50-59 years	.005	<.001
Age & Gender		.006	.001
Age & Education	60-69 years	-	*ns*
Age & Gender		-	*ns*

Also contrary to expectations, there was a significant main effect for Age for Digits
Backward, $F(5, 95) = 8.69$, $p < .001$, $\eta^2 = .156$ (Age & Education) or $F(5, 95) = 10.44$, $p < 001$, $\eta^2 = .182$ (Age & Gender). There were no significant main effects for either
Education or Gender. There were no significant interaction effects. Post-hoc test results
revealed that the younger group performed significantly better than the older two groups as
evident in Table 9.17.

Table 9.17

Post-hoc results for Age and Digits Backwards

		Group	
		60-69 years	70-79 years
Analysis		*p*	*p*
Age & Education	50-59 years	<.001	<.001
Age & Gender		<.001	<.001
Age & Education	60-69 years	-	*ns*
Age & Gender		-	*ns*

There was support for the hypothesis that Age would have a deleterious impact on Digit Symbol-Coding performance. There was a significant main effect for Age $F(5, 95) = 22.5$, $p < .001$, $\eta^2 = .324$ (Age & Education) or $F(5, 95) = 28.5$ $p < .001$, $\eta^2 = .328$ (Age & Gender). Post-hoc test results, as displayed in Table 9.18, revealed that the younger group performed significantly better than both the two older groups, and that the performance of the 60-69 year olds was significantly better than the 70-79 year olds.

Table 9.18

Post-hoc results for Age and Digit Symbol- Coding

		Group	
		60-69 years	70-79 years
Analysis		*p*	*p*
Age & Education	50-59 years	<.001	<.001
Age & Gender		<.001	<.001
Age & Education	60-69 years	-	.012
Age & Gender		-	.010

There were no main effects for either Years of Education or Gender on this measure, although there was a significant Age x Gender interaction, $F(5, 95) = 5.12$, $p = .008$, $\eta^2 = .098$. As can be seen in Figure 9.3, males 50-59 years appear to perform worse than their female counter parts.
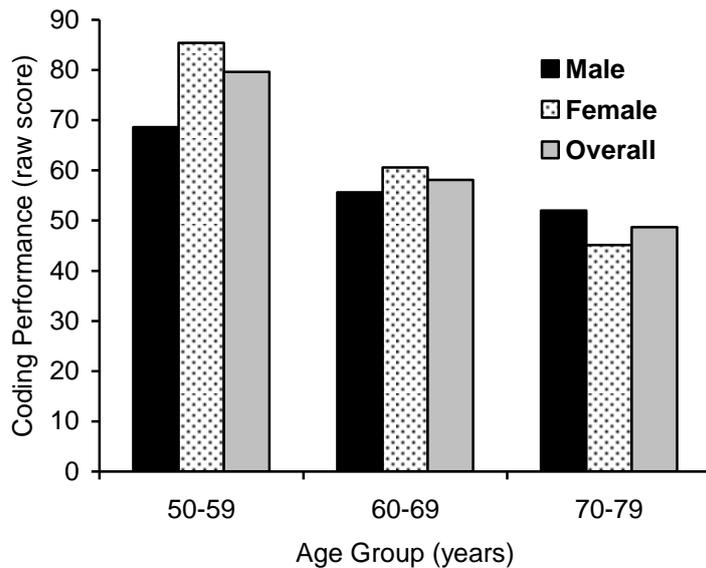
Figure 9.3. Digit Symbol-Coding performance by Age and Gender.

9.10 Relationships Within and Between Measures across Cognitive Domains

To explore the relationships between the cognitive variables and their respective domains, bivariate Pearson product-moment correlations were computed and the complete matrix is available in Appendix B5. In all tables proffered based on this data, correlation coefficients are only reported for relationships significant at *p* = .01 level or higher given the large number of correlations computed. As can be seen in Table 9.19, *r* values tend to decrease with Age and increase with Years of Education. As can also be seen in Table 9.19, Age is significantly correlated with all variables excepting dual-task performance and AU errors, and Education is correlated with most variables. While both are treated as continuous variables, it is important to note that they are not normally distributed and Education in particular is restricted in range. In Section 9.7 it was reported that the younger members of the sample have a greater number of years of education. The negative correlation between Age and Education is significant, *r* = -.448.

To test the significance of differences between correlation coefficients with age for both executive and non-executive measures, the method suggested by Garrett (1966) was

used. The results for these comparisons are available in Appendix B5. Only two

comparisons show statistically significantly larger correlations for executive tests versus non-

executive tests. Both of these results were for AU correct. A further statistically significant

result in the opposite direction showed the correlation between Age and Digits-Symbol

Coding to be greater than that between Age and Semantic Fluency.

Table 9.19

Relationships between Age, Education, and Cognitive Measures

	r values	
Domain and Tests	Age	Education
Executive Function		
Phonemic Fluency	*ns*	.342**
Semantic Fluency	-.395**	.373**
Alternate Uses Correct	-.578**	.517**
Alternate Uses Errors	*ns*	*ns*
Stroop	.367**	-.350**
Dual-Task	*ns*	*ns*
Memory		
HVLT-R Immediate	-.520**	.431**
HVLT-R Delay	-.423**	.428**
HVLT-R Recognition	-.293*	ns
ROCFT Delay	-.447**	.347**
Digit Span Raw	-.408**	.354**
Digit Span Forward	-.341**	.260*
Digit Span Backward	-.393**	.326**
Processing Speed		
Digit Symbol-Coding	-.663**	.440**

* = significant at *p* .01, ** = significant at *p* .001

The relationships between and within domains were also examined. Selected results are proffered in Table 9.20. Again, the full matrix is available in Appendix B5. In the interests of simplicity, Dual-Task results are not included as there were no significant relationships between this variable and any other cognitive measure. The same holds for AU errors, with the exception of a significant negative relationship with AU correct, $r = -.303$, $p = .002$.

To test the significance of the difference between correlation coefficients, the procedure recommended by Garrett (1966) was again used. These calculations are also included in Appendix B5. There was no evidence to suggest that the strength of the inter-correlations among executive measures was greater than the inter-correlations between executive and non-executive measures.

Table 9.20

Relationships between select Executive and Non-Executive Measures

	Executive Function					Memory		PS
r	Phon Flu	Sem Flu	AU Cor	Stroop	Hop Im	Rey Del	Dig Raw	Cod Raw
Sem Flu	.481**	-						
AU Cor	.327**	.438**	-					
Stroop	*ns*	*ns*	.299*	-				
Hop Im	.401**	.408**	.460**	*ns*	-			
Rey Del	.270*	.276*	.376**	*ns*	.307**	-		
Dig Raw	.303*	.337**	.338**	.334**	.407**	.397**	-	
Cod Raw	.430**	.561**	.564**	.358**	.450**	.508**	.497**	-

* = significant at *p* .01, ** = significant at *p* .001

As there is some controversy as to whether Digits Forward and Backwards measure the same or different functions, the relationship between the measures is given consideration. In regard to any differential relationships between Digit Span, Digits Forward and Digits Backwards, as displayed in Table 9.21, all Digits Span variables are significantly correlated with one another at the $p = .01$ level. All the digits span indexes appears to correlate to a similar magnitude whether a divergent measure is executive or non-executive, with the only exception being for the Stroop with Digits Backwards, where a significant correlations was not recorded. Digits Forward and Backwards are significantly correlated with each other at r $=.518$.

Table 9.21

Relationships between Digit Span Variables and other Cognitive Measures

r	Digits Raw	Digits Forward	Digits Backward
Digits Raw	1	-	-
Digits Forward	.787**	1	.861**
Digits Backward	.861**	.518**	1
Stroop	-.334**	-.324**	*ns*
Semantic Fluency	.337**	.268*	.350**
Alternate Uses	.338**	.228*	.432**
Hopkins Immediate	.407**	.317**	.394**
RCFT delay	.397**	.297*	.402**
Coding	.497**	.387**	.517**

* = significant at p .01, ** = significant at p .001

As evident in Section 9.9, and as depicted in Figure 9.4, main effects and data for all three Digit Span indices followed a similar pattern. There was also a similitude of η² values suggesting roughly equivalent effect sizes (Trusty, Thompson & Petrocelli, 2004).
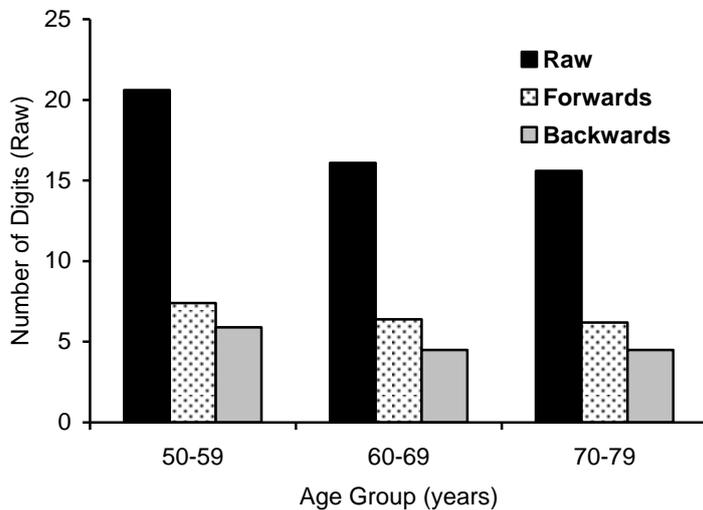
Figure 9.4. Digits Span performance.

9.11 Discussion

The aim of the current study was to further elucidate the impact of normal ageing on executive function by comparing three groups of older adults; 50-59 year olds, 60-69 year olds and 70-79 year olds. West (1996) suggests the frontal ageing hypothesis can account for many of the changes that are observed throughout the normal ageing processes. Conversely, proponents of global accounts of cognitive ageing suggest that brain changes are diffuse and impact all cognitive abilities to the same proportional extent (Craik, 2000; Salthouse, 2005). In line with the frontal-ageing hypothesis, and based on the findings of previous research (see Section 9.1) it was predicted herein that executive measures would be impacted to a greater degree than non-executive measures. However, the results ran counter to predictions, with non-executive measures being more consistently impacted by normal ageing than executive

ones. A particular secondary aim of this thesis was to further explore the utility of the

Alternate Uses (AU) test (Guilford, Christensen, Merrifield & Wilson, 1978). The impact of

age on AU performance will be discussed forthwith, while broader discussion of the measure,

including its potential usefulness as a measure of executive function, is held over until

Chapter 11.

9.12 The Impact of Age on Executive Function

9.12.1. Phonemic Fluency

It was expected that Phonemic Fluency would prove invariant to age effects based on

earlier review of the literature (see Sections 7.3 and 9.1). There was indeed an absence of

age-related differences for this measure, as reported in Section 9.8, and this was not

surprising given the results of Bryan and Luszcz (2000b), Parkin and Java (1999), Phillips

(1999), Rhodes and Kelley (2005), Troyer, Moscovitch and Winocur (1997), and Troyer

(2000). Thus, the results of the current study and the existent literature support the earlier

pronouncement made in review by Bryan and Luszcz (2000a), that this test is not adequately

sensitive to detect age effects. The failure to detect a strong age effect in the current study

also appears unlikely to relate to issues of insufficient statistical power given the adequate

sample size (see Section 9.7), and as numerous main effects for age were detected for other

cognitive variables, including Semantic Fluency.

Hughes and Bryan (2002) offer an alternative explanation for the lack of age-related

differences for the Phonemic Fluency task. They suggest that the age-related increase in

word knowledge may assist older adults when their performance is contrasted with their

younger counterparts, masking differences that might otherwise be apparent. However, age-

related differences were found on the Semantic Fluency task in the current study, with the

finding being typical of the existing literature (Ettenhofer, Hambrick, & Abeles, 2006;

Tombaugh, Kezak & Rees, 1999; Troyer, 2000). Given that the Semantic Fluency task also

makes demands of both strategic retrieval and verbal knowledge (Lezak et al., 2004; Strauss et al., 2006), the author postulates that the explanation given by Hughes and Bryan is less tenable. Further, if such a compensatory word-knowledge effect was operant, one would expect it to be maximal for extreme-age group designs, and nominal within narrower age ranges, such as that employed by the current study. A more credible explanation is the suggestion that Phonemic Fluency may more measure lexical access than executive function (Bryan & Luszcz, 2000b; Fisk & Sharp, 2004; Shores et al., 2006) and thus not make sufficient demands on executive function. This is a position that the author is inclined to agree with, given the pattern of results returned for the two measures, especially when one considers that if anything, the Phonemic Fluency task by virtue of a greater number of trials should have a reliability and thus sensitivity advantage (Strauss et al., 2006).

While the author does postulate that the Phonemic Fluency paradigm is not sufficiently executively demanding to reveal age-related difference, the position is held with moderate conviction only, given that the current analyses, in lieu of more sophisticated techniques such as linear regression, factor analysis and structural equation modelling which require very large samples (MacCallum, Widaman, Zhang & Hong, 1999; Tabachnick & Fidel, 2001), cannot greatly clarify this validity issue. As reported in Section 9.10, Phonemic Fluency was significantly correlated with Semantic and Ideational Fluency, and did not correlate with the Stroop or the divided attention measure, indicative of a degree of convergent and divergent validity for the measure within the executive domain. However, the Phonemic Fluency task also correlated significantly with Memory measures and Processing Speed, suggesting otherwise.

In terms of gender differences, females demonstrated an advantage over males on Phonemic Fluency performance of 6.4 words. The result is in contrast to the findings of both Tombaugh et al., (1999) and Troyer (2000) where gender differences were nominal or non-

existent. With respect to the current study, the advantage for females does not appears to be accounted for by the impact of education given that there was great similitude in years of education between the genders, and if anything males were slightly more educated. While an advantage for females is not the most common finding, it is far from unprecedented as per review by Strauss et al., (2006). Mean Phonemic Fluency values for all three age groups in the current study (see Table 9.4) are consistent with the normal range for the age and educated adjusted norms provided by Tombaugh et al., (1999).

9.12.2 Semantic Fluency

An important feature of the current study was the inclusion of the Semantic Fluency task. The measure is often omitted in studies of age and executive function in favour of the Phonemic Fluency paradigm, with the work of Bryan and Luszcz, (2000b; 2001), Fisk and Sharp (2004), Hughes and Bryan (2002), Parkin and Lawrence (1994) and Rhodes and Kelley (2005) all serving as cases in point. As predicted, based upon Ettenhofer et al. (2006), Tombaugh et al. (1999), and Troyer (2000), Semantic Fluency performance was sensitive to age. As shown in Table 9.6, the 50-59 year old group exhibited superior performance to the 70-79 year olds, but not the 60-69 year olds.

The result is consistent with the existing literature, which indicates that Semantic Fluency is one of the more age sensitive tests of executive function (Ettenhofer et al., 2006; Parkin and Java, 1999; Salthouse, 2005; Troyer, 2000; Tombaugh et al., 1999). The only study reviewed herein where an age effect was not recorded for Semantic Fluency performance was that of Treitz, Heyder and Daum (2007). The discrepant result of Treitz et al., could potentially be accounted for by design issues; namely their small cell sizes (between $n = 13$-17) and their use of both broader age bands and a sample that was younger overall than that employed by the current study. The absence of a gender effect in the current study was also consistent with the existing literature (Lezak et al., 2004; Tombaugh et al.,

1999), while the lack of an education effect was consistent with Troyer (2000), but not Tombaugh et al., (1999). As with the Phonemic Fluency data, the mean values recorded by the groups in the current study for Semantic Fluency performance (see Table 9.4) were well within the average range as per the norms provided by Tombaugh et al., (1999).

9.12.3 Ideational Fluency – the Alternate Uses (AU) Test

As predicted in Section 9.1, the impact of Age upon Ideational Fluency performance was significant. In terms of number of correct alternate uses generated, the 50-59 year olds out performed both the 60-69 year olds and the 70-79 year olds (see Table 9.7). Thus, the age effects recorded were stronger than for the other two fluency paradigms employed, an observation supported by the examination of the η^2 values being greater at .144 for AU than the .068 recorded for Semantic Fluency (Trusty et al., 2004). The age effect is also consistent with the results of Bryan and Luszcz (2000b), and provides stronger evidence for an age effect than the work of Parkin and Lawrence (1994) who sampled a boarder age range.

Interpretation of the error data is less straightforward. There was a significant main effect for Age, but not in any predictable direction. As evident in Table 9.8, the 60- 69 year olds made significantly more errors than both the 50-59 year olds *and* the 70-79 year olds. The curvilinear result depicted in Figure 9.1 does not suggest a direct relationship between age and errors, despite the 70-79 year olds committing more errors (but not significantly so) than the 50-59 year olds. The inferior performance of the 60-69 year olds does not appear to be explained by education; not only are education levels similar between the two older groups (see Table 9.3), if anything, the 60-69 year olds have a slight advantage over the 70-79 year olds. The 60-69 year olds were however the only group where any participant made more than 20 errors. Three high error scores within this group may have accounted for the result. In terms of previous research, only Butler et al., (1993) and Parkin and Java (1999) analysed errors with respect to age. Parkin and Java (1999) found younger adults generated fewer

inappropriate uses (only one class of errors), whereas as Butler et al., reported no significant differences in the commission of errors.

9.12.4 The Stroop Test

Outside of the sphere of verbal fluency, but still within the domain of executive function, in Section 9.1 it was predicted that there would be a significant impact of age on Stroop performance. The prediction proved accurate with the 50-59 year olds out performing the 70-79 year olds (see Table 9.9). As with the Semantic Fluency task, the Stroop task is one of the executive measures that most consistently demonstrates age effects among normal ageing populations (Bryan, & Luszcz, 2000a; Troyer, Leach, & Strauss, 2006). The age effect demonstrated in the current study provides additional support for the findings of Ettenhofer et al., (2006) and Lowe and Rabbitt (1997), who both demonstrated age differences within older adult samples, and is also consistent with the work of others using more extreme age ranges (Bryan, & Luszcz, 2001; Bugg, DeLosh, Davalos, & Davis, 2007; Hughes & Bryan, 2002; Klein, Ponds, Houx & Jellemer, 1997; Taconnat et al., 2006; Troyer et al., 2006; van der Elst, van Boxtel, van Breukelen & Jolles, 2006; Wecker, Kramer, Wisniewski, Delis & Kaplan, 2000).

An interference index was calculated (see Section 9.4.4), as opposed to simply using the time taken to complete the incongruent trial as the dependent measure. This allows greater confidence that the age effect recorded is indeed accounted for by true differences in executive abilities, rather than simply representing baseline differences in processing speed (Strauss et al., 2006; Troyer et al., 2006). In the current study, neither the effect of education or gender was significant. The lack of an education effect is in line with the results of Troyer and colleagues (2006) who found only a minimal effect. The absence of gender effects is consistent with Troyer et al., (2006), but not with Van der Elst et al. (2006) and Klein et al., (1997); the latter two groups detected an advantage for females on this measure.

9.12.5 Divided Attention – Telephone Search While Counting (TSC)

The inclusion of the TSC herein represents a contribution to the cognitive ageing literature, given the measure's purported sensitivity and lack of use (Hennessy, Geffen, Pauley & Cutmore 2003; Robertson et al., 1994). Contrary to the prediction made in Section 9.1, there was no age effect on the dual-task / divided attention measure, Telephone Search While Counting (TSC; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994). There are no available published studies where the TSC has been employed with ageing cohorts, excepting those conducted by the test developers. Results of other normal ageing studies using other dual-task paradigms have been mixed. Treitz et al., (2007) found 61-75 year olds to exhibit a larger dual-task decrement than all other age groups, including 46-60 year olds. They also found that 46-60 year olds performed significantly more poorly than two younger groups. Fisk and Sharp (2004) however, did not find a relationship between age and dual-task performance. Consistent with data reported by Robertson et al., (1994), in the current data set standard deviations were large, either equal to or in excess of the mean (see Table 9.4). The mean dual task decrements recorded by the current study (1.2 -1.5 seconds) are in line with those at the 50th percentile for the respective ages according to norms provided by Robertson and colleagues, while being smaller than those recorded by normal controls in a stroke study reported elsewhere in the same manual.

There were no main effects for either education or gender on TSC performance. There was however a significant and unexpected interaction between Age and Gender. As depicted in Figure 9.2, there appeared to be an advantage for 50-59 year old females relative to males. The difference does not appear to be explained by differences in education. As shown in Table 9.2, there were no major gender differences in education; if anything men were slightly more educated. Two of the males in the 50-59 year old group had particularly

large dual-task decrements, and given that there were only eight males in this age group, the result may simply be spurious.

When the Pearson product-moment correlations were examined, it was apparent that there were no significant relationships at $p = .01$ level between TSC and any other cognitive measure, be it executive or non-executive. That is, the dual task employed herein was independent of other measures, a finding which is consistent with the results of factor analytic studies by Chan, Hoosain and Lee (2002) and Bate, Mathias and Crawford (2001). The independence of the TSC from other measures also lends support to a finding from the process fractionation studies by Miyake et al., (2000) and Fish and Sharp (2004). Using a different dual-task than the TSC, these two investigations found dual task performance to be independent of their three-factor solutions. The performance of older adults on the TSC in normal ageing cohorts warrants further investigation.

9.13 The Impact of Age on other Cognitive Measures

Contrary to predictions made in Section 9.1 and the frontal ageing hypothesis (West, 1996), Non-Executive measures demonstrated age effects more consistently than Executive measures. In a finding which was also surprising, all of the Non-executive measures were sensitive to age effects, including those expected to be largely invariant such as Digit Span and recognition memory (Hickman, Howieson, Dame, Sexton & Kaye, 2000; Lezak et al., 2004; Myerson, Emery, White & Hale, 2003). A break down of the findings for each task follows.

9.13.1 Hopkins Verbal Learning Test-Revised (HVLT-R)

There were main effects for Age for all three HVLT-Rindexes; Immediate Recall, Delayed Recall and Recognition. The effects for HVLT-R Immediate and Delayed Recall

were in-line with predictions made in Section 9.1, and consistent with age effects demonstrated by Benedict, Schretlen, Groninger and Brandt (1998), Brandt, & Benedict, (2001), Hester, Kinsella, Ong & Turner (2004) and Vanderploeg et al., (2000). In the current study, the Immediate and Delayed Recall performance of the 50-59 year olds was superior to both the 60-69 year olds and the 70-79 year olds (see Tables 9.11 and 9.12 respectively). There were also significant advantages for females on Immediate Recall (almost 5 words) and Delayed Recall (almost 2 words). Among the existing HVLT-R literature previous gender results have been mixed. Hester et al., (2004) did not detect gender differences, while in a study by Vanderploeg and colleagues (2000), such differences were large and in excess of the effects for age. Interestingly, while the gender effects recorded by the current study do not exceed the age effects, they are of a similar magnitude in terms of mean number of immediate words recalled as in the study by Vanderploeg et al. The gender advantage for females observed by Brandt and Benedict (2001) was much smaller. van Hooren et al., (2007) also demonstrated superior verbal memory performance for females, using a different list-learning instrument.

With reference to normative data, the mean values recorded by this study's participants (see Table 9.10) are consistent with those of Hester et al. (2004), while being somewhat lower than those of Benedict et al. (1998). As per the observation made by Hester and colleagues with reference to their own work, the discrepancy between the current data set and Benedict et al., (1998) appears to be an artefact of the high education levels in the sample of the latter. The norms produced by Vanderploeg et al., (2000) are not age-stratified and thus do not allow ready comparison.

While age effects were expected on HVLT-R Immediate and Delayed recall, the differences recorded on the Recognition trial were not given that recognition memory is typically more robust to normal ageing (Lezak et al., 2004; Strauss et al., 2006). However,

the effect was only significant when analysing Age x Gender (as opposed to Age x Education), with the 70-79 year olds performing worse than both the 50-59 year olds and the 60-69 year olds (see Table 9.13). The result is in contrast to Hester et al., (2004) who found HVLLT-R Recognition to be insensitive to age, even with an upper age range of 80 – 89 years, which is higher than that employed by the current investigation. Nevertheless, the finding is not unprecedented as Vanderploeg et al., (2000) suggested that age effects observed in their study were consistent for *all* HVLT-R indices, even though they only reported values for Immediate Recall. In practical terms, it could be argued that the difference in Recognition performance between the 70 – 79 year olds and the two younger groups, of approximately two words (out of a possible 24), holds little clinical significance.

9.13.2 The Rey-Osterrieth Complex Figure Test (ROCFT)

As predicted in Section 9.1, age had a negative impact on ROCFT delayed recall performance, with the 50-59 year olds exhibiting superior recall than the two older groups (see Table 9.14). The result is consistent with the existing literature, where age effects, particularly declines after 70 years of age, are well documented (Fastenau, Denburg & Hufford, 1999; Gallagher & Burke, 2007; Rosselli & Ardila, 1991). While gender differences have proved controversial (Fastenau et al., 1999; Gallagher & Burke, 2007), they are at best nominal according to reviews by Lezak et al., (2004) and Strauss et al., (2006). The absence of a significant effect of gender in the current study is consistent with both Fastenau et al., (1999) and Gallagher and Burke (2007).

9.13.3 Digit Span

As with HVLT-R recognition memory performance, and as detailed in Section 9.1, age differences were not expected for Digit Span performance as the measure has been shown previously to be fairly robust to the effects of normal ageing (Hickman et al., 2000; Lezak et

al., 2004; Myerson et al., 2003; Psychological Corporation, 1997a). Contrary to this expectation, for all three indexes; Total, Digits Forward and Digits Backwards, there were significant main effects for Age. The 50-59 year olds performed significantly better than both the 60-69 years olds and the 70-79 year olds (see Tables 9.15, 9.16 and 9.17 respectively). Education and gender were not found to have a significant impact. And while the difference in total Digit Forward and Backwards scores between the 50-59 year olds and the two older groups of around 1 to 1.5 digits (see Table 9.10) proves statistically significant, it does not represent a clinically significant difference.

As noted previously within Section 4.16, there is debate within the literature as to whether Digits Forward and Backwards measures similar or different functions. Some authors posit that Digits Backwards is inherently more executive in nature (Bopp & Verhaegen, 2005; Lezak et al., 2004). While limited, the results of the current study tend to support the contrary position held by Strauss et al. (2006), that the two indexes measure similar things rather than representing different functions. In the current data set there did not appear to be any differential age effects for any of the indexes over the others. As postulated by both Hester et al., (2004) and Myerson and colleagues (2003), if Digits Backwards as a task is more executive in nature, one would predict a disproportionate disadvantage for the oldest adults on Digits Backwards in comparison with Forward. However, as depicted in Figure 9.4, this was not the case. The performance patterns were similar across the indexes and age groups. Further, there was a similitude of effect sizes for all three indices base upon η^2 values (Trusty, Thompson & Petrocelli, 2004), which ranged from .138 -.182. The pattern of results is consistent with those of Hester et al., (2004), Myerson et al. (2003), Verhaeghen, Marcoen and Gossens (1993), and in contrast to those of Bopp et al., (2005).

When considering convergent and divergent relationships, all Digit Span variables were significantly correlated with one another at the $p = .01$ level (see Table 9.21). As also

evident in Table 9.21, Digit Span indexes correlate to a similar magnitude whether a measure is executive or non-executive. The lack of a significant relationship between the Stroop and Digits Backwards was the sole exception; a significant correlation was not recorded. The relationship between Digits Backwards and Forwards, significant at $r = .52$, is consistent with the $r = .54$ recorded by Lamar, Zonderman & Resnick (2002) who also sampled older adults. While the age bands used herein are not directly comparable to those used in the WAIS normative data tables (Psychological Corporation, 1997b), mean values recorded by the current study (see Table 9.10) appear to be consistent with those norms.

9.13.4 Digit Symbol-Coding

Digit Symbol-Coding (Psychological Corporation, 1997b), was the sole measure of information processing speed employed. While the task is multifaceted, it has been validated as having processing speed as the primary determinant (Joy, Kaplan & Fein, 2004; Kennedy et al., 2003; Kreiner & Ryan, 2001; Lezak et al., 2004; Strauss et al., 2006). As predicted in Section 9.1, there was a significant impact of age for the measure. The age effect was arguably the strongest and clearest of all detected by Study 1. Not only did the 50-59 year olds outperform the two older groups, but the performance of the 60-69 year olds was superior to that of the 70-79 year olds (see Table 9.18). This is the only instance where the performance of the 60-69 year olds was significantly superior to that of the 70-79 year olds (excepting the AU errors result, discussed previously in Section 9.12.3).

The age result recorded is consistent with Digit Symbol-Coding being a highly sensitive index of central dysfunction (Lezak et al., 2004) and with age effects documented previously by Joy, Kaplan and Fein (2004), and the Psychological Corporation (1997b). Age-related declines in processing speed are well established within the literature (Bunce & MacReady, 2005; Park, Polk, Mikels, Taylor & Marshuetz, 2001; Span, Ridderinkhof & van der Molen, 2004; Salthouse, 2005). The pattern of results is also consistent with the

conclusion reached in the literature review of Chapter 7, that the influence of reduced processing speed on cognitive ageing is considerable, and greater than that of executive function (see Section 7.3). In the current study the strength of the finding is limited by the domain of processing speed being indexed by a sole test. With reference to normative data, again the age bands used herein are not directly comparable to those used in the WAIS normative data tables (Psychological Corporation, 1997b), although mean values recorded within the current study (see Table 9.10) do appear to be consistent with those norms.

There were no significant main effects for either Education or Gender, while there was a significant and unexpected interaction between Age and Gender. The interaction is actually quite difficult to interpret. As depicted in Figure 9.3, there appeared to be an advantage for 50-59 year old females relative to males. As with the TSC result, the difference does not appear to be explained by differences in education. As evident in Table 9.2, there were no major gender differences in education, and if anything men were slightly more educated. Further, even if there were, education is known to exert only a modest impact on Digit Symbol-Coding (Joy et al., 2004). In their reviews both Lezak et al., (2004) and Ryan, Kreiner & Tree (2008) note an advantage for females on this task. Such a finding however, with relation to the current data set, does not account for the advantage being evident in the 50-59 year old group only. A tentative explanation might be that in the current study, the higher proportion of females in the 50-59 year old group (65%), maximised their gender advantage, an advantage which may have been masked to a degree by the more even gender balance within the 60-69 year old and 70-79 year old cohorts (see Table 9.2). However, as depicted in Figure 9.3, the gender effect is not consistent across the three cohorts. While not statistically significant, the males in the 70-79 year old group recorded higher scores than the females, leading the author to suggest that the finding is simply spurious.

9.14 Summary and Conclusions

Contrary to predictions made in Section 9.1, and the frontal ageing hypothesis (West, 1996), the non-executive measures employed by the current study demonstrated age effects more consistently than the executive ones. The pattern of results is more in line with global factor accounts of cognitive ageing (Craik, 2000; Salthouse, 2005). Among the more age sensitive measures was the AU test, which is discussed in further depth, and jointly with the AU results from Study 2, in Chapter 11. Processing speed was the most age sensitive of all measures, showing differences between not only the 50-59 year olds and the two other groups, but also between the 60-69 year olds and the 70-79 year olds. The issue of frontal versus global accounts of cognitive ageing will be returned to in Chapter 11.

CHAPTER 10

Study 2 - The Impact of TBI on Executive Function for Older Adults

10.1 Aims and Hypotheses

The aim of Study 2 was to investigate the impact of traumatic brain injury (TBI) upon executive function for older adults. Draper and Ponsford (2008) identify that TBI and executive function is understudied, and Goldstein et al., (1999,) Goleburn and Golden (2001) and Rapoport et al., (2006) have all called for further investigation of the cognitive sequelae of TBI within older adult populations. Thus, this study aimed to contribute to the literature by providing much needed data from older adult TBI sufferers in general, and on executive measures inparticular. It was decided to study older adults 6-12 months post-injury to extend the literature as chronicity of deficits remains a critical issue (Binder, 1997; Leak et al., 2004).

Among younger TBI samples it is often reported that the cognitive sequelae of mTBI resolve by three months post-injury (Belanger, Curtiss, Demery, Lebowitz & Vanderploeg, 2005; Ponsford et al., 2000). Older adult TBI patients most commonly suffer mTBI through low velocity falls (Goldstein and Golden, 2001) and it remains unclear as to whether this same pattern of recovery holds for this age group. Questions remain as to whether the cognitive sequelae of TBI for older adults are qualitatively and quantitatively different from that of their younger injured counterparts. The literature which does exist has been typified by problems with small samples, heterogeneity of outcome measures and a failure to control for injury severity (Goleburn & Golden, 2001; Rapoport et al., 2006 and see Sections 8.8 and 8.12). The current study contributes to the literature by virtue of a design which exercises some control over time since injury and severity, and by carefully matching control subjects and patients on Age, Education and Gender.

The TBI literature in general is also equivocal as to whether particular cognitive domains are differentially impacted by injury. The architecture of the brain, the pathophysiology of ageing and the high incidence of diffuse axonal injury (DAI) within the age group of interest, suggests that executive function would be more severely impacted by TBI in an older sample relative to measures of memory (Bamdad, Ryan & Warden, 2003; Flanagan et al., 2006; Goleburn & Golden 2001; McDonald, Flashman & Saykin, 2002; Thompson et al., 2006). In keeping with the secondary aim of this thesis, the Alternate Uses (AU) test (Guilford, Christensen, Merrifield & Wilson, 1978) is included so its utility as a measure of executive function can be further examined. The intention is to examine usefulness by establishing whether the AU test is sensitive to TBI, and if so, to consider the effect size relative to other measures.

1. All measures of executive function will be negatively impacted by TBI (Bate, Mathias & Crawford, 2001; Brooks, Fos, Greve & Hammond, 1999; Chan, 2000; Crawford, Wright & Bate, 1995; Goldstein et al., 2001; Goleburn & Golden, 2001; Hennessy et al., 2003; Henry & Crawford, 2004; Milders, Fuchs and Crawford, 2003; Rapoport et al., 2006; Robertson et al., 1994)

2. Information processing speed will be negatively impacted by TBI (Axelrod, Fichtenberg, Liethen, Czarnota & Stucky, 2001; Blake et al., 2009).

3. Severity of injury will be associated with poorer cognitive outcome (Goldstein & Levin 2001; Goldstein et al., 2001; Ponsford et al., 2000; Schretlen & Shapiro, 2003).

In addition, it is not expected that measures of memory will show group differences based on work by the following; Bruce and Echemendia (2003), Falconer, Geffen, Olsen & McFarland (2006), Fernandez, Bartolomore & Ramos (2002) and Rapoport et al., (2006). It is not expected that any of the Digit Span Indexes (Psychological Corporation, 1997b) will

show group differences based on Hickman, Howieson, Dame, Sexton and Kaye (2000) and Myerson, Emery, White & Hale (2003) among others. Also with respect to Digit Span, as best can be deduced with the modes of data anaylsis available to the current investigation, it is expected that Digits Forward and Digits Backwards will reflect a similar function (Strauss et al. 2006), rather than there being evidence for Digits Backwards to be inherently more executive in nature (Lezak et al., 2004) as reviewed previously in Section 4.16.

10.2 Participants

The TBI sample was recruited from a wider population based TBI outcome study conducted in Southern Tasmania, the Neurotrauma Register of Tasmania (NTR). The NTR attempted to prospectively recruit all TBI patients presenting at the Department of Emergency Medicine (DEM) and other wards of the Royal Hobart Hospital (RHH), as close to the time of injury as possible, between December 2003 and June 2008 (although the author was able to recruit into the current study by tracking and then later following up those newly injured until December 2008). The RHH is the largest hospital in the state of Tasmania, Australia. To qualify for inclusion in the NTR study, patients had to have suffered TBI, defined as either a period of LOC, transient confusion, or post-concussion symptoms following trauma involving the head. All injuries were closed rather than penetrating. Patients had to score above 23 on the MMSE (Folstein, Folstein & McHugh, 1975) to be included. Aside from MMSE score, patients were excluded if they were under 16 years of age, or if they were suffering a degenerative neurological condition such as dementia or Parkinson's disease. The NTR project and protocols are detailed by Langley, Johnson, Slatyer, Skilbeck and Thomas (2010), and Thomas, Skilbeck and Slatyer (2009). Only 14% of eligible participants refused to enter the study and around 60% of mild-to-moderate cases were retained by the one year follow-up point (Langley et al., 2010).

For the current study additional exclusion criteria were imposed. Patients were ineligible if they had experienced any of the following; multiple TBIs, current serious medical problems impacting cognition, past inpatient psychiatric treatment, current major mental illness, a history of substance abuse, or if they had inadequate vision or audition to complete experimental tasks. Study 2 initially recruited patients from the NTR between the ages of 60 and 79 years who were between 6 and 12 months post injury, and who had suffered mild-to-moderate injuries (less than 7 days PTA). By October 2007 however it became apparent that there were too few eligible subjects. Aside from exclusion criteria, other factors that conspired to reduce the availability of subjects included instances where patients had been treated at the RHH but were living in other parts of the state or mainland Australia, and on occasion, death. Thus after recruiting only $n = 11$ TBI subjects, the decision was made to reduce the lower age limit to 50 years in an effort to increase the available subject pool. In excess of 17 subjects were expected to be necessary to provide adequate power, based on calculations using tables provided by Kirk (1995), following the usual practice of having an 80% probability of detecting a 1 standard deviation distance between groups, with an alpha level of .05. During the subsequent period an additional 9 participants were recruited; 6 in the 50-59 year old group, and 3 who were older than 60 years, giving a total TBI sample of 20 subjects and thus adequate power.

The majority ($n = 15$) of the TBI patients were tested at the NTR, while the remainder elected to be tested within their own homes. Testing at home reduced demand characteristics around access to transport and other related barriers. All participants had English as their primary language and had normal or corrected-to-normal vision. No incentives were offered for participation, and all participants were appropriately debriefed post testing. Any participants identified as experiencing ongoing difficulties without appropriate supports were referred to rehabilitation and other services. Ethics approval (H8650) was granted by the

Southern Tasmania Health and Medical Ethics Committee. Controls were drawn from Study 1's normal ageing subject pool and matched as closely as possible with patients for Age, Education and Gender.

10.3 Procedure and Measures

Demographic data and injury information was taken from TBI patient's medical records and at interview (see Appendix A2). As per the NTR protocol, the Hospital Anxiety and Depression Scale (HADS; Zigmond & Snaith, 1983) was administered, thus depression was screened for. The cognitive battery from Study 1, as detailed previously in Sections 9.4 and 9.5, was administered and it had some overlap with the NTR protocol. In total cognitive testing took around an hour and twenty minutes. Breaks were given as necessary, and most participants completed testing in a single session. For the few that wished it, testing was conducted over two sessions. A premorbid IQ estimate was calculated using National Adult Reading Test score (NART; Nelson & O'Connell, 1978).

The longitudinal nature of the NTR project (see Langley et al, 2010; Thomas et al., 2009) necessitated alternate forms of some measures. Thus the battery was identical to that used by Study 1, with the following exceptions; participants tested at 12 month follow-up (n = 10) completed the BHT version of Phonemic Fluency (Borkowski, Benton & Spreen, 1967), and an alternate form of Digit Span (Lezak et al., 2004). As Trail-Making Test Part-B (TMT-B) data was available as part of the NTR protocol, it was also included even though it was not available for the normal controls. As direct comparison between patients and controls was not possible, normative data was used to percentile rank each TBI patient's TMT-B score. Percentile ranks were calculated from normative data based upon values presented by Ivnik, Malec, Smith, Tangles and Petersen (1996), and by Tombaugh, Rees and McIntyre (1996, as cited by Spreen & Strauss, 1998), after being transformed from Z scores.

As NART data was unavailable for normal controls, IQ estimate was calculated using a demographic estimate based on Crawford and Allan (1997). As the current sample was largely composed of retirees, occupation was defined as the work the participant had done for the greatest part of their working lives. The procedure for coding of occupation is detailed in Crawford, Allan, Cochrane and Parker (1990). As data pertaining to spousal employment was unavailable, those endorsing home duties were coded equivalent with unskilled work. Finally, 2.9 was subtracted from the scores based on the WAIS-R derived equation to reflect the average drop in IQ score from the WAIS-R to the WAIS-III (see McCarthy et al., 2003 for discussion of this issue).

It is not ideal that different methods were used to estimate premorbid IQ. Nevertheless, this should not represent a major confound as both methods have been shown to be well correlated with IQ (Cahn-Wiener, Malloy, Boyle, Marran & Salloway, 2000; Crawford, Parker, Stewart, Besson & De Lacey, 1989; Langeluddecke, & Lucas, 2004; Mathias, Bowden & Barrett-Woodbridge, 2007). Further, individuals were expected to be within the average IQ range and both NART and demographic estimate methods have been shown to be valid within that range (Cahn-Wiener et al., 2000; Langeluddecke, & Lucas 2004; Mathias et al., 2007). Word-reading methods of estimating premorbid IQ have also been shown to be valid within the mild-to-moderate and of the TBI injury spectrum, being more problematic at the severe end only (Mathias et al., 2007). Thus for the current studies purpose, the premorbid IQ scores derived from either method should be fairly accurate.

10.4 Data Analysis

The intention for Study 2 was to analyse data using a series of independent samples t-tests. However, as is reported forthwith in Section 10.5, there was a significant difference in premorbid IQ scores between the groups. Thus the decision was made to adopt a series of one way ANCOVAs, allowing the influence of premorbid IQ to be controlled. For

ANCOVAs where there were no violations of assumptions, the alpha level was set to .05. As per Study 1, in cases where there Levene's test statistic was significant, the alpha level was set to the more stringent .025, as suggested by Tabachnick and Fidell (2001). The rationale for doing so remains the same as presented for Study 1; it was desirable to retain the natural scores of the data set rather than performing any data modification (Cahn-Wiener, Malloy, Boyle, Marran & Salloway, 2000; Rapoport et al., 2008). While there was natural variability, there was no reason to believe that the scores were subject to any artificial measurement artefact thus they were retained. No outliers were identified during data screening using the criteria of Kirk (1995). The influence of injury variables, and some other relationships among the TBI group are explored using Pearson product-moment correlations; the modest sample size precludes the use of more sophisticated techniques or detailed analyses (MacCallum, Widaman, Zhang & Hong, 1999; Tabachnick & Fidel, 2001). As with Study 1, due to the large number of Pearson product-moment correlations calculated, the alpha level was set to .01. Complete ANCOVA tables, correlation matrices and other SPSS output for all analyses can be found in AppendixC, including instances where statistical values are not reported due to the absence of significant results.

10.5 Demographic Data

The TBI subjects and controls were closely matched on demographic variables, as shown in Table 10.1.

Table 10.1

Demographic data for TBI subjects and Matched Controls

	Demographic Data				
Group	Age	Education	Premorb. IQ	Time Since Injury (days)	PTA (hours)
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
TBI (*n*=20)	63.6 (8.9)	11.5 (3.1)	108.6 (7.6)	291 (88.61)	22.9 (33.2)
Controls (*n*=20)	63.8 (8.9)	11.6 (3.0)	102.3 (8.5)	-	-

Gender balancing between the two cohorts was perfect, and as evident in Table10.1, the matching of the cohorts in terms of Age and Years of Education, is extremely close. However, Independent samples t-test revealed that there was a significant difference in premorbid IQ estimate, favouring the TBI subjects, $t(38) = 2.46$, $p = .018$.

The criteria of Lezak et al., (2004), and Stein (1996), were used to rate TBI severity using duration of PTA. Sixty-five percent of the sample suffered mild injuries and thirty-five percent moderate. Table 10.2 displays demographic variables by severity group and as can be seen, there were no systematic differences in Age, Education or Premorbid IQ. There was however a tendency for moderate cases to be captured at the 12 rather than 6 month time point, potentially confounding severity with time since injury. This should not prove a major issue however as the primary focus of this study is examining any differences that may exist between an injured and non-injured group.

Table 10.2.

Demographic data for Mild and Moderate TBI subjects

	Demographic Data				
	Age	Education	Premorb. IQ	Time Since Injury	PTA (mins)
Group	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Mild (*n* =13)	63.7 (9.2)	11.2 (2.7)	109.2 (6.5)	266 (81.4)	4.7 (5.9)
Mod (*n* =7)	63.4 (8.9)	12.1 (3.7)	107.4 (9.6)	337 (87.9)	56.6 (37.1)

Mechanism of injury could be split into two categories, Falls and Motor Vehicle Accident (MVA). The Falls category is self explanatory. Accidents predominantly describes MVAs (*n* = 4), although motorcycle accidents (*n* = 2) and bicycle accidents (*n* = 2) were also included in the interests of simplicity. As shown in Table 10.3, there were 12 Falls patients and Falls patients were older than MVA patients. The MVA patients experienced longer duration of PTA than Falls patients. Males and Females were equally represented in the Accident category, while Females outnumbered Males in the Falls category 2:1.

Table 10.3

Average Age and PTA for Mechanism of Injury

Variable	Falls (*n* =12) *M (SD)*	MVA (*n* =8) *M (SD)*
Age	67.1 (7.0)	58.5 (9.3)
PTA hours	16.1 (18.4)	33.1 (47.4)

10.6 The Effect of TBI on Executive Measures

Before proceeding to the results of the analyses for Group and Executive Function, means, standard deviations and η^2 values for each of the Executive measures by group are displayed in Table 10.4.

Table10.4

Performance of TBI Sufferers and Controls on Executive Measures

Measure	TBI		Controls		η^2 for sig differences
	M	*SD*	*M*	*SD*	
Phonemic Fluency	38.3	17.5	42.4	12.4	.100*
Semantic Fluency	19.1	5.9	18.1	3.8	*ns*
AU correct	11.1	7.1	13.8	7.5	.130*
AU errors [a]	5.7	6.5	7.7	6.3	*ns*
Stroop Index [a]	2.4	.81	2.1	.57	*ns*
Stroop Incongruent [a]	13.8	3.3	14.8	3.8	.177**
Stoop Control [a]	18.1	4.9	20.3	7.9	*ns*
Dual-Task [a]	.55	.82	2.7	4.06	.213**
TMT-B seconds [a]	95.2	39.7	-	-	-
TMT-B % Rank	48.5	32.4	-	-	-

* = significant at p<.05, ** = significant at p<.01, *** = significant at *p*<.001.
[a] note. Low scores represent better performance.

The effect of Group for Phonemic Fluency performance was significant $F(1, 38) = 4.11$, $p = .050$, $\eta^2 = .100$, as was the effect of the covariate, premorbid IQ. The performance of control subjects was superior to TBI subjects, giving support to the hypothesis that measures of executive function will be negatively impacted by TBI. In contrast, there was

not a significant main effect of Group for Semantic Fluency performance which does not support the same hypothesis. Complete output for all ANCOVAs is contained within Appendix C4.

There was a significant main effect of Group for Alternate Uses Correct, $F(1, 38) = 5.54$, $p = .024$, $\eta^2 = .130$, lending support to support to the hypothesis that measures of executive function will be negatively impacted by TBI. The effect of the covariate was also significant. The performance of control subjects was superior to TBI subjects. There was no significant main effect of Group for Alternate Uses total errors.

The Stroop results provide partial support for the hypothesis that measures of executive function will be negatively impacted by TBI. A main effect of Group for Stroop Performance, in favour of Controls, using the index score fell just short of statistical significance $F(1, 38) = 3.84$, $p = .057$, $\eta^2 = .094$, and the effect of the covariate was not significant. However, if the score for the incongruent colour naming trial only is taken, the effect of Group, favouring Controls, is significant, $F(1, 38) = 7.98$, $p = .008$, $\eta^2 = .177$. Although the Levene's test was significant, this is not problematic as the p value is well below .025 (Tabachnick & Fidell, 2001). There was no significant effect of Group on the control condition (colour naming).

The Dual-Task results provide support for the hypothesis that measures of executive function will be negatively impacted by TBI. There was a significant main effect of group on Dual-Task Performance, $F(1, 36) = 9.48$, $p = .004$, $\eta^2 = .213$, and for the covariate. Although the Levene's test was again significant, this is not problematic as the p value is well below .025. The performance of the control group was superior to that of TBI sufferers.

The TMT-B result does not lend support for the hypothesis that measures of executive function will be negatively impacted by TBI. As noted previously in Section 10.3, only the TBI subjects were administered TMT-B. The TMT-B data did not violate any assumptions

of normality, tested by the Kolmogorov-Smirnov statistic, with output available in Appendix C5. The overall mean percentile rank for the TBI group was 48.5 (SD = 32.4), placing their performance well within the normal range; that is they scored as would be predicted for a non-injured sample.

10.7 The Effect of TBI on other Cognitive Measures

Before proceeding to the results of the analyses for Group and Executive Function, means, standard deviations and η² values for each of the Non-Executive measures by group are displayed in Table 10.5.

Table 10.5

Performance of TBI sufferers and Controls on Non-Executive Measures

Measure & Domain	TBI		Controls		η² for sig differences
	M	*SD*	*M*	*SD*	
Memory					
HVLT-R Immediate	21.9	6.1	21.6	7.1	*ns*
HVLT-R Delay	7.7	3.0	7.9	2.5	*ns*
HVLT-R Recognition	22.3	1.8	21.8	1.6	*ns*
ROCFT Delay	18.2	8.6	18.1	6.1	*ns*
Digits Raw	17.2	4.9	17.1	4.6	*ns*
Digits Forward	6.4	1.5	6.4	1.2	*ns*
Digits Backward	4.9	1.5	5.0	1.4	*ns*
Processing Speed					
Dig Symbol-Coding	67.7	20.2	56.9	15.9	.161*

* = significant at p<.05,

As expected, there were no significant main effects of Group for Hopkins Verbal Learning Test Revised (HVLT-R; Brandt & Benedict, 2001) Immediate Recall, Delayed Recall or Recognition performance, with the full output available in Appendix C4. The effect of the covariate, premorbid IQ estimate was significant for HVLT-R Immediate Recall but not for either Delayed Recall, or Recognition. Also consistent with expectations, there was no significant main effect for Group on delayed recall performance of the Rey-Osterrieth Complex Figure Test (ROCFT), and none for the covariate.

The Digit Span data also conformed to expectations. There were no significant main effects of Group for either Digit Span performance, Digits Forward or Digits Backwards. The covariate had a significant impact on Digits Backwards only. There was a significant main effect of Group on Digit Symbol-Coding performance, $F(1, 38) = 7.08$, $p = .011$, $\eta^2 = .161$ in favour of the control group, and a significant main effect for the covariate.

10.8 Relationships Between Injury Variables, Demographic Variables and Cognition for the TBI Group

To explore the relationships between the cognitive variables and their respective domains within the TBI cohort, bivariate Pearson product-moment correlations were computed and the complete matrix is available in Appendix C6. There were no significant correlations at $p = .01$ level between Time Since Injury and any of the measures of cognition, and the same was true of length of PTA and cognition. Among the TBI group there were significant relationships between Education and the following cognitive variables only; Semantic Fluency ($r = .59$), Alternate Uses Correct ($r = .56$) and the Stroop ($r = -.54$). Thus only Executive measures correlated with Education. There was a sole significant negative relationship between Age and ROCFT Delayed Recall, $r = -.65$ $p = .002$. The same relationship was not significant amongst the matched normal controls. It must be noted

however, that the sample size was quite small for this type of analysis (Gatsonis & Sampson, 1989) and it was conducted in an exploratory fashion only.

10.9 Relationships Within and Between Measures across Cognitive Domains for the TBI Group

The relationships between and within domains for the TBI group were examined. Again, the corelational data was analysed in exploratory fashion only. Selected results from the TBI group are proffered in Table 10.6. In the interests of simplicity, Dual-Task and AU Errors results are not included; there was a significant relationship between these two variables, ($r = .62$), but not for either of these variables with any other cognitive measure. When visually inspecting the data, displayed in Table 10.6, when relationships are significant, the magnitude of those relationships appears fairly similar among the Executive and Non-Executive measures. There were a small number of significant correlations between Executive and Non-Executive measures. At an individual task level, TMT-B from the Executive domain, and HVLT-R Immediate Recall from the domain of memory demonstrated the best convergent and divergent validity.

Table 10.6

Relationships between select Executive and Non-Executive measures for TBI patients

r	Executive Function						Memory		PS
	Phon Flu	Sem Flu	AU Cor	Stroop	TMT-B	Hop Im	Rey Del	Dig Raw	Cod Raw
Sem Flu	ns	-							
AU Correct	ns	.598*	-						
Stroop	ns	ns	ns	-					
TMT-B	.736**	ns	.636*	ns	-				
Hop Im	ns	ns	ns	ns	ns	-			
ROCFT Delay	ns	ns	.726**	ns	ns	.580*	-		
Dig Raw	ns	.667	ns	ns	ns	.568*	ns	-	
Cod Raw	ns	ns	ns	ns	.662*	.590*	ns	.590*	-

* = significant at *p* .01, ** = significant at *p* .001

As with Study 1, due to the controversy as to whether Digits Forward and Backwards measure the same or different functions, the relationship between the measures is given attention. In regard to any differential relationships between Digit Span, Digits Forward and Digits Backwards, as displayed in Table 10.7, all Digits Span variables are significantly correlated with one another. Only total Digit Span score correlated significantly with other variables.

Table 10.7

Relationships between Digit Span variables and other Cognitive Measures for TBI patients

r	Digits Raw	Digits Forward	Digits Backward
Digits Raw	1	-	-
Digits Forward	.719**	1	-
Digits Backward	.591*	.735**	1
Stroop	*ns*	*ns*	*ns*
Semantic Fluency	.667*	*ns*	*ns*
AU Correct	*ns*	*ns*	*ns*
HVLT-R Immediate	*ns*	*ns*	*ns*
ROCFT Delay	*ns*	*ns*	*ns*
Coding	.590*	*ns*	*ns*

* = significant at *p* .01, ** = significant at *p* .001

10.10 Discussion

The aim of Study 2 was to investigate the impact of TBI upon executive function among older adults. To do so a group of TBI sufferers ($n = 20$), between the ages of 51 and 78 years ($M = 63.6$ years), were tested. It was decided to study older adults 6-12 months post-injury to extend the literature, as the chronicity of deficits remains a critical issue (Binder, Rohling & Larrabee 1997; Lezak et al., 2004). It is often reported that the cognitive sequelae of mTBI are resolved by three months post injury (Belanger, Curtiss, Demery, Lebowitz & Vanderploeg, 2005; Ponsford et al., 2000). What remains less clear however is whether this holds for older adults, who most commonly suffer mTBI after low velocity falls

(Coronado, Thomas, Sattin & Johnson, 2005). The architecture of the brain, the pathophysiology of ageing and the high incidence of diffuse axonal injury (DAI) within the age group of interest, led to the prediction in the present study that executive function would be preferentially impacted by TBI in an older sample (Bamdad et al.,2003; Flanagan et al., 2006; Goleburn & Golden 2001; McDonald et al., 2002; Thompson et al., 2006).

10.11 Sample Characteristics

The TBI group and normal controls were well matched in terms of age, years of education and gender (see Section 10.5). Despite this careful matching, there were significant differences in premorbid IQ estimate hence the need to covary this variable during data analysis. It is not possible to make strong epidemiological comparisons from a sample as modestly sized as the current TBI one. Additionally, it should be borne in mind that severe cases were ineligible for entry into the study.

The current sample sustained predominately mild injuries (65%), with the remainder being moderate (see Table 11.2). Sixty percent of the sample suffered falls leaving forty percent in the motor vehicle accident (MVA) category (see Table 10.3). The high proportion of falls as a mechanism of injury, followed by MVA, is consistent with previous research into TBI and ageing (Coronado et al., 2005; Goleburn & Golden, 2001; Helps et al., 2008; Hillier et al., 1997; Tate et al., 1998; Thompson et al., 2006). Among such populations, Thompson et al., observed the rate of falls to be 51% and Coronado and colleagues noted an incidence of 67%. Thus, the 60% incidence documented by the current study falls well within the ranges of Coronado et al. and Thompson et al.

As evident in Table 10.3, falls sufferers tended to be older while accident victims experienced longer duration of post-traumatic amnesia (PTA). Both findings are consistent with Goldstein, Levin, Goldman, Clark & Altonen (2001) and Goleburn and Golden (2001) who observed these same trends among samples with similar age parameters. The older age

of the falls sufferers recorded herein is consistent with the well documented sharp increase of falls incidence after 60 years of age (Coronado et al., 2005; Flanagan et al., 2006; Helps et al., 2008; Tate et al., 1998). The greater severity of injury resulting from MVA is also unsurprising and has been observed previously by Goldstein et al., (2001), Ponsford et al., (2000) and Tate et al., (1998).

As reported in Section 10.5, females experienced double the rate of falls of men. This is inconsistent with the existing literature. Helps et al., (2008) found that females overall had a greater incidence of falls as the mechanism of injury (53%) in comparison to men (37%). A smaller study by Hillier et al., (1997) found females only to have a 5% higher incidence of falls than males. However, the 5% recorded by Hillier and colleagues does not approach the magnitude of the gender imbalance recorded by the current investigation. Studies by Coronado et al., (2005) and Myburgh et al., (2008) do not serve as additional reference points as neither report mechanism of injury by gender. Perhaps the finding in relation to the over-representation of females suffering falls recorded herein can be explained by women being either more willing to volunteer for research participation, or more likely to comply with follow-up. However, in analysis of loss to follow-up for the NTR project overall, no gender differences were noted (J. Langley, personal communication, May 27, 2010). The finding may simply represent an idiosyncratic artefact of Study 2's modest sample size.

10.12 The Impact of TBI on Executive Function

10.12.1 Verbal Fluency Measures

As predicted in Section 10.1, the performance of TBI sufferers was inferior to that of controls on the Phonemic Fluency task. The lack of a difference predicted in Section 10.1 however between TBI sufferers and controls for Semantic Fluency was unexpected as both measures have been previously shown to be sensitive to the impact of TBI (Belanger et al., 2005; Henry & Crawford, 2004; Goleburn & Golden, 2001; Goldstein et al., 2001; Rapoport

et al., 2006; Raskin & Rearick, 1996). The lack of significant differences on the Semantic Fluency task is further surprising given that Henry and Crawford (2004) noted a similitude of effect sizes between the two fluency paradigms in their meta-analysis of TBI patient data. It is also surprising given that Rapoport et al. (2006) were able to detect differences between patients and controls at 12 months post-injury in their study of adults 50 years and older, who, as per the current sample, had also suffered mild-to-moderate injuries. Perhaps in the more modestly sized current sample, it was simply that the Phonemic Fluency task, having a greater number of trials, was the more reliable and thus sensitive of the two paradigms. The number of trials has certainly been identified previously by Strauss et al., (2006) as a procedural and interpretative concern when comparing the two tasks. Such an explanation is given more credence in light of the trend in the predicted direction, with TBI sufferers generated approximately four fewer words than controls (see Table 10.4). And while discordance in the number of trials between the Phonemic and Semantic Fluency task can be viewed as a problematic, employing the standard forms facilitates both ease of comparison with the existing literature and generalisability to clinical practice.

Consistent with the prediction made in Section 10.1, TBI sufferers performed significantly worse than controls with respect to Ideational Fluency, as measured by total number of correct uses generated on the Alternate Uses (AU) test (Guilford, Christensen, Merrifield & Wilson, 1978). There were no significant differences between the two groups in terms of commission of errors. As to where the results fit with respect to existing TBI research, there is little published data available for comparison. Milders, Fuchs and Crawford (2003) recorded a trend for poorer performance of TBI sufferers relative to controls using a small sample of young severely injured patients. Patients and controls in that study did not differ on the proportion of errors versus correct uses generated. Prior to the work of Milders et al., Crawford, Wright & Bate (1995) published a conference abstract suggesting that the

AU task was the most sensitive of verbal fluency measures employed within their TBI sample. As the AU test was shown to be adequately sensitive to TBI in the current study, greater discussion of the paradigm's utility as a measure of executive function is held over until Chapter 11, where it can be considered in tandem with the findings from Study 1.

The dissociation between the Phonemic Fluency task's invariance to age and its converse sensitivity to TBI was not anticipated when commencing the literature reviews for this thesis. The same disparity was apparent in the pattern of results returned by Studies 1 and 2, and has not received commentary within the literature to date. Further discussion of the issue takes place within the final Chapter. In terms of validity, it has been suggested that the Phonemic Fluency task merely taps lexical access (Fisk and Sharp, 2004; Shores, Carstairs & Crawford, 2006; Turner, 1999) rather than strategic retrieval and goal-directed behaviour (Bryan, & Luszcz, 2000a; Strauss et al., 2006). As per Study 1, the current analyses, in lieu of more sophisticated techniques such as linear regression, factor analysis and structural equation modelling, cannot greatly clarify the issue (MacCallum, Widaman, Zhang & Hong, 1999; Tabachnick & Fidel, 2001). Of all the cognitive variables, the Phonemic Fluency task correlated significantly with TMT-B only, at $r = .73$; whereas Semantic Fluency and AU total correct correlated with one another at $r = .59$ (as per Section 11.9).

10.12.2 The Stroop Test

It was predicted in Section 10.1 that TBI would be deleterious to Stroop performance. Taking the Stroop index score only, there was a strong trend for inferior performance of TBI sufferers at $p = .057$. Using the index score is preferable to time taken to complete the incongruent trial due to the potential for baseline differences in processing speed to exert an extraneous influence (Strauss et al., 2006; Troyer, Leach, & Strauss, 2006). Nevertheless, when analysing results for time taken in seconds on the incongruent trial by way of further

exploring the above noted trend, the performance of the TBI patients was significantly poorer relative to normal controls. Further, there was no significant difference between the two groups on the control condition which goes some way to allay concerns that the result merely represents baseline speed differences between the two groups. Thus, in line with predictions, it can be concluded that there was a deleterious impact of TBI on the Stroop task for the older adult patients captured by the current study.

In terms of the literature reviewed previously, the Stroop was either employed infrequently or collapsed together with other variables to give a composite executive score making cross-study comparisons difficult. Within the non-ageing TBI literature, poorer performance was demonstrated in severe cases by Bate, Mathias and Crawford (2001) and in mild-to-moderate cases by Chan (2000), although the latter's subjects were recruited on the basis of subjective attentional complaint. Hennessy, Geffen, Pauley and Cutmore (2003) did not find differences between mTBI patients and controls at one month post-injury. In review Strauss et al., (2006) deemed the Stroop to be TBI-sensitive, but not at the milder end of the injury spectrum. However, that finding may not hold among older TBI sufferers given the differences detected in the current sample, especially given the preponderance of mild injuries and the non-acute interval between time of injury and testing. It is unlikely that the influence of age and education account for the differences recorded herein due to the close matching of the TBI and control samples (see Table 10.1). Perhaps in this age group the effects of normal ageing combined with insult from TBI assailed cognitive reserve beyond a critical point. Further replication among older adult TBI populations is warranted.

10.12.3 Trail Making Test Part B (TMT-B)

As noted in Section 10.3, control participants were not administered the TMT-B, so normative data was used for comparison purposes. In this instance, the prediction made in Section 10.1 that TBI would preferentially impact executive function was not supported. The

TBI patients performed on average at the 48th percentile, although the standard deviation was large (32.4; see Table 10.4). The result is consistent with the existent literature. In review Strauss et al., (2006) deemed the TMT to have questionable utility in mTBI populations. Brooks, Fos, Greve & Hammond (1999) found poor performance in mTBI patients relative to controls at only three days post-injury, while Hennessy and colleagues (2003) did not demonstrate deficits for mTBI cases at one month post-injury. Chan (2000) failed to document poorer performance in mild-to-moderate TBI patients on the TMT-B, despite recruiting on the basis of attentional complaint. With respect to older TBI samples, Goldstein et al., (2001) recorded differences between moderate TBI sufferers and controls at 1 month post-injury on the TMT-B, while Ashman et al., (2008) did not when testing subjects several years post-injury. And while the current TMT result is consistent with the existing literature a caveat is warranted. Due to the longitudinal nature of the NTR protocol, participants had typically completed the TMT at least twice previously, thus practice may have advantaged the TBI cohort in comparison to the normative control data. That is, repeated measurement for TBI sufferers may have led to an underestimation of true difference, thus further testing of older adult TBI patients on the measure may be warranted. Additionally, Lezak et al., (2004) have previously argued that the large standard deviations on Part-B may obscure true differences and thus contribute to negative findings.

101.2.4 Divided Attention – Telephone Search While Counting (TSC)

As predicted in Section 10.1, the performance of the TBI cohort was inferior to that of control subjects on Telephone Search while Counting (TSC; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994). At $\eta^2 = .213$, the effects size was noteworthy (Trusty, Thompson & Petrocelli, 2004). The result gives stronger support for Robertson and colleagues (1994) assertion of the index's great sensitivity than either Hennessy et al. (2003), or Chan (2000). Hennessy and colleagues had previously documented differences between controls and mTBI

sufferers on this measure at only 1 month from injury, while Chan (2000) differentiated moderate and severe TBI sufferers from controls at a mean time of 14 months post-injury using a group recruited on the basis of subjective attentional complaint. Ziino and Ponsford (2006) failed to demonstrate differences in a sample of mixed TBI severity relative to controls, although great heterogeneity in time since injury and large SDs in the TBI group may have obscured such differences. Bate et al., (2001) also failed to detect differences between controls and severe TBI patients on this measure and suggested that Robertson et al., may have succeeded in doing so due to having a shorter post-injury interval, by not controlling for the influence of IQ and due to possible sampling error given that there were only 15 patients sampled. The IQ criticism does not apply to the current study as the variable was covaried. As with the Stroop result, the impact of TBI coupled with a reduction in cognitive reserve via the normal ageing process, may account for differences detected on the TSC in comparison to the lack of differences that have been documented for younger patients either more severely or acutely injured. As no available published studies have used the TSC among an older TBI cohort, replication is merited.

10.13 The Impact of TBI on other Cognitive Measures

As detailed in Section 10.1, it was expected that the memory measures employed by the current study would be robust to the impact of TBI given that patients were in the mild-to-moderate end of the injury spectrum and the non-acute phase of injury. As anticipated, there were no significant differences on Hopkins Verbal Learning Test Revised (HVLT-R; Brandt & Benedict, 2001) Immediate, Delayed or Recognition memory between TBI patients and controls. Also in-line with the expectations outlined in Section 10.1, there were no significant between group differences on the Rey-Osterrieth Complex Figure Test (ROCFT) delayed recall score, or for any of the three Digit Span indexes. It was however hypothesised in Section 10.1 that TBI would exert a deleterious effect on the information processing speed

measure employed, Digit Symbol-Coding. This prediction proved accurate and thus the data conformed to all expectations in relation to non-executive measures.

10.13.1 Hopkins Verbal Learning Test- Revised (HVLT-R)

Originally developed as an alternative to the California Verbal Learning Test (CVLT) for work with dementia populations (Lezak et al., 2004; Strauss et al., 2006), the HVLT-R has not been widely employed in the TBI field. Invariance to the influence of TBI for HVLT-R performance was anticipated given that impaired performance in TBI sufferers has only been previously documented during the highly acute phase of injury (Bruce & Echemendia, 2003; Falconer, Geffen, Olsen & McFarland, 2006). While adequate sensitivity of the HVLT-R may be an issue, one can have more confidence that the lack of differences recorded herein reflects a truer similitude of memory performance between patients and cotnrols given that there was also no impact of TBI upon ROCFT delayed recall performance. Power should have been adequate (Kirk, 1995). It appears that TBI did not have a significant impact over and above that of age upon HVLT-R performance. Nevertheless, further replication using a larger sample is necessary to be able to draw this conclusion with greater confidence.

10.13.2 The Rey-Osterrieth Complex Figure Test (ROCFT)

As expected, there were no significant differences between TBI patients and controls for delayed recall of the ROCFT. The lack of an impact of TBI for ROCFT delayed recall performance is consistent with the result of Rapoport and colleagues (2006), who used a larger TBI sample of individuals who were also aged 50 years and older. Rapoport et al. did not detect differences between mild-to-moderate TBI cases and controls at 12 months post injury. From the non-ageing TBI literature, Fernandez, Bartolomore & Ramos (2002) detected no differences between controls and TBI patients using a moderate TBI cohort, 12

months from injury. Differences between patients and controls detected by Schwarz, Penna and Novack (2009) were from subjects who were more severely injured and tested more acutely (one month post injury).

Within the current TBI cohort, ROCFT delayed recall was the sole measure where a significant negative relationship with Age existed ($r = -.65$, $p = .002$). The magnitude of this relationship among the matched normal control group was non-significant ($r = -.31$), although it did exist within Study 1's larger normal ageing cohort at $r = -.44$, p <.001. The relationship with age in the presence of other neurological insult gives additional support for Study 1's finding of the ROCFT's age sensitivity.

10.13.3 Digit Span

As noted in Section 10.1, group differences were not expected for Digit Span indexes as they have previously been demonstrated to be quite robust to TBI (Aharon-Peretz et al., 1997; Blake, Fichtenberg & Abeare, 2009; Duncan, Johnson, Sawles & Freer, 1997; Langeluddecke, & Lucas, 2003). This prediction was supported by the current results for all three indices (Total, Forwards, and Backwards). As aforementioned, controversy exists around the contribution of executive processes, or lack thereof, to Digits Backwards (Lezak et al., 2004, Strauss et al., 2006). Any dissociation between Digits Forward and Backwards performance is postulated to reflect executive function and such a dissociation should be greatest among a TBI group relative to normal controls (Lezak et al., 2004). No such dissociation was evident; there was actually great similitude of performance between the two groups. Such a result is in agreement with the results of Study 1, and while limited, lends additional support for the position held by Strauss et al. (2006), that the two indexes measure similar rather than different constructs.

All Digit Span variables were significantly correlated with one another, as is evident when perusing Table 10.7. Neither Digits Forwards or Backwards correlated significantly

with other measures, while overall Digit Span score correlated both with Semantic Fluency (r = .66) and Digit Symbol-Coding (r = .59). The strong correlations between these measures may reflect a common element; the ability to hold information in working memory while processing at speed.

10.13.4 Digit Symbol-Coding

As noted previously, Digit Symbol-Coding is the sole measure of information processing speed employed by the current study. While the task is multifaceted, it has been validated as having processing speed as the primary determinant (Joy, Kaplan & Fein, 2004; Kennedy et al., 2003; Kreiner & Ryan, 2001; Lezak et al., 2004; Strauss et al., 2006). As predicted in Section 10.1, TBI had a significantly deleterious impact upon performance, and the effect size of η^2 = .161, was one of the larger recorded by Study 2 (Trusty, Thompson & Petrocelli, 2004), with only those for the TSC (η^2 = .213), and the incongruent trial of the Stroop (η^2 = .177), being larger. The result is consistent with Digit Symbol-Coding being a highly sensitive index of central dysfunction (Lezak et al., 2004), and is in agreement with previous findings of impaired performance by TBI sufferers (Axelrod et al., 2001; Blake et al., 2009).

10.14 Relationships between Injury Variables and Cognition

The ability to conduct detailed analysis of the impact of injury variables upon cognition in the current study is limited by the modest sample size (Gastonis & Sampson 1989; Kirk, 1995). At the outset it was hoped that a sufficient number of subjects would be recruited to allow division of the TBI cohort into two severity groups; mild and moderate. However, this did not prove to be the case, even after lowering the minimum age for entry into the study to 50 years in response to recruiting difficulties. Pearson product-moment correlations revealed no significant relationships between the severity marker duration of PTA and cognition. However, as noted previously, the sample was small and this line of

analysis was conducted in exploratory fashion only. Age was not correlated with severity or outcome in the older TBI cohort of Mazzucchi et al., (1992) and the same finding was of surprise to Goleburn and Golden (2001) in their review of TBI patients older than 65 years. Goldstein and Levin (2001) and Goldstein et al., (2001) however report more of a dose-injury relationship with cognition, and a high degree of variability in psychosocial sequelae, consistent with findings from the non-ageing TBI samples of Ponsford et al. (2000), and Schretlen and Shapiro (2003).

The contrary finding of Mazzucchi et al., (1992) arose from a sample featuring greater heterogeneity of time since injury and severity than either the current study, or those of Goldstein and Levin (2001) and Goldstein et al., (2001). Further, in a self-contradictory manner, Mazzucchi and colleagues did find what they termed 'normal outcome' to be associated with PTA of less than one week. Taking all the above into account, it can be hypothesised that if the current study had succeeded in recruiting a larger sample, a degree of a dose relationship between severity and cognitive outcome would have been apparent. The relationship between severity and outcome warrants greater elucidation among older TBI samples, particularly at the milder end of the injury spectrum.

Using the same mode of analysis, and having the same limitations, there was also an absence of a significant relationship between time since injury and any measure of cognition. Cognitive deficits have been detected within three months from injury, even in mild older TBI cases, by Goldstein and Levin (2001) and Goldstein et al., (2001). By twelve months post-injury however, few cognitive deficits have been detected. Rapoport et al., (2006) documented such deficits at 12 months post-injury in moderate cases only, while studies including severe cases recorded deficits more distally (Ashman et al., 2008; Mazzucchi et al., 1992). As noted earlier in Section 10.5, it is a limitation that time since injury was confounded with severity in the current data as there was a tendency for moderate cases (as

opposed to mild) to be captured at the 12 rather than 6 month time point. As with severity and outcome, the relationship between time since injury and outcome warrants further investigation using older samples, especially at the milder end of the injury spectrum.

10.15 Wider Discussion

Given that a deleterious impact of TBI upon cognitive function within the general population has been widely demonstrated as being among the sequelae of injury (Christensen et al., 2008; Ponsford, Draper & Schonberger, 2008; Schretlen & Shapiro 2003; Sigurdardottir, Andelic, Roe & Schanke, 2009) it is not surprising that the same holds true for older adult samples (Ashman et al., 2008; Goldstein et al., 2001; Goleburn and Golden, 2001; Hukkelhoven et al., 2003; Mazzucchi et al., 1992; Rapoport et al., 2006; Raskin, Mateer & Tweeten, 1998). The more troublesome question is whether the cognitive sequelae of TBI for older adults are qualitatively and quantitatively different from that of their younger counterparts. The Stroop and TSC results in the present study give support for a difference that is at the very least quantitative.

Another important question is whether particular cognitive domains are more sensitive to the impact of TBI than others. It has remained unclear whether the pattern of cognitive impairment and the rate of recovery that typically follows TBI is expressed uniformly across the age span (Ashman et al., 2008). Study 2 sought to contribute to the literature by further elucidating the impact of TBI within an older adult cohort, 6-12 months post injury, with a particular emphasis on measures of executive function.

By focusing on executive function, this study also made a contribution towards addressing the neglect of executive function among TBI populations noted by Draper and Ponsford (2008). This study also responds to the imperatives of Goldstein et al., (1999), Goleburn and Golden (2001) and Rapoport et al., (2006) for further investigation of the cognitive sequelae of TBI within older adult populations. The mild to moderate spectrum

was targeted as the bulk of TBI sustained by older adults are within the mild to moderate range (Goleburn & Golden, 2001) yet paradoxically, very little is known about cognitive outcome at this end of the severity spectrum (Rapoport et al., 2008). While capturing a cohort 6-12 months post-injury proved a greater recruiting challenge, capturing patients at this time point was meritorious as chronicity of deficits is a critical issue (Lezak et al., 2004; Binder et al., 1997).

Much of the previous research has been typified by problems with small samples, heterogeneity of outcome measures and a failure to control for injury severity (Goleburn & Golden, 2001; Rapoport et al., 2006). While the current study was limited to a sample of 20 TBI patients, time since injury and severity was controlled, and care was taken with the matching of the control subjects on Age, Education and Gender. Even though Age was lowered from 60 to 50 years to capture enough subjects, a 50 year lower limit is common within this field, with work by Goldstein et al. (2001), Goleburn and Golden (2001), Mazzucchi et al., (1992) and Rapoport et al., (2006) all serving as examples. While modest in size, the sample provided adequate power (Kirk, 1995).

The results of Study 2 supported the postulate and prediction, that executive function would be preferentially and negatively impacted by TBI, in comparison to memory at least. The prediction that processing speed would be negatively impacted by TBI was also confirmed. It is not uncommon for the domain of principal interest to this thesis, executive function, to suffer post TBI (Kim et al., 2005; Kliegel, Eschen & Thorne-Otto, 2004; Levine et al., 1998). Whether executive function is more sensitive to other domains, or even a valid construct in its own right, is more hotly contested. The literature reviewed earlier in Chapter 8 revealed no clear picture as to the cognitive domains most impacted by TBI for older patients.

The mTBI literature is almost as mixed concerning differential impairment across cognitive domains. In meta-analysis, Binder et al., (1997) determined that severity of injury was more influential than any one cognitive domain, and Mathias, Beall and Bilger (2004) found their domain of interest, processing speed, to have effect sizes similar in magnitude to other domains, including executive function. Conversely, Belanger and colleagues (2005) indicated that memory and fluency tests were the most sensitive to mTBI. Conducting meta-analysis of TBI and verbal fluency across the full severity spectrum, Henry and Crawford (2004) found that such measures made a unique contribution over and above processing speed. Using a selectively recruited severe TBI sample, Kim and colleagues (2005) also found that executive function made a unique contribution to inattentive behaviour, a contribution that was not explained away after controlling for processing speed.

Thus the results of the current study lend additional support to work by, Hart et al. (2005), Kim et al. (2005), Kliegel et al. (2004) and Levine et al. (1998), indicating that executive function is differentially more sensitive to the impact of TBI. Further, this study's pattern of results suggests that executive function may be particularly vulnerable among older adult TBI populations, and thus outcome for this population may be at least quantitatively different in comparison to younger patients. The vulnerability of older TBI sufferers most likely represents interplay between both the pathophysiology of normal ageing and the particular pathophysiology of sustaining TBI during older adulthood. In addition to age-related frontal lobe atrophy, the architecture of the skull renders the frontal lobes particularly vulnerable to injury in the event of TBI (Bamdad, Ryan & Warden, 2003; McDonald, Flashman & Saykin, 2002). And while the latter vulnerability applies to TBI sufferers irrespective of age, older adults are at particular disadvantage. Older adult TBI sufferers are susceptible to subarachnoid haemorrhage (Flanagan et al., 2006), their cerebral veins are more vulnerable to tear even in the event of minor trauma (Goleburn & Golden 2001) and the

increased adherence of the dura to the skull in advanced age and higher rates of the use of anti-coagulant also contribute adversely (Thompson et al., 2006). All these factors increase their vulnerability in comparison to their younger counterparts.

While it has been well-established that recovery from TBI is most rapid within the first 6 months post injury (Christensen et al., 2008; Schretlen & Shapiro, 2003), it has remained unclear whether the rate of recovery is expressed uniformly across the age span (Ashman et al., 2008). Thus it is of note, that among the current older sample, with injuries primarily at the milder end of the spectrum, that various measures of executive function and processing speed remained sensitive to the impact of TBI at 6-12 months post injury. The finding is not entirely consistent with the small body of existing research examining cognitive outcome after TBI for older patients. Among the exiting literature, cognitive deficits have been detected within three months from injury in mild older TBI cases, while by twelve months few deficits are revealed (Goldstein, & Levin, 2001; Goldstein et al., 2001; Rapoport et al., 2006). Consistent with the results of the current study, Rapoport and colleagues (2006) documented deficits at 12 months injury, using a sample that was similar in terms of both age and severity of injuries. At twelve months post injury Rapoport et al., (2006) too found deficits on measures of processing speed and semantic fluency, and additionally the Boston Naming Test (BNT; Kaplan, Goodglass & Weintraub, 1983). Poorer performance on measures of executive function in the present study was evident on a wider range of instruments than Rapoport et al., (2006), and injuries were typically milder.

Too few published studies have examined older adults at the 6-12 month time point to draw strong conclusions in either direction, and none have measured executive function in as much detail as in the current study. The study by Kliegel et al., (2004) is the only available published study of older TBI patients that targets executive function with sufficient methodological rigour. Kliegel and colleagues examined executive facets of prospective

memory performance among a severely injured older cohort, using different instruments and methods of analysis than the current study. As such their work does not relate directly to the current investigation.

The current study warrants replication and could be expanded to measure processing speed with greater rigour, and to also examine other cognitive domains in greater detail. The finding of impairment at 6-12 months departs from the non-ageing TBI literature, where impairment is typically evident within the first month and absent by three (Brooks et al., 1999; Belanger, et al., 2005; Ponsford et al., 2000; Mathias et al., 2004). Additional executive measures could be added or substituted, with the WCST being a logical choice. The WCST was not employed in the current investigation to reduce the demands made of participants, and as it has been indetified as a task older adults find unpleasant (Bryan & Luszcz, 2000a; Rhodes, 2004). It would however be informative to establish whether older TBI patients exhibit quantitatively and qualitatively different WCST performance, given the lack of impairment detected for mild younger cases by Ord, Greve, Bianchini and Aguerrevere (2010), and in light of quantitative differences for Stroop and TSC results detailed herein. The results of the current study suggest that TBI produces a negative cognitive impact more distally from injury for older adults than that demonstrated within younger TBI samples, and a differential one, at least with respect to measures of memory.

10.16 Summary and Conclusions

In line with predictions, Executive Function and Processing Speed were deleteriously impacted by TBI, while memory was spared. The results provides some evidence for at least a quantitative difference between older and younger TBI patients, given that TBI produced a deleterious cognitive impact in a longer period post-injury than that demonstrated previously within younger samples. It is also of note that TBI was disruptive to the executive function of this study's patients, despite the majority suffering only mild injuries. Issues surrounding

TBI in older adulthood will become even more exigent as our population continues to age and further research is warranted.

CHAPTER 11

General Discussion

The results of Study 1 suggest that the executive functioning of community dwelling healthy older adults remains largely intact, at least until 80 years of age. Performance on the Alternate Uses (AU) test (Guilford, Christensen, Merrifield & Wilson, 1978) was the exception. In contrast to executive function, measures of memory and information processing speed were deleteriously impacted by normal ageing. The cognitive profile exhibited by the older adults in Study 1 differed to that of the older TBI patients from Study 2. At 6-12 months post injury, patients 50 years and older, suffering TBI of mild-to-moderate severity, exhibited compromised executive function on most instruments administered within that domain, while memory was spared. What the two samples did have in common was that both normal ageing and TBI negatively impacted information processing speed.

The lack of age effects for measures of executive function in Study 1 was not predicted (see Section 9.1), and is not what the frontal ageing hypothesis of West (1996) postulates. Global factor or 'common cause' accounts of cognitive ageing (Crawford, Bryan, Luszcz, Obonsawin, & Stewart 2000; Salthouse, 1996) are at odds with the frontal ageing hypothesis (West, 1996) and the very validity of executive function as a construct in it's own right has also been questioned (Duncan, Johnson, Sawles & Freer, 1997; Salthouse, 2005). While the literature is very mixed, in review, there appeared to be evidence for executive function explaining a small but unique proportion of the variance in cognitive ageing once other variables like g and processing speed were accounted for (Bryan, & Luszcz, 2001; Ferrer-Caja et al., 2002; Levine, Stuss & Milberg, 1995). Therefore, while an age-related decrement in processing speed was expected, so too were decrements in executive function.

As age effects for executive measures were largely absent, debating the contribution of executive and non-executive processes to performance on such measures in this instance becomes largely moot. As postulated in Chapter 9, the lack of significant age group differences on executive measures in Study 1 does not relate to issues of sufficient statistical power (Kirk, 1995). It is possible that the preponderance of measure of verbal fluency may have contributed to the lack of age effects for executive function, especially given the arguments for the multifactorial rather than unitary nature of executive function (Miyake et al., 2000; Stuss, 2006). That is, emphasis on measures of verbal fluency may have too narrowly examined executive function and employing a broader array of executive measures may have revealed age-related deficits. Verbal fluency measures are said to largely rely on the hypothesised processes of 'Updating' and 'Shifting' (Fisk & Sharp, 2004; Miyake et al. 2000). Nevertheless, 'Inhibition,' Miyake et al.'s third factor, was tapped by the Stroop task and a measure of divided attention was also included. The addition of more complex measures to a battery such as Tower Tasks, the SET and WCST, as suggested in Chapter 9, would be needed to demonstrate age effects or a lack thereof on executive function with greater confidence. In the current stratified sample of older adults, executive function was preserved, even after 70 years of age, while memory and information processing suffered.

As apparent in Chapter 7's literature review, factor analytic techniques appeared to be particularly successful in detecting age effects, as per the data of Bryan and Luszcz (2000b), Ettenhofer, Hambrick and Abeles (2006), Lowe and Rabbitt (1997) and van Hooren, Valentuin, Ponds and van Boxtel (2007). If Study 1 had captured an even larger sample, allowing the use of factor analytic techniques (MacCallum, Widaman, Zhang & Hong, 1999; Tabachnick & Fidel, 2001), executive deficits may well have been evident, especially in light of age related downward trends for poorer performance when examining the mean values for the Semantic Fluency task (see Table 9.4). Alternatively, it may simple be that age related

decrements in executive function are minimal, a position with which Salthouse and Crawford would be expected to concur. Age related decline was most clearly demonstrated on the index of information processing speed, Digit Symbol-Coding. Thus, the results of Study 1 lend support to the position of Salthouse (1996; 2005) and others, that a reduction in the speed of mentation is the primary determinant of the cognitive decline observed during normal ageing.

In contrast to Study 1, Study 2 yielded positive results for executive measures, revealing the domain to be differentially sensitive to TBI in comparison with various indexes of memory. As discussed in the previous Chapter, the result was in line with predictions, and prognosticated given the pathophysiology of TBI renders the seat of executive function, the frontal lobes, particularly vulnerable (Bamdad, Ryan & Warden, 2003; McDonald, Flashman & Saykin, 2002), with older patients being even more so (Flanagan, Hibbard, Riordan & Gordon, 2006). A more difficult question is whether the significant differences that existed between TBI patients and controls were due to the executive elements of those tasks rather than non-executive ones. While techniques such as factor analysis can explore the question more fully (MacCallum, Widaman, Zhang & Hong, 1999; Tabachnick & Fidel, 2001), the issue is largely beyond the scope of the present study. Nevertheless, some results have a tentative bearing on the issue.

Correlational methods showed the dual-task to be independent of other measures in both studies, including the processing speed index, which bodes well for it's construct validity. That is, dividing attention appears to represent a distinct cognitive process, not correlated with memory or information processing. The pattern of Stroop results evident in Study 2 can be also be interpreted as giving support to that measure's construct validity. The Stroop results for TBI sufferers was suggestive of executive process being the critical determinant given that the significant differences in speed on the incongruent trial in favour

of control subjects was not accompanied by baseline difference in colour naming speed. However, group difference for the index score, which controls for the same, reached trend level only. Nevertheless, this is not damning in terms of validity as a contribution of working memory and processing speed would also be expected given the demands of the task (Bryan, & Luszcz, 2000a; Lezak et al., 2004). Executive measures by virtue of their very nature are not expected to be process pure (Rabbitt, 1997).

Overall, as shown previously in Table 10.6, among the TBI group, inter-correlations among executive measures were slightly highly than inter-correlations for the non-executive measures. It is possible that this pattern of results reflects a common executive deficit inherent with TBI although caution is warranted when interpreting the finding given the modest sample size. As differential deficits have been identified on purportedly executive measures for older TBI sufferers, additional research is needed to replicate the results and further elucidate the cognitive and pathophysiological processes underpinning them.

11.1 Further Discussion of the Alternate Uses (AU) Test

A secondary aim of the current investigation was to further examine the utility of the AU test as a measure of executive function. This was achieved principally by testing the measure's sensitivity to ageing and TBI. To date, investigations into age effects have been scant, despite the paradigm's potential to be both a sensitive and valid measure of executive function (Bryan, & Luszcz, 2000a; Butler, Rorsman, Hill & Rogerio, 1993). Published research employing the task with TBI patients is even scarcer.

The impact of Age on AU performance was significant in Study 1, with the 50-59 year old group out performing both the 60-69 year olds and the 70-79 year olds in terms of correct uses generated (see Table 9.8). That finding is consistent with earlier work by Parkin and Lawrence (1994), and by Bryan and Luszcz (2000b), documenting age related decrements. Study 2 demonstrated that the AU test was sensitive to TBI in older patients.

This was also consistent with the very limited amount of previous work conducted among TBI populations. The result extends the finding of Milders, Fuchs and Crawford (2003) who noted the AU task as being sensitive (but not statistically significantly so) to TBI using a severely injured young sample, and Crawford, Wright and Bate (1995) who noted superior sensitivity of the AU test to injury in comparison to other verbal fluency measures in a TBI sample.

Examination of the effects sizes is relevant to discussions of sensitivity and thus utility, especially given Bryan and Luszcz's (2000a) suggestion of the promise this task holds for detecting sub-clinical decrements in executive function. Particular support comes from Study 1, where the measure had the largest effect size of any of the executive measures. Further support from Study 1 is evident when contrasting the AU effect sizes with those of Digit Symbol-Coding. For comparison purposes, η^2 values are reported in Table 11.1.

Table 11.1

Effect sizes for AU Correct and Digit Symbol-Coding from the Normal Ageing cohort

	Age x Education η^2	Age x Gender η^2
AU Correct	.198	.440
Coding	.324	.328

Depending on which analyses is proffered (Age & Education or Age & Gender), it could be argued that either the AU test had the largest effect size of all measures in Study 1, or that it was second in sensitivity only to Digit Symbol-Coding. Either way, the measure was shown to be very age sensitive. Regarding the sensitivity of the task in Study 2, the Alternate Uses Test ($\eta^2 = .130$) was more sensitive to TBI than Phonemic Fluency ($\eta^2 = .100$) and Semantic Fluency ($\eta^2 = .001$), while greater values were recorded for both Telephone Search While Counting (TSC; Robertson, Ward, Ridgeway, & Nimmo-Smith, 1994; $\eta^2 = $

.213), and for Digit Symbol-Coding (η^2 = .161). The results of both studies, particularly Study 1, support the postulate of Bryan and Luszcz (2000a) and provide further evidence for the Alternate Uses paradigm as a sensitive, and thus potentially very useful, measure of executive function.

With reference to construct validity, the measure is argued to have face validity in that generating alternate uses represent a novel and ambiguous situation (Bryan, & Luszcz 2000a; Garden, Phillips & MacPherson, 2001). In terms of convergent and divergent validity, among the normal ageing population of Study 1, Correct Uses generated correlated significantly with Semantic and Phonemic Fluency, but not the Stroop, which suggests a degree of validity (see Table 9.20). However, the relationship with HVLT-R Immediate Recall and processing speed were even higher than for the two other fluency measures, which questions validity. Nevertheless, executive measures are not process pure and working memory (to monitor output and goal) and processing speed (given the task is timed) are expected to contribute. In Study 2, within the modestly sized TBI cohort, the AU task had a significant relationship with Semantic but not Phonemic Fluency and the TMT-B (see Table 11.6). The largest relationship for the AU task was between it and delayed recall of the Rey-Osterrieth Complex Figure Test (ROCFT). The pattern of results from the two studies suggests a large contribution of memory to AU performance. Further study is needed to establish the construct validity of the task and factor analytic techniques may be particularly useful to those seeking to address the issue.

Normative data and standardised procedures for the AU test are lacking. As evident when examining methodological differences presented in Table 12.2, differences in the number of trials used, the objects used for trials, and time given per trial precludes direct comparison of the scores from the current study to that of controls and other clinical groups

from within the existing literature, and between existing studies within one another. In

relation to the current studies, the exception is the work of Milders et al. (2003).

Table 11.2

Methodological differences in select studies employing the AU Test

Study	Population	Time per trial	Object(s)
Grattan & Eslinger (1989)	Mixed lesion	unknown	"Form B"
Wilson & Gilley (1992)	Parkinson's disease	5 mins	Magazine
Butler et al., (1993)	Frontal Lesions	1 min	Shoe, Pencil
Parkin & Lawrence (1994)	Normal Ageing	4 mins per group of 3 items	Pencil, Tyre, Spectacles / Shoe, Key Button
Parkin & Java (1999)	Normal Ageing	1.5 mins	x 6 unspecified
Turner (1999)	Autism	2.5 mins	Brick, Pencil, Mug, 3 x 'Junk' items
Bryan & Luszcz (2000b)	Normal Ageing	1.5 mins	Bottle, Paper Clip
Obonsawin et al., (2002)	Frontal lesions	3 mins	Brick, Bottle
Tomer, Fisher, Giladi & Aharon-Peretz (2002)	Parkinson's disease	untimed	X 5, unspecified
Milders et al., (2003)	Severe TBI	1.5 mins	Bottle, Paper Clip and Hat
Current Studies 1 & 2	Normal Ageing / TBI	1 min	Bottle, Paper Clip, Hat

The mean number of correct uses generated by young controls subjects in the Milders

et al., (2003) study is 20.9, which is very similar to the 20.1 recorded by the 50-59 year olds

in Study 1 (see Table 9.4). The severe TBI subjects ($M = 13.9$) of Milders et al., had slightly

higher scores than both the 60-69 year olds ($M = 10.5$) and the 70-79 year olds ($M = 9.3$) tested

in Study 1, potentially due to their youth, despite suffering neurological insult. The TBI

subjects from Study 2, ($M = 11.1$, see Table 10.4), performed somewhere between that of the

TBI subjects of Milders et al., and from Study 1's participants 60 years and older (see Table 9.4).

The next closest study in terms of procedure for comparison purposes with Study 1's normal ageing groups is that by Bryan and Luszcz (2000b). In that study, adults aged between 72 and 95 years ($M = 76.6$ years), generated on average 9.1 uses across two trials. While being a far from perfect method for adjusting and comparing, if the average number of uses generated by the 70-79 year olds in Study 1 ($M = 9.3$) is divided by 3 and then multiplied by 2 to correct for number of trials, the result, 6.2 uses, is lower than the aforementioned 9.1 uses recorded by Bryan and Luszcz (2000b). The subjects of Bryan and Luszcz (2000b) achieve a score in only *two* trials that Study 1's older participants achieved in *three*, despite being, if anything, older. It is unknown whether education accounts for the discrepancy between the results of Study 1 and the study by Bryan and Luszcz (2000b) as the latter effort does not report educational attainment. The difference may also be methodological in terms of instructions given as Bryan and Luszcz's (2000b) participants were encouraged to "make the uses they give as creative and different from each other as possible" (p. 485). This may have decreased ambiguity and facilitated better performance while having the trade-off of decreasing validity (see Sections 3.4 and 4.1.4 respectively for discussion of validity issues).

By way of convergent validity, Parkin and Lawrence (1994) noted an $r = .38$ between Alternate Uses and Phonemic Fluency performance after the influence of IQ was partialled out, while Obonsawin et al., (2002) recorded an $r = .47$ between Alternate Uses and Phonemic Fluency performance, which was reduced to $r = .26$ once IQ was partialled out. In the current normal ageing study, the AU test correlated with the Phonemic Fluency task at $r = .33$ and with Semantic Fluency at $r = .43$. For the TBI study, AU did not correlate significantly with Phonemic Fluency, but did with Semantic Fluency at $r = .59$ (see Tables

9.20 and 10.6 respectively). By way of divergent validity, the AU measure correlated with a wide range of non-executive measures in Study 1, but only ROCFT Delayed Recall in Study 2 ($r = .72$)

Consistent with the earlier observation by Lezak et al., (2004), standard deviations were large for both correct uses and error scores in the current data set. Given the difficult to interpret Alternate Uses error results (see Section 9.12.3), more work is needed to establish the usefulness, or lack thereof, of error data. Nonetheless, while requiring further validation, the sensitivity of the AU test to both normal ageing and TBI bodes well for the potential utility of the measure in executive function research, and possibly even clinical practice. Directions for future research are given further coverage in Section 11.3.

11.2   Strengths and Limitations of the Current Investigation

There are multiple strengths of the current investigation. The size of the normal ageing sample ($n = 100$) is a virtue, as is the fact that the majority of these individuals were recruited from a random sample of the electoral roll with a healthy response rate. The modest size of the TBI sample was a limitation. Nevertheless, work by others studying the cognitive outcome of TBI among older adults has been scant and the recruitment of such a population made an important contribution. Further, the modest sample size ($n = 20$) is not atypical within this field and power was deemed adequate (Kirk, 1995). It would have been advantageous to have been able to recruit a large enough TBI cohort to divide the patients into mild and moderate groups to allow further exploration of the impact of injury severity. It would have also been desirable to have a greater upwards age range in both studies. In actuality, an age cut-off criterion of 80 years was not set; too few individuals 80 years and older met inclusion criteria in Study 1 to merit testing.

Study 1 could be criticised for not screening for dementia with an instrument such as the MMSE. The argument is that not doing so may have harboured preclinical forms of the

dementias (Bieliasuskas, 2001; Raz, 2004). Nevertheless, participants were excluded on the basis of an existing diagnosis and the potential presence of such individuals could be argued to increase the representativeness of the sample and thus generalisability of the results. It is a design strength that TBI patients were recruited prospectively rather than symptomatically; this also increases the generalisability of the results. While it may have been possible that those with persisting problems may have been more willing to be retained in the Neurotrauma Register (NTR) study over time, or more willing to consent to the additional testing that Study 2 entailed, this is a limitation that applies to other work within this field. When studying attrition from the NTR project, Langley, Johnson, Slatyer, Skilbeck and Thomas (2010), found that severity of injury was the best predictor of retention. Such a limitation applies not just to longitudinal research, but to any study that seeks to test cognition in the non-acute phase.

Study 2 employed 'normal' controls and this could also be construed as a limitation given that it has been suggested that the use of orthopaedic controls reduces the confounding effect of hospitalisation (Larrabee, 2005; Mathias et al., 2004). Naturally recruiting such controls is not always practical. In relation to the current study, the preponderance of individuals with mild injuries which entailed shorter hospitalisation (if not simply outpatient treatment) and thus fewer concomitant physical traumas may reduce the impact of such a confound. Further, in review, Schretlen and Shapiro (2003) found little evidence for orthopaedic patients to be a more appropriate choice of controls in comparison to their uninjured counterparts. Use of an orthopaedic control group may even pose other problems, such as introducing confounds such as the presence of severe pain.

It was important and timely that the AU test received further study among the two populations investigated. The inclusion of the Semantic Fluency task in Study 1 was also important given the previous neglect of the measure in favour of Phonemic Fluency in normal

ageing and TBI research. Be that as it may, it would have been advantageous to have been able to use a broader range of measures of executive function. Adding a Figural Fluency test as an additional measure of Ideational Fluency would have been interesting for comparison purposes given the promising AU results. There would also have been merit in administering variously the WCST, Tower Tests, or subtests from the Behavioural Assessment of Dysexecutive Syndrome (BADS; Wilson, Alderman, Burgess, Emslie, & Evans, 1996), such as Zoo Maps, Action Program and the Six Elements test (SET), especially given the failure of Study 1 to demonstrate age-related decrements in executive function.

As previosuly acknowledged, it was also a limitation that processing speed was indexed with a single measure, that the TMT-B was not administered to both groups, and that National Adult Reading Test (NART; Nelson, & O'Connell, 1978) score was not the sole method of estimating premorbid IQ for both groups. As the latter two measures were already being used by the NTR study, given their relevance, they were incldued in the current study. The discordance of measures used between the samples arose as the original intention was for Study 2 to be a study of individuals in the mild stage of Alzheimer's disease, rather than one of TBI in older adults. However, despite best efforts and prior planning, individuals in the mild stages of Alzheimer's disease proved too difficult to recruit in sufficient numbers. It became necessary to recruit an alternate clinical group.

Because of the longitudinal nature of the NTR project, patients experienced repeat testing of the Phonemic Fluency task, the TMT-B, and Digit Span. This situation would not have existed in the originally devised Alzheimer's study. Nevertheless, with the exception of the TMT, practice effects would be expected to be minimal and alternate forms were utilised to reduce such effects (see Chapter 4 and Section 10.3). Further, if practice had an impact on Phonemic Fluency performance, it would have led to an underestimation of differences between TBI patients and controls, yet significant differences were still detected.

Concessions on original test selection had to be made both to reduce the demands on participants and due to the collaboration with the Menzies Institute on Study 1, which contributed the bulk of the baseline normal ageing data. The collaboration had the virtue of facilitating access to a larger and more representative sample.

11.3 Directions for Future Research

Given the equivocal state of the normal ageing literature with respect to any evidence for preferential decrements in executive function, and the failure to detect such effects in Study 1, there is little to suggest merit in repeating that study's design unless a larger sample was recruited facilitating the use of factor analytic techniques. It would be logical however, to attempt to replicate the design of Study 2 among another, ideally larger, cohort of ageing TBI patients, given the positive findings of a differential impact on measures of executive function from that study. Such a study could also seek to extend the current investigation by broadening the age range sampled in both directions, by adding additional measures of executive function, by indexing processing speed with greater rigour and by measuring additional cognitive domains. It may also prove especially informative to replicate and contrast the results with other purportedly 'frontal' clinical groups. Potential groups to use as a model for such deficits may be those with frontal lobe lesions (Stuss et al., 2002), Alzheimer's disease (Canning, Leach, Stuss, Ngo & Black, 2004), frontotemporal dementia (Mathuranath, Nestor, Berrios, Rakowicz & Hodges, 2000) or Parkinson's disease (Tomer et al., 2002). However, the selection and recruitment of clinical groups for such a purpose is predicted to be inherently challenging.

Those with discrete frontal lobe lesions can be difficult to recruit in sufficient numbers (Stuss, Milberg, Alexander, Schwartz & Macdonald, 1998). A cohort in the early stages of Alzheimer's disease proved too difficult to recruit when an attempt was made locally to include such individuals in the current investigation. The situation exists in part

due to a lack of tests adequately sensitive to the early stages of the disease (De Jager, Hogervost, Combrinck, & Budge, 2003; O'Dowd, Chalk & de Zubicaray, 2004) which compounds the difficulties identifying and then recruiting such individuals. Those in the later stages of the disease are too cognitively compromised for the purposes of the investigation envisioned. The aggressive rate of decline and only secondary emergence of cognitive deficits associated with frontotemporal dementia (Lezak et al., 2004) represent barriers. Parkinson's disease may also present an opportunity to model executive dysfunction. However, the neuropathology of Parkinson's is more subcortical in nature (Lezak et al.,) rendering the model less analogous to other frontal groups including TBI.

A potentially interesting line of enquiry arises from a finding unanticipated at the outset of the study. When comparing the results of Studies 1 and 2, and while reviewing the ageing and the TBI literature, dissociation between the sensitivity of the Phonemic Fluency task to TBI relative to the task's invariance to normal ageing was evident. The discrepancy is indeed curious. Within the normal ageing literature, the measure fails to detect reliable age differences (Bryan, & Luszcz 2000a; Troyer, Moscovitch, & Winocur, 1997). Conversely however, within the TBI literature, Phonemic Fluency is found to be one of the most sensitive measures, for both younger and older patients, and even in cases of mild injury (Aharon-Peretz et al.,1997; Goldstein et al., 2001; Raskin, & Rearick, 1996), with evidence from meta-analysis by Henry and Crawford (2004) being particularly compelling. Therefore it is surprising, to the author at least, that in all the literature reviewed herein, including reviews and commentary by Bryan and Luszcz (2000a), Lezak et al., (2004), Henry and Crawford (2004), Strauss et al., (2006) and Troyer (2000), that no other investigator has commented upon the discordant performance of these two commonly studied populations on the measure.

There is merit in attempting to establish the nature of the impaired Phonemic Fluency of TBI sufferers versus the intact nature of the task for normal ageing adults. On the one

hand, the task may not be sufficiently executive in nature to tax older adults (Bryan, & Luszcz, 2000a). However, if the non-executive aspects, such as speed of processing (the task itself is speeded), or working memory underpin the poorer performance of TBI sufferers, it would be expected that these same factors would exert a deleterious impact upon the performance of normal ageing adults; these are the same domains that were impacted by the normal ageing process in Study 1 and such decrements are well established by the ageing literature (Bieliasuskas, 2001; Park, Polk, Mikels, Taylor & Marshuetz, 2001; Raz, 2004). However, this was not the case, leading one to deduce that it is the executive demands that disadvantage TBI sufferers. Meta-analysis by Henry and Crawford (2004) certainly suggested the same when this contrasting the fluency performance of patients with measures of IQ and processing speed.

Analysis of clusters and switches (see Troyer et al., 1997; Troyer, 2000), may be one useful avenue for attempting to determine the contribution of executive aspects (particularly strategy use), and non-executive ones in comparing the two groups. Examining error data may prove less useful. Within normal populations a low incidence of errors is typically observed (Strauss et al., 2006), consistent with the results of Study 1 hence the decision not to analyse error data. Errors also occurred infrequently for the TBI patients in Study 2 and again precluded analysis. Qualitatively, TBI patients recruited by this project were not observed to make a great number of errors or to exhibit perseverative tendencies. Contrasting the performance and determinants of Phonemic Fluency between TBI sufferers and older adults should prove fertile ground for future research.

The AU paradigm also merits future study. The current pattern of results supported Bryan and Luszcz's (2000a) postulate that the AU paradigm shows promise in investigating executive function in normal ageing, and Butler and colleagues' (1993) suggestion that the task may be useful for assessing executive function in general, by virtue of sensitivity.

Future efforts could develop standardised procedures and normative bases given the lack of both. The age effects recorded by the current study warrant attempted replication. There is additional merit in extending the age range sampled in both older and younger directions, especially extending the range downwards. While this research made a contribution to doing the latter by sampling 50-59 year olds, there is scope to extend the downward age range even further as suggested Hedden and Gabrielli (2004). Doing so could help determine whether the decline observed in Study 1 in for AU performance after 59 years represented a gradual age related-decline, or more of a sharp decline past a critical age. This is a particularly pertinent research question given the apparent similitude of performance between the younger controls in the study by Milders et al., (2003) and that of the 50-59 year olds from Study 1.

There is also merit in the further testing of TBI groups on the AU task. In addition to straight replication using a lager sample, another line of enquiry could be to administer the measure to a younger TBI group of similar severity and time since injury to that of Study 2, to establish whether the measure is also sensitive to neurological insult in younger patients. This could allow more to be learnt about the interplay between pathology and normal ageing with reference to the idea of diminished cognitive reserve (Mangels, Craik, Levine, Schwartz & Stuss, 2002). The earlier discussion of testing alternate clinical groups that may provide a model of frontal dysfunction applies to future research with the AU test given the sensitivity to TBI. And while some of this work has been conducted (Butler et al., 1993, Grattan & Eslinger 1989; Obonsawin et al., 2002; Tomer et al., 2002, Wilson & Gilley 1992) standard procedures are lacking.

11.4 Summary and Conclusions

This investigation lent support to the existence of a preferential impairment of executive function post TBI in an older adult cohort. What it did not do was lend support to

West's (1996) frontal ageing hypothesis of cognitive ageing. There was not evidence for normal ageing to have a preferential impact upon executive function. Further, based on the pattern of results and review of the literature, the author has become increasingly sceptical as to whether executive function is a useful construct among non-clinical populations.

Debate rages as to whether executive function actually represents a distinct concept from *g*; with many suggesting that as a construct executive function cannot neurologically stand on its own (Duncan et al., 1997; Salthouse, 2005; Wood & Liossi, 2007). While reviewers such as Bryan and Luszcz (2000a) argue to the contrary, and suggest that insufficient sensitivity of existing instruments results in a failure to detect sub-clinical decrements in executive function, resulting in an equivocal body of literature, this author is doubtful.

Conversely, within the literature, there is no controversy as to whether executive *dysfunction* is a valid concept. The existence of *dysexecutive syndrome* led to interest in studying *executive function*, not the other way around (Baddeley, 2002). Dysexecutive syndrome represents a construct which is clearly defined and widely agreed upon (Lezak, Howieson & Loring, 2004; Chan & Manly, 2002) and is arguably the most common presenting problem in neuropsychological practice (Stuss & Levine, 2002).

The postulate that executive function may not have utility as a construct among normal populations may go some way to explain in general why executive function has proven so difficult to define, operationalise and validate. As the need to study executive function arose from a clinical, rather than a theoretical vantage point, the cart may have been put before the horse. Perhaps it is time to abandon the concept of executive function, and simply delineate the actual mechanisms underlying various aspects of cognitive performance. In this vein, lessons learned from attempts to fractionate executive functions may be of use (Miyake et al., 2000; Stuss, 2006), while the umbrella term itself may not. Perhaps Banich

(2009) will succeed in her ambitious endeavour to produce an overarching theory of executive function that will improve the situation. However, the author predicts that it is more likely that controversy and confusion will remain, leaving executive function as little more than a seldom agreed upon, poorly understood, meta-cognitive process.

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