Working Memory Efficacy and Aging

Katherine Elizabeth Sanderson

PhD

2006

Working Memory Efficacy and Aging

Katherine Elizabeth Sanderson

A thesis submitted in partial fulfilment of
the requirements of the
University of Northumbria at Newcastle
for the degree of
Doctor of Philosophy

School of Psychology and Sports Sciences
– Division of Psychology

July 2006

Abstract

The aim of this thesis is to examine the effects of age on visuo-spatial sketchpad (VSSP) slave system processes and central executive working memory processes within the context of the multicomponent working memory model originally proposed by Baddeley & Hitch (1974). Previous cognitive aging research has tended to use general measures of working memory and little evidence has examined the effects of age specifically within the context of the multicomponent model. A series of seven studies was undertaken utilising a quasi-experimental design. Data was collected from convenience samples of young and old adults for each study, using a range of tasks and measures designed to make demands on VSSP and central executive processes. Effects of age were examined independently of speed of processing and intelligence by using these as covariates in the statistical analysis. Data was analysed using a series of ANOVA and ANCOVA analyses. Findings indicated that old adults were equivalent to young adults in their performance on the VSSP slave system tasks. However they showed an impaired performance on some measures of central executive processing, but not others. In particular, older adults showed a decline in the executive processes of task switching, which cannot be explained by speed of processing; whereas other putative executive processes, such as inhibitory processes, did not show an age-related decline. Results indicated that the age-related decline in task switching at the specific switch point is only evident when the demands for active memory processing are high. An age-related decline in the ability to co-ordinate the two tasks during task switching was also evident, and this age difference was not dependent on the active memory demands. These findings suggest that there are a number of separable executive processes, not all of which decline with age. The findings are discussed in relation to models of cognitive aging and theoretical models of working memory.

Contents

List of Tables

List of Figures

Aknowledgements

I would like to thank my supervisors Dr Tom Heffernan and Dr Lynn McInnes for their support in the completion of the thesis and in particular my Director of Studies, Dr Colin Hamilton for his continued support and encouragement over the years it has taken me to complete this work. I would also like to thank my husband Mark, children Rebecca and Daniel, and parents Maureen and Les Ross for their patience and encouragement. In particular I would like to thank all of the participants who gave up their time on numerous occasions to take part in the studies; without them this work would not have been possible.

Declaration

I declare that this work has not been submitted for any other award and that it is my work alone.

Chapter 1 - Introduction

The focus of this thesis is to examine the effects of age on working memory using the three component working memory model (Baddeley & Hitch, 1974; Baddeley, 1986, 1996) and Logie's, (1995) modified working memory model as a theoretical framework. The aim being to identify age-related changes in slave system and central executive working memory processing and to investigate the pattern of these changes to develop a greater understanding of slave system and executive processing within working memory.

The view that working memory declines with age is one that has been widely discussed within the literature (Baddeley, 1986; Fisk & Warr, 1996; Park & Heddon, 2001; Phillips & Hamilton, 2001; Salthouse, 1991a). However the precise nature of these age differences remains unclear with various researchers offering differing explanations for the observed deficits. In relation to working memory and aging the majority of research suggesting a decline in working memory with age has tended to use measures of working memory general, (e.g. Hasher & Zacks, 1988; Oberauer & Kliegl, 2001; Salthouse & Babcock, 1991). Explanations for these age differences have tended to emphasize some sort of general working memory storage capacity deficit (Anderson & Craik, 2000; Foos, 1989), a general speed of processing deficit (Salthouse, 1991a, 1992a) or an inhibitory processing deficit (Hasher & Zacks, 1988; Lustig, Hasher & May, 2001). However the use of such general measures can be criticised. Firstly they do not take into account developments in the theory behind the working memory model and secondly they make it difficult to identify precisely which storage components and working memory processes are affected by age. The inconsistency in the nature and size of age effects on different working memory tasks is however difficult to explain from a general working memory position and it may be more valuable to investigate the effects of age on specific components of the working memory model.

The initial focus of the thesis is to investigate adult age differences in slave system functioning. Phillips and Hamilton (2001) summarize the current evidence for age-related changes in working memory, by suggesting that within the phonological loop there are little effects of age apart from evidence to suggest that slower articulation

rates among elderly adults may lead to impaired verbal memory; within the visuo-spatial sketchpad there is evidence to suggest that older adults are impaired on mental rotation tasks; and within the central executive there appears to be impairment on a range of tasks.

Specifically considering evidence relating to age-related differences in the visuo-spatial sketchpad the majority of studies have not taken into account Logie's (1995) updated model of visuo-spatial working memory. It is therefore difficult to draw firm conclusions about age-related deficits within specific sub components of the visuo-spatial sketchpad. Many of the tasks utilised (such as mental rotation) also utilise central executive resources (Logie & Salway, 1990) thus making it impossible to clearly identify whether the observed age effects are a consequence of impaired visuo-spatial or impaired central executive processing. There clearly remains a need for research on the effects of age within the specific sub components of the VSSP which is able to disentangle these components from the central executive. Study 1 of the thesis work is designed to address these issues by utilising tasks which separate out visual cache and inner scribe components of the VSSP. Two of the tasks have been specifically designed to minimise the demands on central executive processing with the remaining two tasks utilising some degree of executive processing alongside visual cache and inner scribe resources.

The effects of age on central executive processing have also been studied extensively, however the effects of age on the wide range of purported executive tasks has been variable and the validity of many of the tasks has been questioned (Phillips, 1997; Rabbitt, 1997) as the majority of tasks involve both central executive and non-executive processes. Difficulties in investigating the central executive and aging have also been hindered by the lack of a clear conception of the central executive component itself within the working memory model and few studies have considered the fractionation of central executive processes proposed by Baddeley (1996). There remains a need for research to examine the effects of age on components of central executive functioning; which takes into account recent developments within the central executive component of working memory and which is driven by this conceptualisation of the central executive. As a result of the findings from study 1 and in an attempt to address some of the limitations of previous research on aging and

central executive processing, studies 2 – 7 were designed to investigate the effects of age on central executive processes. To investigate the effects of age on visuo-spatial and central executive processing a quasi-experimental approach was adopted throughout the series of seven studies, which allowed the differences between young and old adults to be identified using a variety of tasks and experimental manipulations. These seven studies form the basis of the thesis discussion.

The next two chapters of the thesis will provide an introduction and background literature review to the empirical work discussed in chapters 4 – 8. Chapter 2 of the thesis reviews relevant theoretical models of working memory. Chapter 3 reviews the literature related to cognitive aging, specifically concluding with a section integrating age-related changes with working memory.

The remaining chapters will consider the empirical work undertaken as part of the doctoral process. Chapter 4 will present study 1, which investigates age-related changes in visuo-spatial working memory by examining the performance of four different age-groups (young, middle-aged, young elderly and old elderly adults) across four visuo-spatial tasks designed to make demands on a different visuo-spatial processes. Chapter 5 will discuss studies 2 and 3 which examine age-related changes in executive processing using verbal and non-verbal fluency tasks, particularly looking at the use of strategy within these tasks. Chapter 6 presents studies 4 and 5. Both of these studies investigate age-related changes in executive processes by utilising both random number generation and a non verbal random keypress procedure. A range of randomness measures are utilised throughout these studies. Chapter 7 presents studies 6 and 7, which investigate age-related changes in the executive processes of task switching, using a task switching paradigm. The conclusions from all of the studies will be discussed and synthesized in chapter 8 and the implications for cognitive aging theories and theoretical models of working memory considered. Conclusions from the studies will contribute to current understanding of how age differentially impacts upon different working memory processes and will also be useful in advancing understanding regarding the role of central executive processing on working memory functional architecture.

Chapter 2
Literature Review – Working Memory

2.1: What is working memory?

The general concept of working memory has been much debated within the literature and a common consensus on what working memory actually is, is only just beginning to emerge. There is general agreement that working memory can be described as the limited capacity system or mechanisms that are responsible for the temporary storage and processing of information that can be used during the performance of complex cognitive tasks (Richardson, 1996; Shah & Miyake, 1999). However the diverse range of working memory models that have been put forward to explain working memory performance are not agreed on a number of issues such as the distinction between working memory and short-term memory; the distinction between working memory and long-term memory; whether working memory is a unitary or non-unitary system; how working memory is controlled and regulated and what specific factors underlie the limited capacity of working memory.

Baddeley & Hitch (1974) have put forward a 3 component model of working memory that focuses on the fractionation of working memory into specialised modality specific slave system components that are controlled by the central executive. This model and its more recent revisions form the theoretical basis for this thesis and will therefore be the main focus of this chapter. Within section 2.2 of this chapter the assumptions of the working memory model will be considered in relation to other theoretical accounts of working memory and empirical evidence relating to the different models will be discussed. In this section it will be argued that there is strong evidence supporting the fractionation of working memory, which is a central feature of the Baddeley & Hitch (1974) model and its more recent revisions, which suggest that the three components in the original working memory can also be fractionated further.

2.2: Theoretical Accounts of Working Memory

A variety of theoretical accounts of working memory have been put forward (see Miyake & Shah, 1999), one of the most influential accounts being the multicomponent working memory model (Baddeley & Hitch, 1974), which emphasises the non-unitary nature of working memory, in particular distinguishing between modality specific slave systems responsible for temporary storage of information and a modality free attentional control component. This will be contrasted to the North American models such as those proposed by Cowan (1988) and Engle (1996), which emphasises the unitary nature of working memory. These models will be considered as examples of working memory accounts because of their contrasting assumptions to the multicomponent working memory model and because of the emphasis on the attentional control of memory; however it is acknowledged that other models of working memory are available within the literature.

2.2.1: The Multicomponent Working Memory Model

Early research into the fractionation of memory into different systems highlighted the dichotomy between short-term memory (STM) and long-term memory (LTM) (e.g. Atkinson & Shiffrin, 1968). STM was seen as a temporary store with a limited capacity which utilises a process of rehearsal to maintain items within the store long enough to transfer them into the more permanent limitless capacity LTM store. Atkinson & Shiffrin (1968) suggested that their STM could be considered as a working memory as it was necessary for the learning of new information, the retrieval of information from LTM and for the performance of a range of cognitive tasks. This early model was able to account for a range of empirical findings such as the serial position curve (Glanzer & Cunitz, 1966), where free recall of words in a list shows that the last few items are well remembered (recency effect) and the first few items are well remembered (primacy effect) but recall of the middle words is poor. The recency effect is abolished if recall is delayed and rehearsal prevented, whereas the primacy effect remains, indicating the existence of a durable long-term store which accounts for the primacy effect and a temporary short-term store which accounts for the recency effect.

However the concept of a unitary, modality free STM such as that proposed by Atkinson & Shiffrin, (1968) cannot account for neuropsychological evidence which demonstrates that patients with impaired STM are still able to show long-term learning and relatively normal performance on other cognitive tasks (e.g. Shallice & Warrington, 1970). Additionally experimental evidence also demonstrated that long-term learning did not necessarily depend on STM rehearsal time (Craik & Watkins, 1973).

Baddeley & Hitch (1974) investigated the concept of working memory further using a dual task paradigm. The assumption being that if working memory has a limited capacity, then having to perform a secondary task such as digit span (which utilises STM limited capacity resources) will have a devastating effect on a primary cognitive task that also utilises the same resources. However although an effect of concurrent secondary digit span task on a range of primary tasks such as learning, comprehension and reasoning was found, the size of that effect was smaller than anticipated (see Baddeley, 1986 for review). Based on these findings Baddeley & Hitch (1974) suggested that although the STM store responsible for digit span overlapped with the concept of working memory they were not equivalent. They proposed a working memory model consisting of a number of sub-systems rather than a unitary working memory (see figure 2.1).

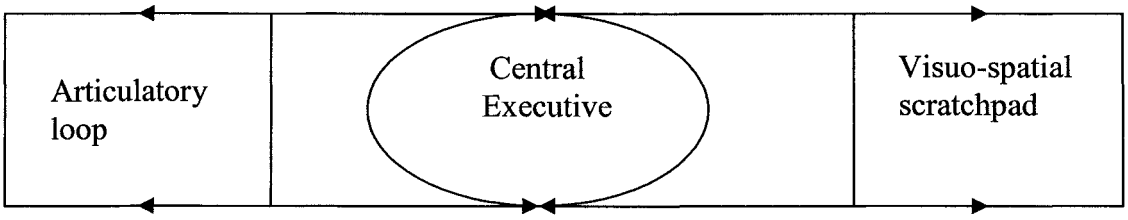


Figure 2.1: Baddeley & Hitch (1974) working memory model

The original model proposed that working memory consisted of three components. Firstly, the articulatory loop (which later became known as the phonological loop and will be referred to throughout the thesis as such) that is responsible for the maintenance of verbal or speech based information. Secondly, the visuo-spatial scratch-pad (which later became known as the visuo-spatial sketchpad and will be referred to as such throughout the thesis), which is responsible for the maintenance of

visuo-spatial information. The final component, the central executive, is seen as an attentional controller that co-ordinates and controls the two slave systems.

Empirical evidence relating to working memory comes mainly from dual task studies using healthy adults, studies looking at individual and developmental differences and neuropsychological studies using brain-damaged individuals or brain imaging techniques. The rationale behind dual task studies is that concurrent secondary tasks will show differential disruption to primary tasks dependent upon which components of working memory the two tasks rely on. For example the multi-component model would predict that a verbal task such as digit span which relies on phonological loop resources will impair performance on another task that utilises the phonological loop, but will have little impact upon tasks placing demands on the visuo-spatial sketchpad or the central executive. Whereas a unitary working memory model would predict that a secondary task will interfere with a primary task if the total limited capacity resources are exceeded regardless of the modality of the two tasks involved.

Using the dual task paradigm a number of studies have found evidence suggestive of a fractionation between the phonological loop and the visuo-spatial sketchpad (e.g. Baddeley, Grant, Wight & Thomson, 1975; Cocchini, Logie, Della Sala, McPherson & Baddeley, 2002; Farmer, Berman & Fletcher, 1986; Morris, 1987). Using a primary task of the Brooks matrix, Baddeley et al (1975) found that visual pursuit tracking disrupted memory for the visuo-spatial material but not for the verbal material, whereas Brooks (1968) found the opposite pattern with verbal interference disrupting the verbal more than the visuo-spatial material. Similar patterns of selective interference of secondary tasks have also been found by Farmer et al(1996), with articulatory suppression disrupting performance on a verbal reasoning task only and spatial suppression (a spatial tapping task) disrupting spatial reasoning only. More recently Cocchini et al (2002) have also used the dual task paradigm to illustrate that a multiple component working memory model with separate temporary visuo-spatial and verbal stores is better able to account for dual task performance by demonstrating selective interference effects between tasks. Generally unitary models of working memory (e.g. Anderson, Reder & Lebiere, 1996; Engle, Cantor & Carullo, 1992; Engle, Kane & Tuholski, 1999; Just & Carpenter, 1992) are not able to account for the findings from dual task studies.

Another method for investigating the fractionation of working memory processes is to examine the pattern of deficits within a brain-damaged population. In relation to the Baddeley & Hitch (1974) working memory model neuropsychological evidence relating to Alzheimer's patients (e.g. Baddeley, Logie, Bressi, Della Sala & Spinnler, 1986; Morris, 1986) and patients with frontal lobe damage (e.g. Baddeley, 1996; Lehto, 1996; Shallice, 1982, 1988) is of particular relevance and has been linked to an impairment in the central executive component. Performance on tests of frontal lobe or executive functioning however are not always correlated (Burgess, 1997; Lehto, 1996) which casts doubt upon the validity of the neuropsychological tests of executive functioning (Phillips, 1997) and suggests that executive functioning itself may not be unitary (Lehto, 1996). This is consistent with more recent developments in the working memory model which highlight the potential fractionation of the central executive (Baddeley, 1996). Evidence relating to central executive functioning and its fractionation will be discussed in greater depth in section 2.4, along with a consideration of the validity of measures of executive functioning.

Since the construction of the original Baddeley & Hitch (1974) working memory model empirical evidence has led to the further fractionation of the three components and to the addition of a fourth component – the episodic buffer. A revised model of the phonological loop suggests that it consists of two separate systems, a passive phonological store and an active rehearsal process (Baddeley & Lewis, 1981, Baddeley, 1986). A similar distinction within the visuo-spatial sketchpad (VSSP) has also been made. Logie (1995) argues that the VSSP can be fractionated into a passive visual cache and an active spatial rehearsal system, the inner scribe (see section 2.3). Baddeley (1996) has also suggested that the central executive may be fractionated in terms of functional processes (see section 2.4).

Early work assumed that the central executive was responsible for both the processing and storage of information (Baddeley, 1986; Baddeley & Hitch, 1974). The central executive could be used to increase the storage capacity of the slave systems, however more recently (see Baddeley, 2002; Baddeley & Logie, 1999) it has been argued that the central executive is purely an attentional system and has no storage capacity itself. Evidence supporting the separation of processing and storage functions comes from early dual tasks studies showing that performance on two demanding tasks can be combined so long as they don't utilise the same resources (e.g. Baddeley, Logie,

Bressi, Della Sala & Spinnler, 1986), and from developmental studies (e.g. Case, Kurland & Goldberg, 1982; Towse, Hitch & Hutton, 1998). More recently studies by Duff & Logie (1999, 2001) have examined whether processing and storage share the same general resources during working memory span tasks and found that a model proposing separate processing and storage components can best account for the results.

The original working memory model viewed working memory as being structurally separate from LTM and assumed that information can enter working memory either from sensory input or from LTM (Baddeley, 1986, 1992). The passage of information between working memory and LTM was seen as unidirectional. More recently the working memory model has been revised to take into account the contribution of LTM knowledge to working memory storage and processing (Baddeley, 1996; 2000; 2002; Baddeley & Logie, 1999; Logie 1995), allowing for a bidirectional exchange of information between working memory and LTM. The relationship between the central executive and LTM has also been highlighted by Baddeley (1996) who argues that one of the functions of the central executive is the temporary activation of LTM. This can then be used during complex cognitive tasks such as reading comprehension (Baddeley & Logie, 1999). However, given that the central executive has no storage capacity itself the problem remains of where the activated LTM representations are temporarily maintained and integrated with information from the slave systems to perform complex tasks. This issue has been addressed by the proposal of a fourth component, the episodic buffer, which is responsible for the integration of information between the working memory components and LTM and provides a temporary store for the integrated representation (Baddeley 2000, 2002). See figure 2.2 for revised model including the episodic buffer.

As yet very little research has been done regarding the addition of the episodic buffer to the working memory model, and further research investigating the precise nature of the link between working memory and LTM proposed by the model is required in relation to the integration of information from different sources and in relation to how separate the episodic buffer and episodic LTM are.

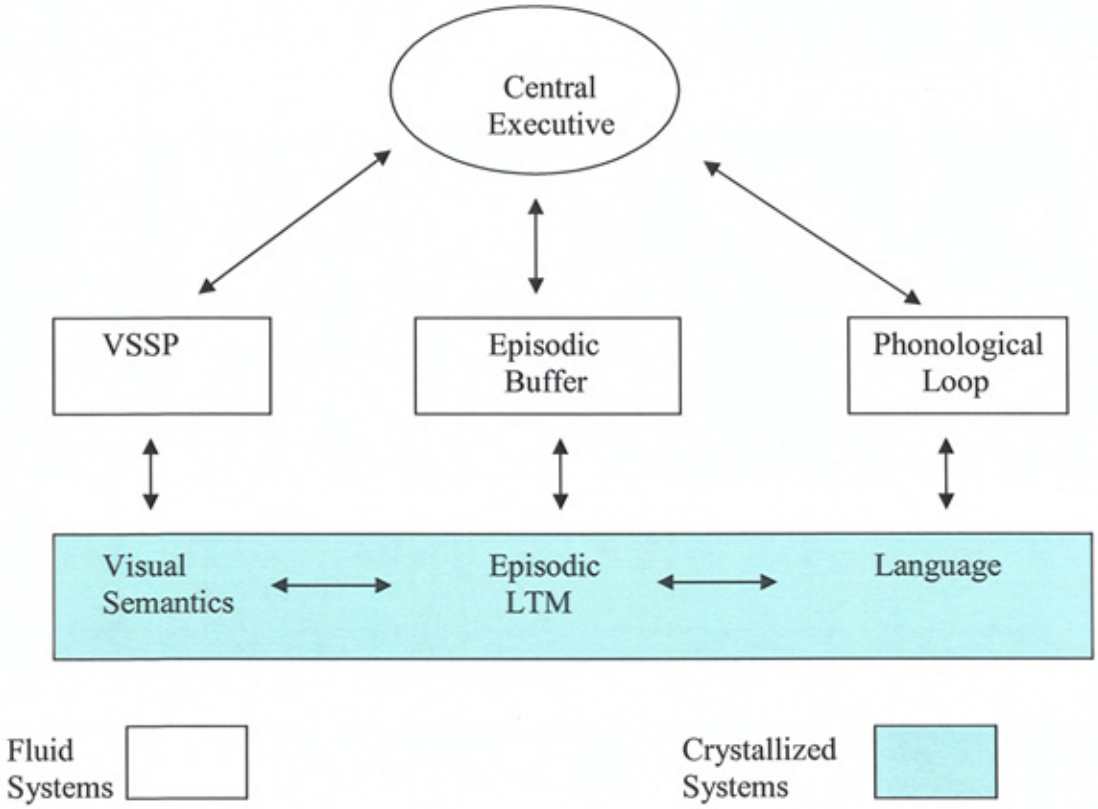


Figure 2.2: Current model of Working Memory (Baddeley, 2000)

2.2.2: Unitary / modality free account of Working Memory

An alternative approach to the dual task paradigm which is essentially designed to investigate the fractionation of working memory is to examine individual or developmental differences across working memory performance. The individual differences approach is common in the North American research which tends to emphasize the unitary nature of a general working memory. The assumption being that working memory is a general limited capacity resource which is responsible for both the storage and processing of information during complex tasks. To investigate this general resource tasks such as the reading span (Daneman & Carpenter, 1980) were developed. The reading span task requires participants to read a series of sentences and recall the last word of each sentence. Using this task Daneman & Carpenter (1980) found a high correlation between this measure of working memory span and reading comprehension suggesting that capacity differences in a general working memory resource are responsible for individual differences in reading

comprehension. Just & Carpenter (1992) explain these individual differences in working memory capacity in terms of the total amount of activation available.

The view that working memory capacity is unitary and domain free is also supported by Engle & colleagues (e.g. Engle, 1996; Engle, Kane & Tuholski, 1999a; Engle, Tuholski, Laughlin & Conway, 1999b); who argue that individual differences in working memory capacity can be explained in terms of inhibition differences. Engle (1996) suggests that individual differences in working memory span tasks are a result of differences in controlled attentional resources which are required to inhibit distracting or goal irrelevant information, not automatic activation of memory.

Although this model appears to be inconsistent with the Baddeley & Hitch (1974) model, Engle et al (1999a, 1999b) highlight the similarity between the two models by suggesting that their term 'working memory capacity' refers to only one part of a working memory system (controlled attention) which is equivalent to the central executive component of Baddeley & Hitch's (1974) working memory model. Similarly to Baddeley & Hitch (1974) they highlight that working memory capacity (or the central executive) is purely an attentional system that acts upon a short-term memory that has domain specific codes and maintenance (similar to the phonological loop and VSSP), although they do not specify the precise number or relationship between these short-term memory processes (Engle, 1999b).

2.2.3: Evaluation of Working Memory Evidence

Generally evidence from dual task studies supports a fractionated model of working memory, however differential effects of secondary suppression tasks have not always been found. Jones, Farrand, Stuart & Morris (1995) found that serial recall of locations was not only impaired by a secondary spatial task, but also by verbal suppression tasks such as articulatory suppression and irrelevant speech. They interpreted this as suggesting that verbal and spatial serial memory are not separate and that a unitary model, such as the object-oriented episodic record model (Jones 1994), can best account for their pattern of results; whereby memory for serial order for both verbal and spatial information is determined by its episodic or procedural organisation rather than by its modality. One alternative explanation for these results may be that given the requirement for the retention of serial order these tasks make

demands not just on the slave systems, but also on the central executive; and it is this demand on the modality free central executive which accounts for the lack of modality effects.

Supporting evidence for a general working memory capacity model rather than a fractionated model as discussed earlier is usually based on the correlation between working memory span measures (e.g. reading span) and working memory tasks (e.g. reading comprehension). However, as the majority of span tasks used as evidence to support this explanation of individual differences in reading comprehension are verbal it is not possible to generalise to different modalities (Engle, 1996). Although the implicit assumption of general capacity models such as Just & Carpenter (1992) is that working memory is a unitary general resource, the evidence relating to reading span and reading comprehension does not justify that assumption, because of the modality specific nature of the tasks.

Evidence that has examined the correlation between reading comprehension and other less verbal span tasks does not support the concept of a single general capacity resource and is much more consistent with a multicomponent model. Baddeley, Logie, Nimmo-Smith & Brereton (1985) investigated the correlation between reading comprehension and a similar measure to the reading span, and a counting span task. They found a high correlation between comprehension and reading span but a much smaller correlation between comprehension and the counting span. If comprehension relies on a general working memory resource which is not domain specific then similar correlations should be found with the counting span task. These results are therefore not consistent with the idea of a single general working memory resource. However Baddeley et al (1985) acknowledge that there are criticisms of the counting span task and that it may not be a valid measure of working memory span in adults. The processes involved in span tasks such as these have also been questioned by Conway & Engle (1994) and Waters & Caplan (1996) who argue that these measures reflect a number of subcomponents rather than a unitary processing and storage resource pool. It is also unclear how resources are allocated between storage and processing during these tasks.

Evidence from a developmental approach, like the views based on individual differences research, has also been used to demonstrate both the unitary and non-unitary nature of working memory. The unitary view of a general limited capacity resource pool has been highlighted by studies using complex span tasks (e.g. Case et al, 1982). In a study of 6 – 12 year old children Case et al (1982) found a linear relationship between memory capacity (measured by counting span) and processing difficulty (measured by counting speed). They argued that this was evidence of a limited capacity pool of working memory resources which could be allocated between storage and processing. Younger children with slower processing speed would use more resources counting and therefore have less resources for memory storage, thus leading to lower counting spans. However, this general resource sharing account has been criticised by Towse & Hitch (1995) and by Towse, Hitch & Hutton (1998) who argue that the results could be explained in terms of forgetting. They argue that rather than sharing resources between storage and processing children may use a task switching strategy where they switch between storage and processing. Younger children with slower processing will have a longer time for forgetting during the processing component of the task, thus leading to a lower span. This explanation is more consistent with either a serial processing strategy or with a model of working memory that has separate systems for storage and processing. To test these differential explanations Towse et al (1998) used adapted span tasks that kept the amount of processing required constant but manipulated the temporal duration over which the processing occurred. Using a similar age group to Case et al (1982) they found that varying the temporal duration had an effect on a range of span tasks (counting span, operation span and reading span) which could not be explained by a general resource model of working memory. The results can more easily be accounted for by a model that proposes separate storage and processing components.

Further developmental evidence supporting the fractionation of working memory comes from studies examining differential patterns of development in working memory tasks among children (e.g. Hamilton, Coates & Heffernan, 2003). Using tasks designed to make demands on the fractionated VSSP components, the inner scribe and visual cache, Hamilton et al (2003) found that children aged 8 – 10 years showed poorer performance than adults on tasks presumed to make demands on not only inner scribe and visual cache functions, but which also made demands on central

executive functions: whereas children and adults showed similar levels of performance on tasks that reduced demands on the central executive component. This suggests that with these particular tasks the VSSP and central executive components have different developmental patterns, with age differences in working memory being a consequence of central executive differences rather than differences in the slave systems. This differential pattern is again consistent with a fractionated model of working memory and cannot be accounted for by a general working memory resource model.

Investigating the differential patterns of age-related changes in working memory can be a useful way of examining the fractionation of working memory processes and components. The developmental studies discussed so far have considered working memory differences during childhood and between children and adults. The effects of age on working memory within an adult population have also been investigated by a number of researchers who have examined differences in working memory performance between young and old adults. Evidence relating to adult age-related differences in working memory form the essential background to this thesis work and will be discussed in depth in chapter 3.

In summary, evidence regarding the fractionation of working memory from an individual differences perspective initially seemed to support a unitary view. However, more recent developments in the individual differences approach and evidence from dual task, neurological and developmental studies seems to support some fractionation within working memory. This has been highlighted by Miyake & Shah (1999) in their review of working memory theories and they suggest that there now seems to be a general consensus that working memory is not completely unitary, although the precise nature of the sub-systems remains a topic for debate.

2.3: Visuo-spatial Working Memory

The Baddeley & Hitch (1974) working memory model proposes a separate component, the visuo-spatial sketchpad, which is responsible for the storage and processing of visuo-spatial information. In section 2.2 evidence supporting the separation between the two slave systems of the model, the phonological loop and the

VSSP was considered. This section will examine the VSSP in more detail, specifically looking at evidence relating to the nature of processing within the sketchpad and its role in the retention of visual, spatial and sequential information. The fractionation of the VSSP itself into subcomponents and the relationship between the VSSP and the central executive will also be discussed.

A variety of methods have been used to investigate the VSSP and visuo-spatial processing generally. In particular dual task methodology, developmental research and neuropsychological studies have been used as methods of investigation. Pearson, Logie & Green (1996) argue that there are two main approaches to the study of visuo-spatial working memory. One is to investigate the retention of visual and/or spatial information over time, often combined with an interference task to identify which components are involved during processing. The second is to investigate mental imagery processes themselves, i.e. the generation, maintenance, manipulation and synthesis of images to see which components are used for different aspects of imagery. The underlying assumption being that the VSSP is responsible for mental imagery as well as the retention of visual and spatial material (Baddeley, 1986).

One of the main debates that have been investigated in relation to the VSSP is whether coding within the sketchpad is visual or spatial. Early evidence for visual coding within short-term memory was found by Phillips & Christie (1977a, 1977b). Using a visual task of matrix patterns Phillips & Christie (1977a) demonstrated a visual recency effect of one pattern, which they interpreted as evidence of a short-term visual store which utilised a visual code and with a capacity for one item. However, when the gap between presentation and recall is filled with a mental arithmetic task this recency effect is eliminated, suggesting that short-term visual memory relies on general purpose executive resources rather than a specialised short-term visual store such as the VSSP (Phillips & Christie, 1977b).

More recently Logie (1986), using a dual task methodology, demonstrated that irrelevant pictures in the form of line drawings disrupts the use of a visual imagery mnemonic but has only a small effect on rote rehearsal, whereas unattended speech interferes with rote rehearsal but not the imagery mnemonic. This can be interpreted as providing evidence of a separate visual short-term store. However, the use of

irrelevant pictures within Logie's (1986) study has been criticised for changes of the drawings at regular intervals, which may place demands on general executive attentional resources by focusing attention on the change (Quinn & McConnell, 1996a). To overcome this problem Quinn & McConnell (1996a) developed a different technique for presenting irrelevant visual stimuli, called visual noise, which involved the presentation of a continuously changing pattern of dots. The assumption being that this continuous change would not focus attention and would therefore be a more valid visual interference technique. Using this task Quinn & McConnell (1996a) found that whilst regularly changing line drawings interferes with both rote rehearsal and visual imagery mnemonic, the visual noise only interferes with the visual imagery mnemonic, supporting Logie's (1986) conclusion that there is a separate store for retaining visual information which uses visual coding.

The studies discussed so far have suggested that coding within the VSSP may be visual in nature; however other early dual task studies using spatial tasks have suggested that spatial coding is utilised within the VSSP (Baddeley et al, 1975; Baddeley & Lieberman, 1980; Morris, 1987; Quinn & Ralston, 1986). Baddeley et al (1975) found that the spatial Brooks matrix task (Brooks, 1967) is disrupted by concurrent visuo-spatial tracking whereas verbal material is not disrupted by concurrent tracking. They argued that this provided strong evidence for a separate short-term visuo-spatial store; however given the nature of the tracking task (following a moving spot of light with a stylus) the results could indicate either a visual or spatial interference effect as the task has both visual and spatial aspects to it. Baddeley & Lieberman (1980) investigated the effect of a secondary spatial tracking task which eliminated the visual element of tracking, on the use of a spatial imagery mnemonic (method of loci) and a visual imagery mnemonic (peg word). They demonstrated that tracking disrupted the use of the spatial mnemonic much more than the visual mnemonic, suggesting that visuo-spatial working memory is spatial rather than visual.

2.3.1: Fractionation of the VSSP

In an attempt to reconcile the opposing findings relating to whether the VSSP is a visual or spatial system, it has been suggested that the VSSP consists of two systems, one responsible for the temporary storage of visual material and one responsible for

spatial material (e.g. Della Sala, Gray, Baddeley, Allamano & Wilson, 1999; Duff & Logie, 1999; Hecker & Mapperson, 1997; Klauer & Zhao, 2004; Logie, 1989,1995; Logie & Marchetti, 1991; Quinn & McConnell, 1996b). Logie (1995) proposes that the VSSP consists of a passive visual cache and an active inner scribe. The visual cache temporarily stores visual information, decays rapidly and is subject to interference from incoming visual material. The inner scribe temporarily stores spatial information, is involved in the planning and control of movement and can also act as an active rehearsal system to maintain information within the visual cache.

Logie & Marchetti (1991) using dual task methodology found that a primary spatial task involving the retention of the sequential order of square locations presented on a screen was disrupted by a secondary spatial task (arm movement) but not by a secondary visual task (irrelevant pictures), whereas the pattern of disruption on a primary visual task involving the retention of colour hue was the opposite with irrelevant pictures impairing performance and arm movements having no impact. They argued that this provided strong evidence for two systems within the VSSP, one responsible for retention of spatial material and one responsible for retention of visual material, thus supporting the distinction between the inner scribe and the visual cache later proposed by Logie (1995).

Further support from dual task studies for the distinction between the inner scribe and visual cache comes from Quinn & McConnell (1996b) who investigated the role of rehearsal within the inner scribe and visual cache components of the VSSP. They found that a visual task presumed to require little active rehearsal because of its dependence on well known locations (method of loci mnemonic) was disrupted by a concurrent visual task only, whereas a visual task requiring active rehearsal because of learning new material (pegword mnemonic) was disrupted by both a concurrent visual task and a concurrent spatial task. This was seen as evidence for a passive visual store and an active spatial and rehearsal system which are functionally separate. Similar differential patterns of disruption between visual and spatial interference tasks have also been found, supporting a fractionation between visual and spatial processing within the VSSP using dual task methodology on a normal healthy adult population (e.g. Della Sala et al, 1999; Duff & Logie, 1999; Hecker & Mapperson, 1997; Klauer & Zhao, 2004).

An alternative source of evidence for the fractionation of the VSSP comes from double dissociations within the neuropsychological literature, where one patient shows intact spatial processing and impaired visual processing and another shows the opposite pattern of impaired and intact processes. Farah, Hammond, Levine & Calviano (1988) report evidence from a patient L.H. who shows good performance on tasks of spatial imagery but poor performance on visual imagery tasks. This is frequently compared to a patient E.L.D. (Hanley, Pearson & Young, 1990) who shows impairment on some spatial imagery tasks but not some visual imagery tasks. However as Hanley et al (1990) argue, this patient does not really provide a double dissociation with L.H. because E.L.D. does show impairment on some visual tasks such as remembering new faces.

More recently stronger evidence demonstrating double dissociations between visual and spatial impairments has been found. Grossi, Becker, Smith & Trojano (1993) describe two Alzheimer patients, who show contrasting patterns of impairment on tasks presumed to draw on spatial resources (Corsi block) and those presumed to make demands on visual resources (pattern matrices); and Della Sala et al (1999) also report a double dissociation between brain damaged patients on Corsi block and visual pattern span tasks. These studies provide converging evidence to support the view of a fractionation between visual and spatial processing.

The study of developmental differences throughout the lifespan can also provide evidence in relation to the fractionation of the VSSP. If differential rates of development and decline are found for visual and spatial processing then this is indicative of a fractionation between the processes. Generally studies looking at the development of visuo-spatial processing in children suggest that the visual and spatial components of the VSSP may be separate. Logie & Pearson (1997) investigated memory for visual patterns and memory for sequences of movements to targets in children aged between five and twelve years. They found that visual short-term memory develops more rapidly than memory for spatial information thus supporting the concept of a separate visual cache and inner scribe.

Similar results supporting a fractionation within the VSSP have also been found by Pickering, Gathercole, Hall & Lloyd (2001). In a developmental study of children aged five to ten years which manipulated not only the visual and spatial aspects of tasks but also whether they were static or dynamic, Pickering et al (2001) found differential patterns of development with a more rapid increase in performance with age in the static visual matrix task and the static spatial maze task compared to the dynamic versions. Although these results support a fractionated model of the VSSP they suggest that this dissociation may be in relation to retention of static versus dynamic information rather than visual versus spatial. These results are equally consistent with the distributed continuum model of visuo-spatial working memory proposed by Cornoldi & Vecchi, 2000; Vecchi, Phillips & Cornoldi, 2001).

Cornoldi & Vecchi (2000) argue that variations in working memory can be explained either in terms of the type of information to be processed (e.g. verbal, visual, spatial etc) and in terms of the amount of active processing required. Different types of information can be processed separately when passive processing is required, whereas information requiring active processing will be processed together. Support for the distinction between active and passive processing within visuo-spatial working memory has been found by a number of researchers (e.g. Pickering et al, 2001; Vecchi, Monticelli, & Cornoldi, 1995). However, the operationalisation of passive and active processing is difficult as no clear definition of what constitutes a passive or active visuo-spatial task has been made (Phillips & Hamilton, 2001). Within the Pickering et al (2001) study for example it is difficult to see how the static and dynamic versions of the spatial maze task differ in relation to the degree of active processing involved. It could also be argued that as well as differing in terms of the amount of active processing the static and dynamic versions of the matrix task also differ in the retention of sequential information, which could account for the differential age pattern seen.

The Pickering et al (2001) study does however highlight a major methodological weakness in terms of the validity of tasks used as measures of visuo-spatial working memory. The main tasks used to investigate visual and spatial processing within the VSSP are tasks such as the Corsi block or sequence span tasks as measures of spatial processing and pattern span or matrix patterns as measures of visual processing.

However, these tasks vary on other dimensions as well as in terms of visual and spatial processing. Pickering et al (2001) argue that as well as varying on a visual versus spatial dimension the Corsi block and pattern span tasks also vary in terms of reliance on dynamic versus static processing. A dissociation between these tasks cannot therefore be used as sound evidence to support a dissociation between visual and spatial components. These tasks, along with some of the secondary tasks used, such as spatial tracking, spatial tapping and irrelevant pictures can also be criticised for making demands on the central executive component of working memory (Morris, 1987; McConnell & Quinn, 1996; Smyth & Pelky, 1992), and for confounding spatial location with sequential order (Della Sala et al, 1999; Jones et al, 1995; Quinn & McConnell, 1996a). The validity of the Corsi block task in particular has been questioned (see Birch, Krikorian & Huha, 1998 for review).

A similar criticism has also been made of the tasks used in the Logie & Pearson (1997) study, that both the visual and spatial span tasks used are likely to make extensive demands on the central executive component of working memory as well as the visual cache and inner scribe (Hamilton, Coates & Heffernan, 2003). In a developmental study examining the contribution of working memory components to visual and spatial span measures, Hamilton et al (2003) found that both the visual span task and spatial span tasks used were disrupted by speech articulation (presumed to disrupt phonological loop processes), spatial tapping (presumed to disrupt inner scribe processes) and verbal fluency (presumed to disrupt central executive processes), but not by visual masking (presumed to disrupt visual cache processes). These results were interpreted as indicating the complex nature of visual and spatial span tasks and highlight their dependence on the different working memory components.

2.3.2: Relationship between the central executive and VSSP

Given these criticisms of the tasks used to measure visuo-spatial processing it is likely that some of the visual and/or spatial processes initially believed to be the responsibility of a specialised visuo-spatial short-term store such as the VSSP may rely more on general purpose or central executive resources. The role of general purpose or executive resources in visuo-spatial processing has been investigated by a number of researchers who have demonstrated the involvement of executive processes

within what have traditionally been considered visuo-spatial working memory tasks (e.g. Bruyer & Scailquin, 1998; Logie, Zucco & Baddeley, 1990; Morris, 1987; Pearson, Logie & Gilhooly, 1999; Salway & Logie, 1995; Smyth & Pelky, 1992).

In a dual task study using visual span and letter span as the primary tasks and secondary interference tasks designed to interfere with either verbal, visuo-spatial or general purpose resources, Logie, Zucco & Baddeley (1990) found a differential interference effect between the verbal and visuo-spatial secondary tasks, whereas the executive task (mental arithmetic) disrupted both visual and letter span tasks. The degree of disruption in the visual span task from mental arithmetic however was much smaller than the disruption of the letter span task. This was seen as evidence for separable specialised verbal and visuo-spatial stores with some input from a general purpose central executive for dual task performance. Similar results have been found by Salway & Logie (1995) and Pearson et al (1996) using different tasks.

2.4: The Central Executive

The initial working memory model proposed the central executive (CE) as an attentional controller, responsible for allocating resources to the two slave systems (Baddeley, 1986: Baddeley & Hitch, 1974) and was thought to have both storage and processing functions (Baddeley, 1986; Baddeley & Logie, 1999). It was conceptualised as being similar to the supervisory attentional system (SAS) in the Norman & Shallice (1980) model of attentional control. Norman & Shallice (1980) suggest that action is controlled by schemata which are automatically initiated by external events or stimuli. These automatic schemata however may run into conflict and they propose two mechanisms for controlling and prioritising the schemata. Firstly, contention scheduling, a semi-automatic process which can give priority to one particular schemata depending on environmental cues and priorities, and secondly, an overall limited capacity control process, the SAS which is under voluntary, conscious control. The SAS is thought to be utilised under the following circumstances: when planning or decision making; for troubleshooting, when dealing with novel or poorly learned sequences of behaviour; in dangerous or technically difficult situations; or when it is necessary to overcome habitual or over-learned responses (Burgess, 1997; Norman & Shallice, 1980). Baddeley (1986) suggests that

this model can account for a number of empirical findings such as highly skilled performance (e.g. Allport, Antonis & Reynolds, 1972), slips of action (e.g. Reason, 1979), random generation data (Baddeley, 1966) and patterns of deficits in patients with frontal lobe damage (e.g. Luria, 1969); and equates the central executive with the SAS.

The functions of the central executive have been investigated using a variety of methods and tasks that are assumed to make demands on executive processes; these can be split into three main approaches. Firstly, the neuropsychological approach which examines the patterns of deficits in executive functioning among patients with frontal lobe damage. Secondly, the individual differences approach which predominantly looks at differences in executive processes in relation to individual differences in general abilities such as intelligence; and thirdly, the experimental approach which has utilised dual task methodology to investigate executive functioning. Findings from these approaches have suggested a number of different executive functions, such as the co-ordination of dual task performance (e.g. Baddeley, 1996; Della Sala, Baddeley, Papagno & Spinnler, 1995); the inhibition of irrelevant or distracting information or responses (e.g. Collette, Van der Linden & Salmon, 1999; Hasher & Zacks, 1988); switching attention between tasks (e.g. Baddeley, 1996; Miyake, Friedman, Emerson, Witzki, Howerter & Wager, 2000); strategic retrieval from LTM (e.g. Baddeley, 1996; Burgess, 1997); the manipulation and integration of information (e.g. Bruyer & Scailquin, 1998; Emerson, Miyake & Rettinger, 1999); and the monitoring and updating of information held in working memory (e.g. Miyake et al, 2000; Morris & Jones, 1990). However although it is generally agreed that executive function consists of a number of control processes that are effortful and under conscious control, such as those mentioned above, there is less agreement on precisely what can be defined as an executive process (Phillips, 1997).

2.4.1: Unitary or Fractionated Central Executive?

One of the main issues investigated in relation to executive processing is whether these functions are the responsibility of a single, unitary executive controller or whether they are separable processes. Early research based on studies of patients with frontal lobe damage assumed that executive processing is a unitary system which resides within the frontal lobes (Duncan, 1986; Luria, 1980; Shallice, 1982, 1988;

Stuss & Benson, 1986) and studies using such patients found evidence of impaired executive processing using a range of tests such as the Wisconsin Card Sorting Test (WCST), verbal fluency and Tower of London which are assumed to measure executive or 'frontal' functioning (e.g. Della Sala, Gray, Spinnler & Trivelli, 1998). However, there have also been a number of studies which have tested patients with and without frontal lobe damage on batteries of traditional executive tasks, which have found patterns of results that are inconsistent with the view that these tests draw upon a single executive system that is impaired in patients with frontal lobe damage (e.g. Duncan, Johnson, Swales & Freer, 1997).

Della Sala et al (1998) examined the performance of frontal lobe patients on a battery of five traditional executive tasks and five non-executive tasks. They found that the average correlation among frontal tests was higher than the average correlation between frontal and non-frontal tests and factor analysis indicated that the factor associated with the frontal tests could account for 53% of the variation in scores. They argued that this provided evidence for the existence of a single concept of executive functioning which is mediated by the frontal lobes. However, there are a number of problems with the interpretation of results by Della Sala et al (1998). Although the average correlation between frontal lobe tests was reasonable (median 0.495), the range of correlations between individual pairs of tasks ranged from 0.15 to 0.77 suggesting that whilst some tasks were strongly related, the association between others was weak, suggesting that not all tasks made demands on a common resource to the same extent. This variation between individual executive tasks may also be interpreted as indicating either that there is a fractionation between different executive functions or that not all of the tasks are valid and pure measures of executive functioning. The issue relating to task impurity and the validity of executive measures will be considered in detail in the assessment of executive processes section, however given the ambiguity of the results this study does not provide clear evidence of a unitary executive processing system.

In a similar study of frontal lobe patients using a range of executive and non-executive tasks, Duncan, Johnson, Swales and Freer (1997) found low correlations among conventional executive tasks, which were no higher than the correlations between executive and non-executive tasks. The common element that these tasks did

share appeared to be related to either general intelligence or what they term goal neglect. These results suggest that there is no single, unitary executive process underlying performance on the traditional executive tasks; a conclusion that has also been drawn by Burgess & Shallice (1996), Collete, Van der Linden & Salmon (1999) and Lehto (1996). Lehto (1996), using a normal healthy population of 15 and 16 year olds, and Collete et al (1999) using Alzheimer's disease patients, tested performance on a range of traditional executive measures adapted from the neuropsychological tests and found evidence for a fractionation of executive processes. Lehto (1996) found no correlation between the different executive measures used and Collete et al (1999) found evidence of executive tasks loading onto two separable factors; one being inhibition and the other being co-ordination, with different anatomical areas being associated with the two separable executive components.

Burgess & Shallice (1996) investigated the performance of patients with frontal lobe lesions, non-frontal lobe lesions and controls with no lesions on the initiation and inhibition conditions of the Hayling test. They found that whilst frontal patients showed impaired performance on both versions of the test there was no correlation between the initiation and inhibition versions, suggesting that these two executive processes can be dissociated.

The results from these studies are all consistent with the notion of a fractionated central executive. The fractionation of executive processes within the central executive component of working memory has also been highlighted by Baddeley (1996) and Baddeley & Logie (1999). Baddeley (1996) identifies four functions of the central executive that may be separable: the ability to co-ordinate performance on two or more tasks; the ability to focus attention by inhibiting distracting stimuli; the ability to switch attention and the retrieval of information from long-term memory.

The dual task paradigm has also been used extensively to investigate the co-ordination of performance on two simultaneous tasks and has been a useful method for identifying the fractionation of the central executive from other components of working memory and the role of the central executive within specific tasks. A number of studies using Alzheimer's disease (AD) patients have demonstrated that compared to controls, AD patients show impaired dual task performance even when

single task performance is matched (Baddeley, Bressi, Della Sala, Logie & Spinnler, 1991; Baddeley et al, 1986; Della Sala, Baddeley, Papagno & Spinnler, 1995; Greene, Hodges & Baddeley, 1995). This has been interpreted of evidence of a central executive deficit in the ability to co-ordinate two tasks simultaneously.

However, although studies such as this demonstrate that this co-ordination ability is a central executive function, they say little about other potential executive functions and the fractionation of the central executive. More recently a dual task study comparing frontal lobe patients with dysexecutive syndrome to frontal lobe patients without dysexecutive syndrome, on dual tasks performance and two other executive tasks (verbal fluency and WCST) found that whilst both groups showed similar impairment on verbal fluency and WCST, the dysexecutive group showed much greater impairment than the non-dysexecutive group on dual task performance (Baddeley, Della Sala, Papagno & Spinnler, 1997). This can be interpreted as indicating either that the dual task is a more valid measure of executive functioning than WCST or verbal fluency, or that the tasks all make demands on different central executive functions, thus supporting a fractionated model of the central executive.

An alternative approach to the investigation of executive functioning is the individual differences approach discussed in section 2.2. This approach considers working memory in general to be a unitary concept: however, Engle (1999a, 1999b) has suggested that this view of a general working memory roughly equates with the central executive component of the Baddeley & Hitch (1974) model. Individual differences studies have tended to concentrate on one executive function to the exclusion of others and account for individual differences in terms of either activation (e.g. Just & Carpenter, 1992) or inhibition (e.g. Engle, 1996; Hasher & Zacks, 1988).

However, more recently one individual difference study has suggested that executive functions may be separable (Miyake et al, 2000). They examined the separability of three executive functions – set shifting, updating and monitoring, and inhibition of prepotent responses. Using confirmatory factor analysis and structural equation modelling they examined the relationship between the three proposed executive processes and between the three functions and performance on a number of conventional executive tasks. Miyake et al (2000) found that the three functions,

although related, were clearly separable and that they contributed differentially to performance on the different executive tasks; thus suggesting that executive processes can be fractionated.

Considering the range of evidence relating to executive functioning it is generally accepted that there are likely to be a number of separable executive functions (see Baddeley & Logie, 1999). However, the precise nature of these functions and how they relate to each other remains a current topic for investigation.

2.4.2: Assessment of executive processes

Early research on executive processing focused on the relationship between executive processing and the frontal lobes; the assumption being that the terms 'frontal' and 'executive' are synonymous. This is apparent within the neuropsychological literature (e.g. Baddeley, Della Sala, Gray, Papagno & Spinnler, 1997; Luria, 1980; Shallice, 1982). However there are a number of problems both with the assumption that the frontal lobes are the anatomical location for executive functioning and with the use of traditional 'frontal' or 'executive' tasks (Baddeley, 1986; 2002; Phillips, 1997; Rabbitt, 1997).

The localisation of executive functioning to the frontal lobes has been questioned on a number of grounds. Firstly, despite the advances of imaging techniques it remains difficult to pinpoint exactly what areas of brain damage individual patients have (Baddeley, 1986). Thus, it makes it difficult to select a patient population which have clearly identified areas of damage within the frontal lobes. Patients used within many of the studies have either ill defined areas of damage or diffuse brain damage, making it difficult to draw firm conclusions as to the precise anatomical region associated with specific cognitive deficits. Secondly, a number of studies have also found that not all patients with frontal lobe damage show impaired executive functioning and some patients show impaired executive functioning who have intact frontal lobes (Baddeley & Della Sala, 1996; Foster, Black, Buck & Bronskill, 1997; Reitan & Wolfson, 1994). Based on these problems with the localisation of function it has been suggested by Baddeley & Wilson (1988) that it is better to consider the observed deficit in patients as a 'dysexecutive syndrome' rather than a 'frontal lobe syndrome'.

The conventional tasks used to assess executive functioning have also been criticised for lacking reliability and validity and for being impure measures of executive functioning. Rabbitt (1997) argues that this stems from an inadequate definition of what constitutes executive processing and how this can be distinguished from non-executive processing. The problem of defining executive processing also highlighted by Burgess (1997) and Phillips (1997) is a major issue in the development of reliable and valid executive tasks and needs to take into account current findings regarding the possible fractionation of executive functions. Traditional neuropsychological tasks such as the Tower of London and WCST are likely to rely on a number of different executive processes and this may well account for the lack of correlations found between them in the studies discussed previously. They are also likely be impure measures in that they make demands on other non-executive processes, thus leading to poor construct validity (Rabbitt, 1997). Studies 2 – 7 make use of fluency tasks, random generation tasks and the task switching paradigm as measures of executive functioning. The validity of these tasks as measures of executive processes will therefore be considered in further detail later in this section.

An alternative method to the investigation of executive functioning is the dual task methodology, where a primary task is performed simultaneously with a secondary task presumed to utlise central executive capacity. The secondary task will impair performance on the primary task if both make heavy demands on the central executive. A common task used as a central executive interference task is random generation (Baddeley, 1986; Baddeley, Emslie, Kolodny & Duncan, 1998). This approach has the advantage of being able to separate out executive from non-executive processes through the use of concurrent visuo-spatial and verbal tasks. However, the value of the approach depends on the validity of the secondary tasks used and the demands that the secondary tasks makes on different working memory components needs to be clearly understood. Another problem with the dual task methodology is that strategy use may vary between individuals, so that some participants will allocate resources equally, whereas others may allocate more resources to one or other of the two tasks. It is therefore important to use a dual task measure that takes performance on both tasks into account (Baddeley et al, 1997).

Verbal Fluency

Verbal Fluency has been used to investigate the executive function of retrieval of information from long-term memory. Verbal fluency tasks involve the retrieval and generation of as many words as possible from long-term memory according to a given cue and within a set time period (e.g. the Controlled Oral Word Association Test, Benton, 1968; Spreen & Benton, 1969). The two most common versions of the task are letter fluency (generation of words starting with a given letter) and semantic fluency (generation of words from a given semantic category). More recently a third type of verbal fluency task, excluded letter fluency, has been developed which requires the generation of words that do not include a given letter (Bryan, Luszcz & Crawford, 1997).

Traditionally, verbal fluency has been considered to be a measure of executive or frontal functioning (Baddeley et al, 1997; Baldo & Shimamura, 1998; Benton, 1968). Evidence for this comes from studies that have shown a deficit in verbal fluency performance in a variety of patient populations with frontal lobe lesions; such as Alzheimer's disease and Huntington's disease (Lezak, 1995; Monsch, Bondi, Butters, Paulsen, Salmon, Brugger & Swenson, 1994; Sherman & Massmen, 1999). However, the validity of verbal fluency tasks as measures of executive processing have been questioned (Phillips, 1997) as fluency tasks have also been used as measures of speed of processing and intelligence (McCrae, Arenberg & Costa, 1987), and it is now generally accepted that there are a number of different executive and non executive processes underlying verbal fluency performance (Hughes & Bryan, 2002; Phillips, 1997, 1999; Rende, Ramsberger & Miyake, 2002; Troyer, Moscovitch & Winocur, 1997).

Considering the role of executive processes in verbal fluency it has been suggested that letter fluency but not semantic fluency relies on executive processes (Rosen, 1980). Rosen (1980) suggests that category fluency utilises non-executive retrieval processes because it is non-effortful, relying on the retrieval of semantic knowledge in the same way as everyday life, whereas letter fluency makes demands on executive processes of strategic retrieval search and performance monitoring because words are not stored in semantic LTM on the basis of their initial letter. This is consistent with the distinctions between executive and non-executive retrieval made by Burgess

(1997) and Moscovitch (1995) and suggests that letter fluency but not category fluency can be considered a valid measure of executive processing.

The dual task paradigm has been used to demonstrate that letter and category fluency make demands upon different processes (e.g. Martin, Wiggs, Lalonde & Mack, 1994; Phillips, 1997; Rende, Ramsberger & Miyake, 2002). The pattern of interference found by Martin et al (1994) suggests that letter fluency places greater demands upon executive strategic search processes, whereas category fluency places greater demands upon semantic knowledge. However, Rende et al (2001) found that both letter and category fluency made extensive demands on the central executive component of working memory, but that category fluency also made demands on the VSSPand letter on the phonological loop, demonstrating the multifaceted nature of fluency tasks. However, the conclusions from this study are limited by the demands of the secondary tasks used. Cube comparison which was used to disrupt VSSP functioning is also likely to make demands on the central executive processes of mental rotation, making it difficult to draw firm conclusions. Both the Martin et al (1994) and Rende et al (2002) study can also be criticised for not taking the influence of verbal intelligence and speed of processing into account which have both been shown to be related to verbal fluency performance.

One dual task study, which has investigated central executive processing in letter fluency, whilst also taking into account the effects of intelligence, is that by Phillips (1997). Phillips (1997) used secondary random generation tasks to disrupt central executive processing concurrently with letter and figural fluency, a non verbal fluency measure, (see section 5.6 for discussion of non-verbal fluency measures) in a sample of adults split into either high or low IQ groups according to their scores on a measure of intelligence. Results indicated a non-significant effect of random generation on letter fluency in both low and high intelligence groups, suggesting that letter fluency does not make demands on the same executive processes as random generation.

Although Phillips (1997) interpreted the results from this study as indicating that letter fluency does not make demands on effortful executive retrieval strategies, an alternative explanation may be that, given the possible fractionation of the central executive, the executive processes used for strategies retrieval from LTM may be

separable from the executive processes utilised during random generation, and that these separable executive processes may be differentially affected by age. This fractionation of executive processes is one explanation for the inconsistency in findings on the interference effects of tasks that make demands on central executive processes on verbal fluency measures and highlights the need for research on verbal fluency that takes the fractionated model of the central executive into account.

Given the multifactorial nature of fluency tasks it has been argued that the number of words generated may not be the most useful measure of fluency performance to demonstrate the underlying processes involved in fluency performance (Abwender, Swan, Bowerman & Connolly, 2001; Rende et al, 2002; Troyer et al, 1997). The use of qualitative measures for strategy use during verbal fluency, in particular clustering and switching of strategies has been suggested by the authors as being of greater value for elucidating the processes underlying fluency performance.

Two measures of fluency performance (clustering and switching) which examine strategy use have been developed by Troyer et al (1997). Clustering is the production of words within semantic or phonemic subcategories and switching is the shifting from one subcategory to a new subcategory (Troyer et al, 1997). It has been suggested that clustering is likely to rely on relatively automatic processes of retrieval from LTM, whereas switching relies on strategic search processes to find new clusters, and therefore is considered to be an effortful executive process (Hughes & Bryan, 2002; Troyer, 2000; Troyer et al, 1997). A number of studies have found that both switching and clustering are related to category fluency performance, whereas only switching is related to letter fluency performance (Robert, Lafont, Medecin, Berthet, Thauby, Baudu & Darcourt, 1998; Troyer et al, 1997), thus supporting the view that letter fluency places greater reliance on executive processes of strategic search, whereas category fluency relies on both automatic retrieval and executive search strategies.

An alternative method of calculating switches between retrieval strategies has been suggested by Abwender et al (2001) which separates out executively mediated strategic switches between two clusters (which they call cluster switches) and non executive switches between clustered and non-clustered single words, or between two

nonclustered single words (which they call hard switches). Abwender et al (2001) also distinguish between different types of clustering, task consistent clustering, which is the production of phonemic clusters on letter fluency and semantic clusters on category fluency; and tasks discrepant clusters which is the production of semantic clusters on letter fluency and phonemic clusters on category fluency. Phonemic clusters are groups of consecutive words that either rhyme or have the same second phoneme. Semantic clusters are groups of words that belong to the same semantic category. The interpretation of the processes underlying these measures of fluency performance and how they relate to letter and category fluency performance is complex. However, Abwender et al (2001) suggest that a deliberate strategic approach which utilises executive resources is likely to be represented by the task discrepant clusters and cluster switching, as these measures will require voluntary controlled strategic retrieval and voluntary controlled switching between strategies. Hard switching may be more related to speed of processing and task consistent clusters more dependant upon automatic non-executive retrieval. They conclude however, that further research regarding these measures of verbal fluency performance needs to be done to clarify their underlying cognitive processes.

Random generation

It has been suggested that random generation tasks place heavy demands on a number of executive processes (Baddeley et al, 1998; Towse & Valentine, 1997). Random generation requires the production of sequences of items such as letters, digits or key presses in a random order and is assumed to make heavy demands on the central executive component of working memory (Baddeley, 1986; Towse, 1998; Van der Linden, Beerten & Pesenti, 1998).

Randomisation performance has been shown to decline as the response speed is increased (Azouvi, Jokic, Van der Linden, Marlier & Bussel, 1996; Baddeley, Emslie, Kolodny & Duncan, 1998; Okura & Ikuta, 1987, cited in Brugger, 1997; Robertson, Hazelwood & Rawson, 1996; Spatt & Goldenberg, 1993; Towse, 1998; Wiegersma, 1984). Baddeley (1986) explains this as indicating that random generation reflects a limited capacity information processing system such as the central executive. During random generation the central executive is presumed to act as a monitoring device, which intervenes to prevent the production of stereotyped responses, as the response

rate is increased the system has less time to control the responses leading to a deterioration in randomness. However, this explanation cannot account for the effect of set size on random generation.

Random generation has also been shown to vary depending on the number of potential responses, with randomness generally decreasing as the set size increases (see Brugger, 1997 for review). One explanation for this is that random generation relies on STM processes (Tune, 1964). Spatt & Goldenberg (1993) argue that in set sizes of 10 or less it should be fairly easy to monitor single items and maintain an even distribution, because this number of items can be maintained within working memory for monitoring of responses. It is more difficult to monitor the distribution of pairs of items because there are too many pair possibilities to maintain and monitor in working memory. This was demonstrated by Spatt & Goldenberg (1993) in a comparison of human random generation and computer random generation, and by Warren & Morin (1965) who found that the more alternatives there were to choose from the higher the redundancy in responses. It is likely that the ability to maintain and monitor response will rely on both passive phonological loop resources and active monitoring and updating executive resources.

Towse (1998) have examined the influence of memory processes on random generation further. They found that randomness under oral production conditions decreased with set size and speed, whereas with key press production and oral production where the potential response set is visible, there was no change with set size and speed manipulations supporting the influence of memory processes on oral random generation performance. However, results from this study provide conflicting evidence for the influence of memory. Memory for responses was either stable or higher with larger set sizes and under dual task conditions an inhibitory load reduced randomness more than a memory load, these results are not consistent with a purely memory based hypothesis. Towse (1998) concluded that random generation relied on a number of processes: the capacity to generate candidate items; memory for previous choices; and the ability to inhibit responses that are primed by preceding choices.

The generation of potential candidate items has also been highlighted as an important process in random generation by Towse (1998). During random generation there is a

tendency to produce items using well-learned schemata, e.g. counting forwards or backwards, reciting the alphabet etc, and the central executive has to constantly override these to generate items randomly. In neuropsychological conditions that affect executive processes this ability to override the well-learned schemata and generate items randomly is impaired leading to the generation of stereotyped responses. This has been demonstrated in a range of conditions, e.g. brain injury (Spatt & Goldenberg, 1993); Alzheimer's disease (Brugger, Monsch, Salmon & Butters, 1996); Korsakov's syndrome (Pollux, Wester & de Haan, 1995).

Baddeley et al (1998) support the idea that random generation performance involves a number of processes. They argue that random generation must involve both the capacity to activate retrieval strategies to generate items and the capacity to inhibit recently generated items (automatic inhibition) and recently used schemata (inhibition under active control). The executive ability to switch retrieval strategies in order to avoid stereotypical responses is therefore seen as an important determinant of performance. However, these conclusions have to be questioned as they are based on the study of key press random generation. Baddeley (1996) and Baddeley et al (1998) argue that key press random generation is equivalent to the more traditional oral random generation, as they have found similar declines in performance on the key press task in terms of declines in randomness at faster rates. No changes in randomness under key press conditions were found by Towse (1998), leading them to conclude that key press random generation was not equivalent to oral generation.

Towse (1998) investigated the effects of both set size and response speed on random generation under both oral and keypress conditions. An effect of set size was found for oral but not keypress random generation, which was attributed to the requirement to internally generate potential responses during oral generation. Increasing the set size increases the difficulty of representing candidate responses. This conclusion was further supported by the finding that providing an external cue of visually presenting the response choices during oral generation eliminated the effect of set size. An alternative explanation for the different findings with keypress generation is that they could be due to methodological differences. Towse (1998) used a single finger key press technique whereas Baddeley et al (1998) used all fingers. The co-ordination of all fingers during the Baddeley et al (1998) task could make the task more demanding.

At present it remains unclear whether the key press random generation task can be considered equivalent to the oral random generation task both in terms of difficulty and the underlying processes that it utilizes.

One criticism of the random generation task as a measure of central executive processing is that the criteria for measuring randomness are inadequate (Wagenaar, 1972). The problem of measurement of randomness has been discussed by a number of researchers and subsequently a variety of measures of randomness have been developed (see Towse & Neil, 1998, for review). It is impossible to measure the concept of randomness therefore the alternative non-randomness (the extent to which a pattern or order can be identified) has to be tested. As there are a variety of different ways to order a sequence of numbers or letters it is therefore important to have a number of different measures of randomness.

One of the most common measures of randomness is the RNG index. The RNG index is a measure of sequential response bias identified by Evans (1978) which examines the distribution of response pairs or digrams. It looks at how often one response follows any other response and is presumed to reflect the limited capacity of the central executive. A similar measure conceptually is the null-score quotient (NSQ). Guttman's (1967) NSQ measure indicates the number of digram possibilities that the participant does not use and is therefore structureally related to the RNG measure (Towse & Neil, (1998). It is also presumed to be a general measure of randomness reflecting the limited capacity central executive.

Other measures of randomness have also been developed which are presumed to measure more specific aspects of random generation. One such is the redundancy measure (R), which examines the frequency of response alternatives generated and compares that to the selection of responses with equal frequency. Coupon is a measure developed by Ginsburg & Karpiuk (1994) which measures the mean number of responses produced before all the response alternatives are given. It looks at the specific strategy of cycling (working through the set of all possible responses). Sequences where a strategy of cycling is used will produce a low coupon score. Both of these measures look at the equality of response usage, i.e. are all possible responses used with equal frequency. Adjacency (A) measures a specific type of stereotyped

score, i.e. the proportion of adjacent items from an ordinal sequence, rather than all possible response pairings as in the RNG index.

Other measures of randomness look at the variability of strategies, for example the runs measure identified by Ginsburg & Karpiuk (1994). The runs measure describes the variability in interval length between two turning points. It is measured as the variance of ascending sequence lengths. A high runs score indicates greater variation in the length of ascending sequences. A second example of this type of measure is the turning point index (TPI) reported by Kendall (1976), which looks at the number of turning points made (changes from ascending to descending sequences, compared to a theoretically determined ideal number of turning points).

Towse (1998) suggests that different measures of randomness are sensitive to different task constraints and place demands on different underlying executive and non-executive task processes. The RNG index (Evans, 1978) which is a measure of sequential response bias is sensitive to both set size and speed; redundancy as a measure of monitoring capacity is sensitive to set size but not speed; and adjacency, presumed to reflect the capacity to inhibit the generation of items from over-learned schemata, is sensitive to speed but not set size. This differential response of the various measures of randomness suggests that random generation relies on a number of different processes, both central executive and non-executive processes.

Towse & Neil (1998) suggest that measures of randomness such as repetition gap, REPAIRS and some phi index measures, which measure response repetition avoidance, are likely to rely on non-executive automatic inhibition processes as they are unaffected by task variations such as set size, speed of response or modality. Measures such as redundancy and the coupon measures, which look at the equality of response usage are likely to reflect the working memory capacity to monitor responses; and measures such as adjacency, turning point index and runs are likely to reflect the central executive functions of inhibiting stereotypical responses and switching of retrieval strategies; whereas general measures such as RNG and NSQ are likely to provide overall measures of random generation which are influenced by a number of different processes (Towse & Neil, 1998). As random generation clearly makes demands on a variety of aspects of central executive and non-executive

processing, investigating the different variables that influence random generation performance on a variety of measures of randomness is likely to be a useful method for discovering more about the processes involved in central executive control.

Task Switching

One experimental paradigm which may provide a purer and more valid measure of the central executive process of task switching is the task switching paradigm, originally developed by Jersild (1927). During a typical task switching experiment participants are required to repeatedly perform simple cognitive tasks (non-switch or pure task block) and to continuously alternate between two simple tasks (switch block), or to switch to a second task following a set number of repetitions of an initial task (block where switch and non-switch trials can occur). Response time is usually greater for switch trials than for non-switch trials and this additional response time on switch trials is known as the switch time cost. The increase in response time is presumed to be a direct measure of executive control processes that are necessary for the voluntary control of performance when switching from one task to another. Similarly to other experimental tasks, which are used in the investigation of executive control processes, task switching performance is dependent on both higher level control processes which implement the shift and lower level task processes (Meiran, 1996). However, by comparing performance on pure task blocks where the simple task is performed repeatedly, with performance on alternating task blocks, where two tasks are switched alternately, it is possible to isolate the executive control processes in the form of the switch cost. Task switching therefore would seem to provide a much purer and more valid measure of executive processes than the more traditional executive tasks, which cannot separate task processes from executive processes.

Various theoretical accounts of the underlying processes responsible for switch costs have been put forward. These can be separated into those which emphasize the role of some sort of executive control process, in the form of either active preparation or reconfiguration of the task set (Jersild, 1927; Spector & Biederman, 1976; Rogers & Monsell, 1995; Meiran, 1996) or inhibitory processes (Arbuthnott & Frank, 2000; Mayr & Keele, 2000); and those which suggest that switch costs may not represent executive control processes (Allport, Styles & Hsieh, 1994).

Early research by Jersild (1927) and Spector & Biederman (1976) suggested that switch costs could be accounted for by the time taken for an anticipatory executive control process that is responsible for identifying and setting up the processing system for the relevant task. They interpreted their results in relation to models of executive control. However, Allport et al (1994) challenge this view, they argue that results from their research found no evidence of the involvement of an endogenous advance preparation control process in task switching, and suggested that switch costs could be better explained in terms of proactive interference from preceding tasks. Allport et al (1994) argued that switch costs reflect proactive interference from competing S-R mappings for the same stimuli from previous trials with different task set instructions. They called this task-set inertia (TSI). It consists of persisting facilitation of previously task relevant S-R mappings and persisting suppression of previously competing (but now relevant) mappings, which results in negative priming of the current task and competition priming of the no-longer-relevant task (Allport & Wylie, 2000). The TSI hypothesis implies that as the previous tasks' S-R mappings remain partially active for some time then interference will dissipate gradually and switch costs will occur even after long response-stimulus intervals (RSIs) which they demonstrate in their experiments. This result they argue is strong evidence for the existence of TSI and is inconsistent with executive control accounts of switch costs, which would predict that long RSIs would allow sufficient time for active preparation to occur before the presentation of the next stimulus and therefore switch costs would be eliminated.

Although passive interference may play a part in the increased time costs when switching between tasks it seems likely that it cannot fully account for all switch costs. Evidence suggests that other processes (in particular executive endogenous control processes that can be used to prepare for a task switch in advance) also play a role in task switching performance (Meiran, 1996, 2000; Rogers & Monsell, 1995). These accounts do not suggest that advance preparation can fully account for switch costs but argue that it forms one component of the time cost that is under intentional control. Whilst the work by Allport & colleagues support the view that switch costs occur as a consequence of non-executive passive processes, the work by Meiran (1996) and Rogers & Monsell (1995) support the view that switch costs make

demands on the central executive, in terms of the voluntary control for advance preparation.

Rogers & Monsell (1995) argue that task switching has two components. Firstly, an endogenous process which involves active preparation in the form of reconfiguration for the next task, this reconfiguration process can be carried out in advance of the stimulus presentation and is under voluntary, intentional control; it can be attributed to executive processing. Secondly, an exogenous process, which consists of an automatic stimulus triggered preparation where the stimuli themselves evoke task-sets associated with them without any intentional control.

To investigate the reconfiguration process Rogers & Monsell (1995) developed the alternating runs paradigm which consists of mixed blocks of trials containing both non-switch and switch trials to avoid differences in memory load, arousal, effort and motivation, which can occur in comparisons between pure and alternating blocks. Throughout their series of experiments participants were required to switch tasks on every second task (e.g. AABBAABB...). Although results from Roger & Monsell's (1995) study appear to indicate that the time cost associated with task switching can be at least partly attributable to an advance reconfiguration process, there are a number of criticisms of the study which cast doubt on the validity of the results. Whilst Roger & Monsell (1995) argue that the reduced switch cost associated with long RSI's demonstrate an advance reconfiguration process, it could also be argued that this pattern of results is consistent with the task-set inertia hypothesis proposed by Allport et al (1994). A long RSI will allow greater time for passive interference to dissipate, which would also have the same effect of reducing the switch costs, making these results equivocal (Meiran, 1996). Meiran (1996) also criticises the use of blocking RSI predictably, suggesting that other processes such as predicting target onset could account for the RSI effects found by Rogers & Monsell (1995).

Evidence for the role of advance reconfiguration during task switching from Roger & Monsell's (1995) study is mixed, with some results being equally well explained by both advance reconfiguration and passive interference or negative priming processes, and some results being inconsistent with a model purely of passive interference. However, additional research from other studies (Mayr & Kliegl, 2000; Meiran, 1996,

2000; Rubinstein, Meyer & Evans, 2001), provide much stronger evidence for the role of executive advance preparation processes during task switching.

Meiran (1996) used a task-cueing paradigm to investigate whether executive processes are utilised during task switching. Like Rogers & Monsell (1995), Meiran (1996) compared switch and no switch trials within a mixed block. However, Meiran (1996) ordered the tasks randomly. A switch trial was classified as one where the current task differed from the previous task, and a no-switch trial was classified as one where the current and preceding tasks were the same. Each trial was preceded by an instructional cue. By holding the RSI constant and manipulating the timing of the instructional cue within that time Meiran (1996) was able to vary the length of time available for advance preparation (cue-target interval), whilst holding the length of time over which passive interference could occur constant. This would avoid the problem of confounding advance preparation time with the time available for passive decay of the previous trial that Roger & Monsell's (1995) study had.

Meiran (1996, experiments 2 & 3) found that switch cost was reduced when the CTI was long compared to when it was short. This is consistent with the utilisation of an advance preparation process, which is able to reconfigure the task-set before the next task stimulus is presented. The results are not consistent with a passive interference explanation, which would predict no change in switch costs, as the RSI remained constant. Like Rogers & Monsell (1995), Meiran (1996) found that switch costs were not completely eliminated by advance preparation, merely reduced. A residual cost remains that cannot be accounted for by advance reconfiguration, suggesting that task switch costs reflect at least two separable processes.

In an attempt to reconcile the two accounts of switch costs and explain the mixed findings discussed so far, Meiran (2000) and Meiran, Chorev & Sapir (2000) proposed a model that accounts for switch costs in terms of three dissociable components. Firstly, a waiting component, which involves the passive dissipation of the previous task set, and is reflected by the effects of the response cue interval (RCI) on switch costs. Secondly, the preparation of the new task set, which is reflected in the effects of the CTI on switch costs, and thirdly, a residual component which reflects the remaining switch cost that is not affected by either the RCI or the CTI.

Supporting evidence for the dissociation between the preparatory component and the residual component comes from a study by Meiran (2000) using a univalent / bivalent manipulation for both target stimuli and responses. The dissociation between the two components is supported by the differential effects of stimulus and response valency on the two components of switch cost. Further support for the three component model is also provided by Meiran, Chorev & Sapir (2000) who demonstrated the differential existence of the passive interference component and the preparatory component by manipulating RSI and CTI times using the task cuing paradigm.

Although it has been suggested that the cued task switching paradigm is able to separate out the time available for passive dissipation and advance preparation and has been the basis for the development of the three component model (Meiran, 1996; Meiran et al, 2000), it has recently been demonstrated that explicit task cuing may not necessarily make demands upon the executive processes of endogenous control during task switching. Logan & Bundesen (2003) have demonstrated that within an explicit cuing paradigm, switch costs can be better explained in terms of a time benefit on repetition trials rather than a time cost on switch trials. This suggests that the task-cuing paradigm may not be a valid measure of central executive control processes during task switching. However, their remains a need for further research to clarify the role of central executive processing in both the alternating runs and task cuing paradigms used to investigate task switching.

The research discussed so far suggests that switch costs may reflect, at least partly, the time taken for advance reconfiguration of the new task-set which relies upon executive processes of voluntary control. It is also clear from the literature that task switching is likely to makes demands on both executive processes, such as advance preparation, and non-executive processes, such as passive dissipation of the previous response set, as well as having a residual component which has not as yet been adequately explained. Task switching therefore may be a useful tool for investigating central executive processing.

2.5: Summary

This chapter has provided an overview of the theoretical and empirical evidence relating to the concept of working memory. Two main approaches to working memory can be identified; firstly, those that emphasize a unitary working memory that is limited by the overall processing and storage capacity available; and secondly, those that emphasize a multi-component working memory with separable processing and storage components, the most influential of these being the Baddeley & Hitch (1974) model. Evidence relating to working memory strongly supports the multi-component model and recently there is a general consensus that working memory can be fractionated into separate components. However, the precise number and function of these components remains debateable. Developments within the Baddeley & Hitch (1974) model suggest that both the two slave systems and the central executive originally proposed can be fractionated further (Baddeley, 1986, 1996) and this revised working memory model will form the theoretical framework for this thesis.

Developments relating to the VSSP suggest that there are two separable components – the visual cache and the inner scribe. However, the role of these sub-components within the processing of visuo-spatial information remains unclear. One reason for this is that the majority of tasks used to investigate the VSSP can be criticised for not clearly identifying which of these sub-components they make demands on, and for also making demands on the central executive component, making it difficult to separate out the function of each component. Future research relating to the VSSP therefore needs to utilise tasks that clearly identify the specific component that they measure.

A similar problem is also evident in relation to the tasks used to investigate the central executive. The evidence discussed has highlighted a number of executive functions; however, the fractionation of these functions and the difference between executive and non-executive functions remains unclear. One reason for this is the lack of valid and reliable tasks that measure executive functioning. There clearly remains a need for research which uses tasks that are able to separate out the contribution of executive and non-executive processes and which can differentially measure the separate executive processes.

One promising approach which may be useful to investigate both the central executive and VSSP components is to examine developmental fractionation. Studies looking at the differential rates of development in children and adults can highlight the separability of processes and components within working memory and may be a useful tool in developing an understanding of the working memory processes. Within the adult aging literature a number of researchers have considered age differences in working memory and these will be the focus of the next chapter.

Chapter 3

Literature Review - Working Memory and Aging

3.1: Introduction

Although it is generally accepted that memory declines with increasing age (Kausler, 1994; Park, Smith, Lautenschlager, Earles, Frieske, Zwahr & Gaines, 1996; Salthouse, 1991b) it is evident from research that whilst some aspects of memory decline others remain stable throughout adulthood (Balota, O'Dolan & Duchek, 2000; Botwinick, 1977; Craik, 1983; Phillips & Hamilton, 2001). The rate of change and age at which change occurs is also variable (Hess & Blanchard-Fields, 1996; Raz, 2000). Theoretical explanations for these age-related changes in memory have also varied, with three main accounts being evident within the literature; reduced speed of processing, impaired inhibitory processing and reduced resource capacity. These explanations have been used to account for age-related changes not only in memory but also in a range of cognitive tasks. This chapter is primarily concerned with age-related changes in working memory. However, as the explanations for age differences within working memory tend to be theoretical accounts of cognitive aging effects in general, evidence relating to other aspects of cognitive aging will also be discussed.

The speed of processing approach argues that age-related changes in memory are a consequence of general cognitive slowing (Cerella, 1985; Salthouse, 1996). A decreased efficiency in inhibitory processing has also been used to explain age-differences in working memory (Hasher & Zacks, 1988; Hasher, Zacks & May, 1999; May, Hasher & Kane, 1999), the argument being that older adults will be more susceptible to interference from irrelevant information within working memory. An alternative account for age-differences in memory is that of a reduced processing resource capacity (Anderson, Craik, Naveh-Benjamin, 1998; Craik & Byrd, 1982; Craik & Jennings, 1992; Park & Heddon, 2001; Salthouse & Babcock, 1991). These explanations all account for age-differences in terms of some sort of general purpose resource, albeit speed of processing, inhibition or working memory. However, these accounts do not take into account the multicomponent working memory model devised by Baddeley & Hitch, (1974) and its later revisions. This chapter will

consider the three main theoretical explanations of age-related changes in working memory and cognition, and will also look at the evidence relating to the multicomponent working memory model. It will be argued that using the multicomponent working memory model as a framework for investigating age-related changes in cognitive performance may be a more useful approach to understanding the pattern of age-related changes in cognitive performance, and will also be a useful tool to investigating the fractionation of working memory.

3.2: Speed of Processing

Salthouse (1996) argues that age-related variation on all cognitive tasks can be explained by the rate at which cognitive processing occurs. Older adults generally have a slower speed of processing and this leads to impaired cognitive performance compared to young adults on a range of tasks. There is a wide range of evidence that older adults have a slower speed of processing than young adults (e.g. Brinley, 1965; Cerella, 1985, 1990; Fisk & Warr, 1996; Madden, 1984, 1989; Salthouse, 1982, 1991a, 1992b, 1996). A number of studies have investigated the influence of speed of processing on age-related changes in cognitive performance. Experimental manipulation of speed of processing is difficult (Salthouse, 1991b) and results do not always support the cognitive slowing hypothesis, rather they suggest that differential strategy use is more important than speed of processing differences (e.g. Craik & Rabinowitz, 1985).

Stronger support for the speed of processing explanation for age-related cognitive declines comes from studies looking at the association between age and cognitive performance, before and after controlling for speed of processing (Finkel & Pedersen, 2000; Hertzog, 1989; Horn, 1982; Lindenberger, Mayr & Kliegl, 1993; Salthouse, 1991b; Salthouse, Kausler & Saults, 1988; Schaie, 1989; Zimprich & Martin, 2002). Whilst all of these studies have found evidence that speed of processing can account for some of the adult age differences on a range of cognitive tasks the amount of variance explained is variable. Finkel & Pedersen (2000), Hertzog (1989) and Schaie (1989) have all found that controlling for speed of processing removed over 90% of the age-related variance in cognitive performance. Whereas, Horn (1982) found only

53%, and Salthouse et al (1988) between 13% – 32% of age-related variance could be explained by speed of processing, depending on the cognitive task.

Whilst the majority of these studies have used large samples with a wide range of ages to demonstrate an association between speed of processing and age-related cognitive performance across a range of tasks, the differential amount of age-related variation explained by speed of processing is difficult to account for from a general cognitive slowing perspective. These differential findings suggest that whilst age-related slowing may be responsible for a decline in performance on some tasks, other factors may also play a part in determining the effects of age on cognitive task performance. This view is supported by studies looking at the contribution of processing speed alongside other explanations for age differences in cognitive performance (Keys & White, 2000; Schretlan, Pearlson, Anthony, Aylward, Augustine, Davis & Barta, 2000; Stankov, 1999). Studies comparing different explanations for adult age differences in cognitive performance will be discussed in section 3.6.

A number of studies have looked specifically at the relationship between speed of processing and working memory in explaining age-related declines in cognitive performance (Fisk & Warr, 1996; Salthouse, 1991b, 1992b, 1994; Salthouse & Babcock, 1991). Salthouse & Babcock (1991) investigated age-related changes in working memory function and found that working memory as measured by complex span measures declines with age and that this age-related decline is mediated by storage capacity, processing efficiency, co-ordination effectiveness and speed of processing; with speed of processing showing the greatest attenuation effect. This attenuation of age-related variance in working memory by speed of processing has also been shown to remain even under self-paced conditions, which minimise the speeded component of the working memory span measures (Salthouse, 1992b). Further supporting evidence for the mediation of age-related working memory reductions by speed of processing comes from Salthouse (1991b), who demonstrated that whilst age-related declines in working memory could account for age differences in performance on cognitive tasks, these working memory age-differences were greatly reduced by statistically controlling for speed of processing.

Although these studies suggest that age-related differences in working memory and other cognitive tasks can be accounted for by reduced processing speed, the conclusions can be questioned because of limitations in the validity of the tasks used to measure both speed of processing and working memory. The concept of processing speed has been measured using a variety of tasks. However, these tasks can be criticised for relying on other processes such as perceptual and motor speed, as well as speed of processing (Salthouse, 1991a). If all processing speed measures represent the same construct then it would be expected that different measures of processing speed would be highly correlated. However, the amount of shared variance among speed of processing tasks is generally low (Madden, 1989; Salthouse, 1988) suggesting that either there are several independent speed factors, or that each measure is influenced not only by a common speed of processing factor, but also by specific task factors (Hertzog, 1989; Salthouse, 1985, Salthouse, 1991a).These problems with the validity of tasks used to measure speed of processing means that conclusions relating to the effects of processing speed using these measures are limited.

These studies can also be criticised for only using general working memory measures such as reading and computational span. The limitations of these tasks in being unable to separate out storage and processing components (see section 3.4) means that it is not possible to examine the effects of processing speed on age-related changes in specific components of the multicomponent model of working memory from these studies. Salthouse (1994) discusses evidence relating to the different components of the working memory model (Salthouse, Kausler & Saults, 1988, relating to the verbal and spatial components; Salthouse, Rogan & Prill, 1984, relating to the central executive component) and argues that because the age-related variance is common across all components, then the Baddeley & Hitch (1974) working memory model is not useful for differentiating the source of age-related effects in working memory, and that there is likely to be a common factor underlying the age differences within the different components. However, as the studies were not specifically designed within a working memory framework the conclusions that can be drawn from them is limited. Further evidence comparing speed of processing and working memory component accounts of adult age differences will be discussed in section 3.6.

3.3: Inhibitory Processing

An alternative account to speed of processing suggests that a reduced efficiency in inhibitory processes is responsible for age differences in cognitive performance (Hamm & Hasher, 1992; Hasher & Zacks, 1988; Hasher, Zaks & May, 1999; May, Hasher & Kane, 1999; McDowd & Shaw, 2000). Hasher & Zacks (1988) argue that reduced inhibition in older adults will result in irrelevant information entering working memory and staying there for longer, leading to poorer performance on recall of target information. It is not the capacity or size of working memory that limits performance, but how well the contents of working memory represent the goals of the current tasks (Stoltzfus, Hasher & Zacks, 1996). Hasher & Zacks (1988) used this inhibitory explanation to account for adult age differences in working memory and reading comprehension.

A number of studies using reading comprehension tasks involving garden path sentences have demonstrated age differences in inhibitory processes (Hamm & Hasher, 1992; Hartman & Hasher, 1991; Hasher, Quig and May, 1997). Further support for the inhibitory account of adult age differences comes from studies showing that older adults not only maintain irrelevant information for longer in working memory, but that they are also distracted by this information when reading text (Carlson, Hasher, Zacks & Connelly, 1995; Connelly, Hasher & Zacks, 1991).

An alternative approach which has frequently been used to investigate the effects of age on inhibitory processing is the negative priming paradigm (McDowd, 2001). Negative priming is the slowing in response time to a target that has been a distracter on a previous trial. It is presumed to be a consequence of inhibitory processing of the distracter from the previous trial, with the efficiency of the inhibitory processing being indicated by the slowed response on the current trial. A number of studies have demonstrated that older adults showed either no effect of negative priming or a reduced negative priming effect compared to young adults (Hasher, Stoltzfus, Zacks, & Rypma, 1991; Kane, Hasher, Stoltzfus, Zacks & Connelly, 1994; McDowd & Oseas-Kreger, 1991; Tipper, 1991) which is interpreted as a reduced ability to inhibit distracting information among older adults.

However, support from negative priming studies for an inhibitory explanation of adult age differences is not always clear cut, with some studies finding no age differences in negative priming (Grant & Dagenbach, 2000; Kramer, Humphrey, Larish, Logan & Strayer, 1994; Schooler, Neumann, Caplan & Roberts, 1997) and some finding that age differences are present or absent depending on the specific task procedures (Connelly & Hasher, 1993; Kane, May, Hasher, Rahhal & Stoltzfus, 1997; McDowd & Filion, 1995). These differences make it difficult to draw firm conclusions about the effects of age on inhibitory processing and conclusions are further limited by the criticism that negative priming may not always measure inhibitory processes (Neill & Valdes, 1992). Neill & Valdes (1992) argue that rather than reflecting inhibitory processes, negative priming may be a measure of the automatic retrieval of the prior processing episode. The processes underlying negative priming is currently still debated (Grant & Dagenbach, 2000; Neill & Valdes, 1996) and future research will need to take into consideration the validity of tasks used to measure inhibition.

One explanation that may account for the inconsistency in age effects on negative priming is that there may be separable inhibitory processes, only some of which may be affected by age. This view is supported by a study examining negative priming of identity and spatial location information (Connelly & Hasher, 1993), which found that whilst both older and younger adults showed a negative priming effect for spatial location information, only younger adults demonstrated negative priming for target identity. A similar distinction between the effects of age on identity and location inhibition has also been made by McDowd & Filion (1995) & Kane et al (1997). Using a range of tasks presumed to make demands on inhibitory processing, Kramer et al (1994), also found support for the notion of separable inhibitory processes. However, their results do not support the separation between identity and location inhibition, as no age-differences were found in identity negative priming or response compatability tasks, which would be expected. Kramer et al (1994) argue that their results are more consistent with a model of frontal lobe aging effects (see section 3.5) in inhibitory processing, with age differences being found in the WCST and the stop signal task, both of which have previously been linked to frontal lobe functioning.

Although the pattern of age-related deficits is different from those found in the studies discussed previously they do suggest that inhibition is not a single construct but that

there are likely to be multiple inhibitory mechanisms, only some of which decline with age. Recently Hasher, Zacks & May (1999) and Hasher, Tonev, Lustig & Zacks (2001) have also suggested that there are separable inhibitory functions. They propose 3 inhibitory functions which operate sequentially to control the contents of working memory: firstly, inhibition of irrelevant or marginally relevant information to prevent it entering working memory; secondly, the inhibition or deletion of information within working memory when it becomes irrelevant; and thirdly, the inhibition of prepotent or habitual responses triggered by familiar cues. Although it is clear that there are likely to be separable inhibitory processes that are differentially affected by age, there is no firm empirical evidence as yet regarding the precise nature of these mechanisms. Future research, investigating the pattern of age-related changes on a range of tasks that make demands on inhibitory processes, will be useful to clarify the nature of inhibitory functioning and the role of different inhibitory processes within working memory.

The original inhibitory explanation (Hasher & Zacks, 1988) for adult age differences and the modified one proposed by Hasher et al (1999), emphasize the role of inhibitory processes within working memory, through the examination of reading comprehension and aging. A number of studies have examined the link between working memory and inhibitory processes more specifically by looking at the effects of interference within working memory. May, Hasher & Kane (1999) and Lustig, Hasher & May (2001) have found that older adults reduced working memory span scores can be accounted for by a greater susceptibility to proactive interference, which is assumed to indicate a reduced ability to inhibit distracting information within working memory.

Although there are a number of studies which demonstrate the age-related effects of inhibitory processing on working memory performance, the conclusion that a reduced efficiency in inhibition is responsible for age-related declines in working memory can be criticised for not taking into account speed of processing differences. The majority of the studies discussed so far do not control for age-related speed of processing differences and therefore cannot rule out the contribution of speed of processing to any effects observed. This criticism has also been highlighted by Salthouse & Meinz (1995) and Shilling, Chetwynd & Rabbitt (2002). Salthouse & Meinz (1995)

investigated the relationship between inhibition, speed of processing and working memory using various Stroop like tasks as measures of inhibition. They found that although the age-related variance in working memory performance was substantially reduced when Stroop performance was controlled for, the measures of inhibition were not independent of speed of processing, with a large amount of shared variance being evident. Salthouse & Meinz (1995) concluded that inhibition as measured by Stroop performance does not mediate age differences in working memory as these effects are not independent of age-related effects of speed of processing. However, considering the notion of separable inhibitory processes it could be argued that tasks which make demands on different inhibitory processes to those measured by Stroop tasks, may not be related to speed of processing and may be able to uniquely account for a proportion of age differences in working memory performance. Similar conclusions have also been highlighted by Shilling et al (2002) who found that age differences in inhibitory processes are not independent of more general influences such as intelligence and speed of processing. The same criticism however, can be levelled at the Shilling et al (2002) study, that inhibition was only measured by Stroop tasks and therefore does not take into account other inhibitory processes that may be measured with a wider range of tasks.

One study that has looked at inhibitory processes using a wider range of tasks is Earles, Connor, Frieske, Park, Smith & Zwahr (1997) who examined the relationship between age, inhibition, interference, speed of processing and working memory. Earles et al (1997) used negative priming, Stroop and reading distraction tasks as measures of inhibitory processing and interference. They found that almost all age differences in both interference and inhibition were mediated by speed of processing, and that interference but not inhibition mediated some age-related variance in working memory, providing much stronger support for the view that age-related inhibitory differences can be accounted for almost completely by speed of processing differences.

The conclusion from the studies discussed so far, is that age-related differences in inhibitory processes share a large proportion of their variance with speed of processing and therefore, do not uniquely contribute to age differences in working memory. However Christ, White, Mandernach & Keys (2001) in a lifespan study of

inhibitory processing found that whilst age-related inhibitory differences between children and young adults could be accounted for by speed of processing differences, speed of processing could not account for all of the variation between young and old adults in inhibitory processing. However, like some of the previous studies Christ et al (2001) can be criticised for only using a Stroop like task to measure inhibition, which does not take into consideration the separability of inhibitory processes.

Although there is strong evidence for age differences in some tasks presumed to make demands on inhibitory processes, further research is necessary to clarify the separabilty of inhibitory mechanisms and the effects of inhibitory processing on working memory performance, independent of general cognitive influences such as speed of processing and intelligence. Further research will also need to take into account the effects of inhibition on different components of the multicomponent model of working memory, as most research has only considered working memory as a general storage and processing capacity.

3.4: Resource Capacity

Another theoretical account of cognitive aging is that older adults have a reduced processing resource capacity, which has generally been conceptualised as a reduction in working memory resources. This reduction in processing capacity with age means that older adults have fewer resources available to them and therefore, performance on a range of working memory and cognitive tasks will be impaired (Cherry & Park, 1993; Craik & Byrd, 1982; Dobbs & Rule, 1989; Foos, 1995; Salthouse, Mitchell, Skovronek & Babcock, 1989). Evidence supporting this view comes from studies investigating the task complexity effect and studies using working memory span tasks.

One such study is that by Salthouse et al (1989). Using both a verbal task (verbal reasoning) and a spatial task (spatial paper folding) Salthouse et al (1989) demonstrated that older adults show a greater impairment in performance with increasing task complexity than young adults, for both of the tasks. This was interpreted as evidence for older adults having a single reduced processing resource which was insufficient to cope with increasing task demands as the task complexity

increased. However, Salthouse et al (1989) also found that whilst statistically controlling for a measure of working memory (computational span) attenuated the age differences on the verbal and spatial tasks, it did not eliminate the age differences, suggesting that a reduced processing resource is not the only factor responsible for the age differences, other factors must also be important.

Although studies such as this, provide support for the reduced processing resource account of adult age differences, conclusions are limited because of the lack of a clear definition of the concept of processing resource (Balota, Dolan & Duchek, 2000; Foos, 1995; Salthouse, 1990). The concept of processing resource has been viewed as either a general attentional resource pool (Craik & Byrd, 1982; Anderson, Craik & Neaveh-Benjamin, 1998) or as a general working memory resource (Park & Heddon, 2001; Salthouse, 1990). From a working memory perspective the use of working memory span measures has led to a lack of clarity of the source of the age differences, with some authors arguing that age-related impairments are a consequence of reduced processing efficiency, some reduced storage capacity and others, a reduced ability to co-ordinate storage and processing (Brebion, Smith & Ehrlich, 1997; Foos, 1995).

Age-related reductions in attentional capacity have been argued to impair older adults on tasks that require a lot of attention demanding processes such as during encoding and retrieval (Craik, 1983, 1986; Craik & Byrd, 1982). Support for this view comes from studies demonstrating that older adults are more impaired by a secondary task during encoding and retrieval than young adults (Anderson et al, 1998) and studies investigating the effects of environmental support. If environmental support for retrieval is poor, then demanding, self initiated, attentional processes will be required which will rapidly deplete older adults reduced attentional resources (Hasher, Tonev, Lustig & Zacks, 2001). A number of studies have shown that tasks which require self initiated retrieval processes show greater age differences, than tasks which have environmental support for retrieval (Anderson et al, 1998; Craik, 1986; Craik & McDowd, 1987; Humphrey & Kramer, 1999). The attentional capacity view of adult age differences however, is very difficult to distinguish from the working memory view of processing resources (Balota et al, 2000; Park & Heddon, 2001) and attentionally demanding self initiated tasks have also been linked to central executive processing within the multimodal working memory model (Baddeley, 1986; 1996).

A number of studies have highlighted an age-related decline in processing efficiency as the cause of adult age differences in working memory tasks (Dobbs & Rule, 1989; Gick, Craik & Morris, 1988; Morris, Gick & Craik, 1988; Salthouse & Babcock, 1991), by demonstrating that age differences are greatest when processing demands are high. Dobbs & Rule (1989) found age differences on working memory span tasks requiring active processing but not passive storage tasks; similarly, Gick et al (1988) found age differences in length of time to verify sentences on a sentence span task, particularly for complex grammatical sentences, but no age differences for passive word recall. These studies suggest that whilst age has a detrimental effect on the ability to actively process information it has no or little effect on passive storage. Other studies however, have found either no effect of age on the processing component of working memory tasks (Babcock & Salthouse, 1990; Salthouse, Babcock & Shaw, 1991), or equivalent effects of age on both processing and storage (Babcock & Salthouse, 1990). Other studies have suggested that it is passive storage that is affected by age rather than processing (Foos, 1989; Foos & Wright, 1992; Stine & Wingfield, 1990).

One explanation for these differential findings may be differences in the emphasis on the storage and processing components within the working memory span tasks. Traditionally, although working memory span tasks require both storage and processing performance is only measured in terms of the storage component, i.e. the number of items correctly recalled. Strategic differences in emphasis on processing or storage may lead to a trade off between the two, with some participants emphasizing storage, some processing and some both; this could lead to apparent variations in performance among people with equivalent working memory resources. Foos (1995), in attempt to overcome these difficulties and clarify whether it is processing, storage or both which are detrimentally affected by age, used a working memory span task and manipulated the instructions given to participants so that either the storage or processing aspects of the task would be seen as most important. Foos (1995) found that age differences only occurred on the processing component when instructions prompted participants to emphasize the storage aspect, and age differences occurred in storage when instructions were neutral or emphasized processing. This was interpreted as strong evidence for an age-related decline in a

single working memory resource pool, that could be allocated flexibly to either processing or storage. Foos (1995) also argued that the results suggested that resources were generally allocated to a more recent demanding task (such as the processing aspect of the working memory span) at the extent of a less demanding prior task; but that this would vary depending on task requirements and instructions.

A similar conclusion was drawn by Brebion et al (1997) who argued that it is not only differences in working memory capacity, but also strategy differences that lead to adult age differences in working memory tasks and reading. Using a working memory span task Brebion et al (1997) manipulated the complexity of sentences to increase processing demands and used a mnemonic preload to vary the storage aspect. They found that whilst young adults were able to store words and process sentences at the same time, older adults generally allocated more of their limited resources to processing to the detriment of storage. Results also showed that a small subset of older adults favoured accuracy to the detriment of speed when there was a heavy preload, with some showing a more conservative pattern of increasing their accuracy by taking much longer to process the sentences.

The use of working memory span tasks to investigate the age-related declines in working memory is limited because of the problems in determining the precise nature of the deficit discussed earlier. The studies by Foos (1995) and Brebion et al (1997) which attempt to address these issues, suggest that the working memory deficit may be associated with the strategic allocation of resources within working memory. This is consistent with the central executive component of the Baddeley & Hitch (1974) working memory model; however it is it is difficult to make firm conclusions regarding the working memory deficit using general working memory measures. The investigation of adult age differences within the different components of the working memory model may be useful in providing a clearer picture of whether the older adults suffer a deficit in passive storage, i.e. within the slave systems, or whether the deficit lies within executive functioning. Although some attempt has been made to distinguish between passive storage and active processing, findings are inconsistent, and the general measures discussed so far are unable to distinguish between verbal and visuo-spatial processing and between different executive processes. Section 3.5

will consider the evidence relating to age differences within the different components of working memory.

3.5: Working Memory Components

Although little research on cognitive aging has been conducted specifically within the framework of the multicomponent working memory model, it has been argued that the working memory model is a useful approach to investigate age effects, because it allows a greater degree of explanation of how and why cognitive changes occur than a general resource theory (Phillips & Hamilton, 2001).

Evidence of age differences within the phonological loop is limited. One task which has frequently been used in the investigation of age differences in working memory is the digit or word span task. Studies investigating general working memory resources have generally used either word or digit span as a passive measure of verbal memory to compare to more active working memory processes, the assumption being that passive verbal recall in the form of word or digit span will show little or no age differences (Dobbs & Rule, 1989; Wiegersma & Meertse, 1990; see Craik & Jennings, 1992, for review). Results from these studies supported this view with no effects of age being found on digit span tasks, suggesting that the passive storage of verbal information, which is the responsibility of the phonological loop, is not affected by age. Other studies which have examined age-related performance on digit span tasks specifically from the perspective of the three component working memory model of Baddeley & Hitch (1974) have also found little or no change in digit span with age (Belleville, Peretz & Malenfant, 1996; Dolman, Roy, Dimeck & Hall, 2000; Fisk & Warr, 1996). Further support for the view of age equivalence in phonological loop functioning comes from Rouleau & Belleville (1996), who investigated the irrelevant speech effect and articulatory suppression in young and old adults. They found that although older adults had a marginally shorter digit span, both groups were equally affected by irrelevant speech and articulatory suppression, with similar patterns of impairment in both age groups.

Although older adults appear to have relatively intact digit span performance, word span impairments have been found in some studies (Belleville, Rouleau & Caza,

1998; Light & Anderson, 1985 experiment 1; Wingfield, Stine, Lahar & Aberdeen, 1988). One explanation for this is that older adults have a slower articulation rate which may account for their reduced word spans (Kynette, Kemper, Norman & Cheung, 1990; Phillips & Hamilton, 2001). In children it has been argued that the effects of a reduced articulation rate on tasks that make demands on both the phonological loop and the VSSP may reflect a general speed of processing reduction (Chuah & Mayberry, 1999; Smyth & Scholey, 1996) and a similar explanation may apply to adult aging effects. As discussed in section 3.2 speed of processing has been used to account for adult age differences in working memory general. However, further research is necessary to examine the extent of speed of processing influences on the specific components of the multicomponent working memory model.

Whilst there appears to be little adult age-related change in tasks believed to make demands on the phonological loop slave system of the working memory model, tasks that make demands on the VSSP slave system do show some evidence of age-related decline (see Craik, 2000; Salthouse, 1991a; Wahlin, Backman, Wahlin & Winblad, 1993). A number of studies have shown that older adults are less able to remember spatial location than younger adults (Light & Zelinski, 1983; Lipman & Caplan, 1992; Park, Puglisi & Lutz, 1982), whereas memory for complex visual scenes remains stable with age (Lipman & Caplan, 1992; Park, Puglisi & Smith, 1986). Although these studies have not been conducted specifically within a working memory framework, the differential effects of age between spatial and visual information appear to mirror the separation of the VSSP into the inner scribe and visual cache; and would be consistent with the inner scribe processing being impaired with increasing age and the visual cache not being affected by age.

Another study, which has also shown that not all aspects of visuo-spatial memory decline with age, is that by Parkin, Walter & Hunkin (1995), who found that whilst visuo-spatial tasks requiring the retention of temporal order showed an age-related decrement, simple spatial discrimination tasks did not. They concluded that memory for temporal order and spatial discrimination rely on different underlying processes and that temporal discrimination was likely to be associated with executive frontal functions.

Overall, although the evidence suggests that there may be an age-related decline in VSSP processing, this evidence is limited, with the majority of studies using tasks that make demands not just on the VSSP components, but also on the central executive. There is clearly a need for further research, specifically within the working memory framework, which utilises tasks that can separate out visual cache, inner scribe and central executive functioning, to provide a clearer understanding of precisely where any age-related deficits may lie.

One study that has attempted to differentiate between visuospatial tasks which require executive functions and those which don't, is that by Libon, Glosser, Malmut, Kaplan, Goldberg, Swenson & Sands (1994), who examined age differences on integrative and non-integrative visuospatial tasks, as well as tasks assumed to make demands on executive processes. They found that older adults showed an age-related decrement on the integrative visuospatial tasks and executive tasks, but not on the non-integrative visuospatial tasks; and that integrative visuospatial tasks correlated highly with executive tasks, whereas non-integrative tasks did not. They argued that this pattern of results suggested that age-related declines in executive functions are responsible for impaired performance on visuospatial tasks among older adults.

Within working memory it has been suggested that the central executive component is particularly impaired in old age (Baddeley, 1986) and that investigating the pattern of age effects on central executive functioning will be a particularly useful tool in studying central executive processes (Baddeley, 1996). Age differences in executive processing have been investigated from a number of different approaches, using both tasks specifically designed to measure central executive functioning and complex executive tasks taken from neuropsychological research.

From the neuropsychological perspective executive processing has been linked to frontal lobe functioning (Luria, 1980; Shallice, 1982) and the frontal lobe hypothesis of cognitive aging has been used to account for age differences in a range of tasks that can be considered measures of executive processing (Dempster, 1992). A number of the tasks used in studies discussed in the previous sections (e.g. stroop task, WCST) to demonstrate an age-related decline in inhibitory processing, are tasks that have also been used from a neuropsychological perspective as measures of frontal lobe

functioning. Age-related declines in performance on these tasks and other measures that are assumed to make demands on frontal lobe functioning have led to the development of an alternative account of cognitive aging; the frontal lobe hypothesis, which argues that cognitive processes supported by the frontal lobes will decline with increasing age, whereas those which are independent of the frontal lobes will remain relatively spared (Daigneault, Braun & Whitaker, 1992; Dempster, 1992; West, 1996). This view is based on two main areas of evidence.

Firstly, a number of studies have demonstrated greater age-related changes within the frontal lobes than other regions of the brain (Goldman-Rakic & Brown, 1981; Haug & Eggers, 1991; Whelihan & Lesher, 1985). However, in a recent review of the evidence (Greenwood, 2000) argues that although there is evidence of age-related declines within the frontal lobes, non-frontal cortical regions also show similar declines, casting doubt on the conclusion that the frontal lobes are differentially affected by age.

Secondly, frontal lobe tasks show a greater decline with age than non-frontal lobe tasks. Older adults demonstrate impaired performance compared to young adults on theWCST and its variants (Daigneault, Braun &Whitaker, 1992; Parkin, Walter & Hunkin, 1995). Age-related declines in performance have also been found on a range of other frontal lobe tasks designed to measure executive functioning, such as: the Tower of London task (Andres & Van der Linden, 2000; Robbins, James, Owen, Sahakian, Lawrence, McInnes & Rabbitt, 1998); verbal fluency (Kozora and Cullum, 1995; Salthouse, 1993); Stroop task (Comalli, Wapner & Werner, 1962; Daigneault et al, 1992); and the self ordered pointing task (Daigneault et al 1992; Shimamura & Jurica, 1994). However, evidence relating to selective age-related impairment on 'frontal tests' compared to 'non-frontal tests' is inconclusive, with age-effects found on some tasks designed to measure frontal functioning but not others, and age-related declines on some tasks which do not make demands on the frontal lobes (see Greenwood, 2000; and Bryan & Luszcz, 2000 for reviews). Further evidence which casts doubt on a general frontal lobe hypothesis is highlighted by Phillips & Della Sala (1998), who argue that there is a differential deterioration of the frontal lobes within normal aging. They argue that it is only tasks which rely on cognitve functions of the dorsolateral prefrontal cortex that will decline with aging, such as fluid

intelligence tests and working memory tasks. Tasks which rely on the functions of the orbitoventral prefrontal cortex, such as emotional problem solving, will not decline with age.

Specifically considering the relationship between the frontal lobes and executive functioning, it is clear that the localisation of executive functions to the frontal lobes (see section 2.4.3 for discussion of this) and the differential effects of age on frontal compared to non-frontal tasks can be questioned; because of this the frontal lobe hypothesis as an explanation for adult age differences in cognitive task performance is limited (Lowe & Rabbitt, 1997; Rabbitt, Lowe & Shilling, 2001; Robbins, James, Owen, Sahakian, McInnes & Rabbitt, 1997). Conclusions relating to executive functioning and aging based on these frontal lobe tasks are also limited because of the poor construct validity of these executive measures (see section 2.4.3), therefore when considering the effects of age on the central executive component of the working memory model, it is important to use tasks that are specifically designed to measure central executive processes and that take the fractionation of the central executive into account.

One task that has been designed to make demands on central executive functioning is the 'keeping track' task (Morris & Jones, 1990), which is assumed to make demands on the memory updating function of the central executive. Few studies examining the effects of age on memory updating have been carried out. However, age related decrements in the keeping track task have been found by Dobbs & Rule (1989) and Van der Linden, Bredart & Beerten (1994).

The effects of age on the four functions of the central executive (inhibition of disrupting information; retrieval and manipulation from LTM; switching of retrieval strategies; and co-ordination of performance on two tasks) highlighted by Baddeley (1996) have been investigated using a range of paradigms. Age-related changes in the ability to inhibit irrelevant or distracting information in order to selectively attend to task relevant information has been discussed in section 3.3, and it was concluded that the concept of inhibition itself needs further clarification and may include separable inhibitory processes. In relation to the role of the central executive in inhibitory processing, further research is necessary to identify precisely which aspects of

inhibition can be considered to be reliant on the central executive and whether these processes decline in old age.

Age-related changes in the executive function of retrieval of information from LTM have been investigated mainly through the use of fluency tasks, which have traditionally been used also as measures of frontal lobe functioning (Denckla, 1994). Verbal fluency tasks generally involve the generation of as many words as possible either beginning with a particular letter (letter fluency), or that fit a particular category (semantic fluency), and are assumed to measure the speed and ease of retrieval from LTM in response to a novel request (Lezak, 1995). Age-related differences in verbal fluency have been variable, with some studies showing a decline in verbal fluency with old age (Kozora & Cullum, 1995; Parkin & Walter, 1992, study 1; Salthouse, 1993; Whelian & Lesher, 1985) and some showing no change with increased age (Mittenberg, Seidenberg, O'Leary & DiGiulio, 1989; Parkin & Walter, 1992, study 2). The effects of age on verbal and non-verbal fluency tasks will be considered in greater detail in section 5.2. In relation to executive functions it has been questioned whether all fluency tasks are valid measures of executive processing (Bryan & Luszcz, 2000; Phillips, 1997) and there remains a need for future research to clarify the processes which determine age-related performance on fluency tasks.

The central executive function of switching retrieval strategies has been investigated within a working memory context mainly through the use of random generation procedures (Baddeley, 1996). During a random generation task participants are required to randomly generate sequences of either numbers (random number generation) or letters (random letter generation) at a specific rate (Baddeley, 1966). In order to maintain a random sequence it is argued that participants must constantly use executive resources to monitor the sequence generated and constantly switch retrieval strategies to break up stereotyped sequences. As yet few studies have investigated the effects of age on random generation (see section 6.2 for discussion of these), those that have found age related declines in random number generation (Van der Linden, Beerten & Pesenti, 1998) and age-related declines in random sequence tapping (Phillips, Gilhooly, Logie, Della Sala & Wynn, 2003). However, random generation is a complex task and it is likely to rely on a number of different processes (Towse & Valentine, 1997). The measurement of randomness is also problematical

(Wagenaar, 1972) and further research is needed to determine the different processes that random generation relies on and to examine the effects of age on random generation performance, taking into account the methodological problems of the measurement of randomness.

The ability of old adults to combine performance on two tasks simultaneously has been investigated using the dual task paradigm. Results from studies have been variable, and meta-analyses of these studies have concluded that either there is no specific age-related deficit with dual-task performance (Verhaeghen, Steitz, Sliwinski & Cerella, 2003), or that age-related differences in dual-task performance are dependent upon whether the two tasks use the same resources (Chen, 2000). It has also been suggested that older adults will show a decrement in dual task performance if the tasks are particularly complex or demanding (McDowd & Craik, 1988). In relation to the multicomponent working memory model the argument by Chen (2000) is particularly relevant. If older adults are specifically impaired on a particular component of the working memory model, then a secondary task that also requires the same component should lead to a much greater dual task effect.

The literature reviewed so far suggests that age related deficits may occur in the VSSP. One study that has found evidence of a particular dual task decrement in the VSSP is that by Maylor & Wing (1996). They found that older adults postural balance was particularly impaired when performing concurrent tasks that were assumed to make demands on the VSSP (Brooks spatial task and backward digit recall), but was not affected by tasks assumed to make demands on the phonological loop (silent counting and counting backwards in threes), or by a task thought to rely on the central executive component (random digit generation). They argued that this provided strong support for an age-related impairment in the VSSP, which could account for the reduced postural stability in older adults. However, the secondary tasks used to tap VSSP resources can be criticised for also requiring central executive resources. Although random generation had no effect on postural sway this may be accounted for in terms of the validity of random generation as an executive task in an elderly population. Phillips & Hamilton (2001) argue that if older adults do not use effortful search and inhibition strategies during random generation, then random generation may not load the central executive adequately to act as a secondary

interference task. Alternatively, it could be argued that random generation makes demands on only one aspect of central executive functioning and that a secondary task that loads onto different executive processes may interfere with postural balance.

Dual task performance on tasks thought to rely on central executive processes has been examined by Phillips et al (2003) using the Tower of London (TOL) task. Secondary tasks of articulatory suppression, pattern tapping and random generation were used to load the phonological loop, the VSSP and the central executive respectively. Phillips et al (2003) found that different patterns of dual task impairment were evident for young and old adults. Young adults showed a greater impairment on the TOL task with concurrent random generation, whereas older adults showed greater TOL impairment with the phonological loop and VSSP tasks, suggesting that older adults make greater use of the slave systems during the TOL task, compared to young adults who mainly use central executive resources. However, similar criticisms to those discussed above, regarding the use of random generation as an executive task can be made.

In terms of conclusions relating to the effects of age on dual task performance, these studies highlight the difficulties in drawing firm conclusions regarding the nature of the age-related deficit in dual-task performance. Conclusions from dual task studies rely upon the assumption that the secondary tasks are valid measures of the working memory component that they are presumed to load. A lack of clarity regarding the underlying processes of many of the secondary tasks used makes it difficult to clearly identify the nature of any age-related deficits. This problem has also been highlighted by Guttentag (1989) in relation to developmental studies utilising dual task methodology. This problem is further confounded by the problem highlighted by Phillips & Hamilton (2001), that old adults may utilise different resources to young adults on some tasks, such as random generation, which means that what may be a valid measure of executive processing for young adults has poor validity for older adults. Future research will need to address these methodological issues and one interesting direction may be to investigate dual task performance using tasks that are designed to assess different executive processes.

3.6: Comparison of Adult Aging Explanations

In order to determine which of these explanations can best account for adult age differences, or whether a combination of factors explain cognitive age differences best, it is important to directly compare different explanations within a single study, however only a few studies have attempted to do this.

One empirical study, which has attempted to clarify the different age-related influences on cognitive performance, is that by Salthouse & Ferrer-Caja (2003). They used structural equation modelling and found that there were three distinct age-related influences on cognitive task performance: firstly, a common influence across all tasks, which they speculated could be some sort of attentional control or executive process; secondly, a speed of processing factor; and thirdly, a memory factor. They suggest that there may also be some age effects which are unique to individual tasks. Whilst this study looks at cognitive performance in general it does not specifically consider the different working memory components. The tasks used are all complex cognitive tasks that are likely to rely on a number of different processes, and it may be useful to also consider experimental studies that are designed to measure specific working memory components and their age-related changes, in relation to other factors such as speed of processing. Another study, which has also examined the age-related influences of different factors on cognitive performance, is that by Schretlan et al (2000). Schretlan et al (2000) examined the contributions of speed of processing, executive functioning and frontal lobe volume, to age-related differences in intelligence, and found that all made significant contributions to age-related differences in fluid intelligence.

Some studies have attempted to consider the relationship between the different working memory components and speed of processing, in particular, given the evidence discussed earlier suggesting that age differences are most evident within the central executive, this has been the focus of the majority of studies. Fisk & Warr (1996), specifically within a working memory framework, investigated the relationship between speed of processing and working memory components in adult aging and found that whilst age differences are evident within the central executive, phonological loop functioning does not decline with age. Age differences within the

central executive were eliminated when speed of processing was controlled for, which they argued supports the view that an age-related reduction in speed of processing is responsible for the decline in central executive processing with age. However, the Fisk & Warr (1996) study only uses one measure of central executive functioning and does not take into account the fractionation of central executive processes.

In contrast to Fisk & Warr (1996) the suggestion that executive processes can contribute to age differences in cognitive performance independent of speed of processing, has been demonstrated by Keys & White (2000), using executive tasks of set formation and set shifting. They found that whilst the age-related impairment in executive task performance was attenuated by controlling for speed of processing, a large proportion of age-related variance still remained, suggesting that speed of processing cannot solely account for age differences on executive tasks.

One explanation for these differential findings may be that the executive tasks used made demands on different executive processes, or that the tasks were poor measures of executive processing. The problem of task reliability and validity as a limitation on conclusions regarding the processes underlying cognitive aging effects is one that has been highlighted by Stankov (1999). In a review of speed of processing and resource capacity theories Stankov (1999) has suggested that both are important in explaining adult age differences in intelligence and cognitive performance. Stankov (1999) suggests that the reason some studies find that speed alone can account for age differences is because the measures of working memory used are unreliable. In particular Stankov (1999) suggests that backward digit span is a poor measure of working memory and has more in common with measures of short-term memory such as the forward digit span.

Anderson & Craik (2000) in a review of the literature also argue that both speed of processing and attentional resources underlie age-differences in memory task performance. They suggest that changes in brain structure and function mediate age-related reductions in speed of processing and the amount of attentional resources available, which in turn will reduce cognitive control in the elderly. It is this reduced cognitive control which underlies age-related decrements in cognitive performance. The concept of cognitive control is seen as being akin to the central executive

component of the Baddeley & Hitch (1974) working memory model, and as such, incorporates inhibitory processing. Anderson & Craik (2000) argue that tasks requiring a greater amount of voluntary control will show greater age differences, whereas with environmental support age differences in cognitive performance will be reduced. Although this view appears to reconcile all of the current theoretical accounts discussed in this chapter, there is little empirical evidence directly testing this account and further research is necessary to clarify the relationship between speed of processing, attentional resources, working memory and cognitive control.

The majority of research on cognitive aging has attempted to explain age differences in terms of one theoretical construct, be it speed of processing, general resource capacity or inhibition. However, from the evidence reviewed, it is clear that no one explanation can fully account for the pattern of differential age effects evident in cognitive task performance. The multicomponent working memory model which provides a framework to deconstruct the pattern of age effects may be a useful way forward to investigate age-related changes in cognitive task performance. However, it is clear that other factors such as speed of processing and intelligence also need to be taken into account. It is also clear that one of the main considerations in future cognitive aging research is the use of tasks which provide more reliable and valid measures of the specific working memory components and processes that they are assumed to measure. Within the working memory model the phonological loop shows little evidence of age-related change, whereas there is contradictory evidence relating to age differences within the VSSP and whether they can be accounted for by age-related differences in executive processing. The effect of age on VSSP components is therefore the focus of the first empirical study within the thesis.

Chapter 4

Study 1 - Visuo-spatial Working Memory and Aging

4.1: Introduction

Age-related declines in working memory have been found in a number of studies (Dobbs & Rule, 1989; Fisk & Warr, 1996; Lustig, Hasher & May, 2001; Salthouse, 1991; Salthouse & Babcock, 1991; Wahlin et al, 1993) and a number of theoretical accounts have been put forward to explain this working memory impairment in older adults, such as reduced speed of processing, impaired inhibitory processing and reduced resource capacity (see chapter 3 for discussion of these). However, the generality of each of these theoretical accounts is limited because of a number of problems related to the methodology of the studies and the theoretical assumptions they are based on.

Firstly the construct validity of all of these general concepts can be questioned, as there does not appear to be a single, common speed of processing factor, (Salthouse, 1991a) or a single, unitary inhibitory process (Hasher et al, 2001). The concept of a resource capacity has also been criticised for lacking a clear definition (Park & Heddon, 2001). A second criticism of these general accounts of age differences in working memory is that they cannot provide an adequate explanation for the differential pattern of age differences on working memory tasks (see section 3.5). Thirdly, the majority of research suggesting a decline in working memory with age has tended to use measures of working memory general (e.g. Brebion et al, 1997; May, Hasher & Kane, 1999; Salthouse & Babcock, 1991). Although the use of such measures have demonstrated age-related declines in working memory, the complex nature of these tasks makes it difficult to determine precisely which underlying task process declines with age. Finally, these theoretical accounts which have utilised general working memory measures and explained adult age differences in terms of a general age-related deficit are based on the assumption that working memory is a unitary concept (e.g. Anderson et al, 1996; Engle, 1996). Other working memory theories suggest however, that working memory is non-unitary (e.g. Baddeley, 1986, 1996, 2000; Baddeley & Hitch, 1974; Logie, 1995; Shah & Miyake, 1996) and although there is little agreement on the precise nature and number of separable

working memory components, there is general agreement that working memory is not completely unitary but consists of some separable domain specific systems (Miyake & Shah, 1999). Theoretical accounts of age differences in working memory therefore need to be able to explain age-related differences within a multicomponent working memory framework.

A more useful framework for investigating the pattern of age differences within working memory is therefore likely to be the Baddeley & Hitch (1974) working memory model and its more recent revisions, because the fractionated nature of the model allows a more detailed explanation of how and why age-related changes occur (Baddeley, 1996; Phillips & Hamilton, 2001). This model is therefore the theoretical basis for this and subsequent studies (see chapter 2 for discussion of the working memory model).

There is little research that has examined age differences within the working memory model framework (Phillips & Hamilton, 2001). However there is evidence in relation to the phonological loop slave system and central executive components of working memory that tasks which require active executive processing rather than passive storage within the slave system are more likely to reveal age-related deficits.

The evidence relating to age-related changes in the VSSP is less clearcut (see section 3.5). The majority of the studies investigating age-related changes in VSSP processing can be crtiticised for using tasks that do not take into account the recent developments in the conceptualisation of the VSSP put forward by Logie (1995), separating the VSSP into the visual cache and inner scribe. Given the lack of clarification of the underlying processes of VSSP tasks and their potential reliance on central executive resources (see section 2.3.2), there is a need for further research investigating the effects of age on visuo-spatial working memory to use tasks which allow the separation of the inner scribe, visual cache and central executive components to provide a clearer understanding of the nature of age-related deficits within the VSSP slave system.

The aim of this study is therefore to identify the effects of age on the inner scribe and visual cache sub-components of the VSSP by using four tasks which are designed to

make demands on visual cache processes (size just noticable difference (JND) task), inner scribe processing (trajectory just noticeable difference (JND) task), combined visual cache and central executive processes (pattern span task) and combined inner scribe and central executive processes (sequence span task). See following discussion for description of these tasks.

The size just noticeable difference (size JND) task was designed to make demands on the visual cache component of working memory, whilst reducing demands on the inner scribe and central executive. Participants are required to remember the size of a single square presented on the computer screen, a second square is then presented and the participant has to decide whether the square is the same size or a different size. The task is based on the principles of Logie & Marchetti's (1991) colour hue task, which was assumed to require the maintenance of visual information without a spatial or sequential component. However, it could be argued that the maintenance of colour hue may be performed using a verbal representation of the colour rather than a visual representation. The size JND task was therefore designed to use a stimulus that could be represented visually, that did not have a spatial or sequential component to it and that would be difficult to represent verbally (Thompson, Hamilton, Gray, Quinn, Mackin, Ferrier & Young, in press). The maintenance of visual information in the size JND task is expected to make demands on the visual cache component of visuo-spatial working memory.

The trajectory just noticeable difference (trajectory JND) task is designed to require the retention of spatial but not sequential information. A moving spot is presented on the screen with the spot following a particular trajectory. The spot then disappears and reappears further along the screen and the participant is required to decide whether the spot is now travelling at the same or a different trajectory angle. By using a task that requires the retention of spatial information, but not sequential order, demands on the central executive component of working memory should be minimised and it is expected that the task will make demands on the inner scribe component of working memory.

The pattern span task developed for this study is derived from previous studies, which have used abstract visual patterns and matrix pattern tasks as measures of visual cache

functioning (Logie & Pearson, 1997; Phillips & Christie, 1977; Wilson, Scott & Power, 1987). Phillips & Christie (1977) used abstract visual patterns as measures of visual working memory processing, suggesting that the use of abstract patterns would be retained visually, as they would not be able to be verbally recoded, thus reducing the involvement of phonological loop resources. More recent studies have utilised matrix pattern tasks as measures of visual cache functioning (Logie & Pearson, 1997; Wilson et al, 1987), where participants have to remember the location of filled in squares within a matrix. The pattern span task in the current study is based on these matrix patterns, but requires participants to remember the location of a number of spots presented on a computer screen, rather than squares within a matrix. By removing the reference frame which is inherent within the matrix patterns, the pattern span task should reduce the potential for recoding of the visual pattern into a verbal description, minimising phonological loop demands. The pattern span task is therefore designed to make demands on visual cache resources.

The pattern span task is also expected to make demands on central executive resources. Hamilton et al (2003) has suggested that central executive processes, as well as visual cache processes, may underlie performance on the matrix pattern tasks through the use of an eye-scanning movement strategy during encoding and maintenance. A number of studies have demonstrated that this type of eye movement, or attentional strategy, utilises central executive processes (Smyth, 1996; Smyth & Scholey, 1994).

Using a Mr Blobby visual span task, Hamilton et al (2003) found that both visual cache and central executive resources are likely to be involved in visual span performance. The pattern span task used in the current study was directly developed from the Mr Blobby visual span task used in the Hamilton et al (2003) childhood development study. In the Mr Blobby task participants are presented with a Mr Blobby figure on the computer screen containing a number of coloured spots, which disappears and then reappears following a short period of time. Participants are required to remember the pattern of spots in the Mr Blobby figure and identify whether the pattern is the same or different when the figure reappears. To make the task more appropriate for adults and an elderly adult population in the current study the Mr Blobby figure was removed and the spot patterns presented on a plain screen

for the pattern span task. Based on the conclusions from these previous studies it is expected that this modified pattern span task will make cognitive demands on both the visual cache and central executive components of working memory.

The spatial sequence span task is derived from the original Corsi block task (Corsi, 1972). In the original Corsi task the experimenter randomly taps a sequence of blocks and the participant is then required to reproduce the sequence of taps. The Corsi task and its more recent computerised derivatives are assumed to act as a measure of spatial memory and memory for movement, and as such is considered to make demands on the inner scribe component of working memory (Logie & Pearson, 1997). As well as requiring the retention of spatial location the Corsi task and its derivatives also require the retention of sequential order information. A number of studies have suggested that the retention of serial order makes demands on central executive resources (Chuah & Mayberry, 2000; Farrand & Jones, 1996; Smyth & Scholey, 1996) and given the serial order requirements of Corsi derived tasks it has been suggested that they rely on both inner scribe and central executive resources (Hamilton et al, 2003).

The sequence span task used in the present study is based on a computerised derivative of the original Corsi task used by Hamilton et al (2003). The Hamiton et al (2003) task presented a Mr Blobby figure with a sequence of spots appearing within the body of the figure and participants were required to remember the sequence of spots. This task was adapted by removing the Mr Blobby figure to make it more appropriate for an adult population. A number of spots were presented on the computer screen in a sequential order and participants required to remember the sequence. This computerised task differs from the original Corsi task in that it has a two dimensional rather than a three dimensional presentation and the movement component is removed. However, based on the results of previous studies (Hamilton et al, 2003; Jones et al, 1995; Pickering, Gathercole & Peaker, 1998; Smyth & Scholey, 1996) the requirements for the retention of spatial location and serial order are expected to make demands on both the inner scribe and central executive components of working memory.

Based on the premise that age decrements will occur in tasks which make demands on central executive processes, but not on tasks which purely rely on passive slave system processing, it is hypothesized that: older adults will have a lower pattern span than young adults; that older adults will have a lower sequence span than young adults; that there will be no difference between young and old adults on the size JND task; and that there will be no difference between young and old adults on the trajectory JND task.

4.2: Method

4.2.1: Design

A quasi-experimental one factor between subjects design was used. The between subjects factor being age, with four levels (young adults aged 20-30 years, middle-aged adults 40 – 50 years, younger elderly adults aged 60 – 69 years, and older elderly adults aged 70 years plus).

The performance of participants within each age group was measured on two out of four dependent variables, with half of the participants in each age group being allocated to a visual task condition and half being allocated to a spatial task condition. Within the visual task condition one dependent variable was designed to make demands on visual cache functioning, which was measured in terms of the percentage shape size change detected using the size JND task. The second visual task condition dependent variable was designed to make demands on combined visual cache and central executive functioning, and was measured in terms of spot pattern recognition using a pattern span task. Within the spatial task condition one dependent variable was designed to make demands on the inner scribe and measured in terms of trajectory angle recognition using the trajectory JND task. The second spatial task condition dependent variable was designed to make demands on inner scribe and central executive functions, which was measured by spot sequence recognition during a sequence span task.

Participants were randomly allocated to either the visual or spatial task conditions, with half of the participants in each age group undertaking the visual task conditions and half undertaking the spatial task conditions. The order of tasks within both the

visual and spatial conditions was counterbalanced. A sub-sample of the participants also carried out one of two control tasks to ensure that that their performance on the size JND and trajectory JND tasks was not due to perceptual constraints.

Measures of IQ and dementia were taken as control variables. Dementia has been shown to lead to declines in working memory (Baddeley, 1986; Kensinger, Shearer, Locascio, Gowden & Corkin, 2003) and given the increasing prevalence of dementia in the population with increasing age (Riedell-Heller, Busse, Aurich, Matschinger & Angermeyer, 2001) the detection and exclusion of participants with dementia will reduce the confounding effect of dementia on task performance. A number of studies have also shown that intelligence may influence performance on working memory tasks and that working memory differences may simply reflect differences in general intelligence (Colom, Flores-Mendoza & Rebollo, 2003; Kyllonen, 1996). To reduce the confounding effects of intelligence on task performance, IQ will be measured and statistically controlled for during data analysis.

4.2.2: Participants

A convenience sample of 104 adults (83 females and 24 males) within the specified age groups was taken (26 participants within each age group). Ages ranged from 20 to 90 years. Within the young adult age group (20 – 30 years) 21 females and 5 males with a mean age of 24.5 years (standard deviation 4.0) were sampled. Within the middle age group (40 – 50 years) 19 females and 7 males, mean age 42.8 years (standard deviation 3.0); within the 60 – 70 yearsage group 19 females and 7 males, mean age 64.6 years (standard deviation 2.5); and within the 70 plus age group 24 females and 3 males with a mean age of 79.2 years (standard deviation 5.5). The sample of young and middle-aged adults was mainly taken from University administrative staff and students, further education college students and the local leisure centre. Older adults were sampled from the local leisure centre, community and day centres and a sheltered housing association.

Inclusion criteria for the study were that participants must fit into the specified age groups, must be living independently in the community, be healthy (determined by participants self report) and have no uncorrected eye sight problems (determined by participants self report). All participants were screened for dementia using the mini

mental state examination (MMSE) (Folstein, Folstein & McHugh, 1975) and excluded from the study if the MMSE score was below the acceptable cut off point (see tasks section for discussion of this).

4.2.3: Tasks

To identify whether potential participants showed any evidence of dementia and should therefore be excluded from the study the MMSE (Folstein et al, 1975) dementia test was used. A number of dementia tests are available, however the MMSE was selected because of the short administration time (approximately 5 minutes), the ease of use for both tester and participant and its reliability and validity. Reliability and validity of the MMSE has been demonstrated in a large scale study of community dwelling elderly adults over the age of 75 (O'Connor, Pollitt, Hyde, Fellows, Miller Brook & Reiss, 1989). They found a reliability kappa score of 0.97 and demonstrated that of those scoring 24 or above, 92% were judged to be cognitively intact using clinical examinations and alternative dementia screening tests. The remaining 8% tended to be well educated, mildly demented participants who scored 24 and 25. Given that the generally accepted cut off point is 26 (23 for the over 85's), the MMSE appears to be a reasonably reliable and valid tool for dementia screening, particularly in the population used in the present study where very few participants are over the age of 85.

The MMSE consists of a number of questions which the participant has as much time as required to answer (see appendix 1 for copy of questions). The final score is the total number of correct answers. A score of 26 or less out of a possible 30 (23 or less in the over 85's) suggests the possibility of dementia or some sort of mental impairment, and participants scoring equal to or below this cut off point were excluded from the study.

To determine IQ the National Adult Reading Test 2nd edition (NART) was used (Nelson & Willison, 1991). The NART consists of 50 single words of varying difficulty which the participant has to read out loud (see appendix 2 for list of words). An error score is then obtained which is the number of words incorrectly pronounced. The error score is translated into an equivalent WAIS-R IQ score using the standardised tables provided in the test instruction booklet. The IQ scores predicted

by the NART have been shown to be reliable up to the age of 84 years (Brayne & Beardsall, 1990), with inter-rater reliability of 0.96-0.98 and test-retest reliability of 0.98 (Crawford, Parker, Stewart, Besson & De Lacey, 1989). It has also been shown to be a valid measure of general intelligence in a normal adult population (Crawford et al, 1989).

The four main computer-based experimental tasks were designed using Qbasic software (Coates, Hamilton & Heffernan, 1997) to make demands on the visual cache component (size JND task), the visual cache and central executive components (pattern span task), the inner scribe component (trajectory JND task) and the inner scribe and central executive components (sequence span task).

Each of the computer-based tasks involved starting off at the easiest level of the task and progressing onto the next level of difficulty if a correct run was obtained for the easier level. To obtain a correct run the participant's performance was measured over a number of trials (maximum of 20), if they made the correct response ten times in a row, or if they scored less than 6 errors in total (a minimum of 14 correct responses), then a correct run was recorded and the participant went on to the next level. The scoring method for a correct / incorrect run was based on binomial probability theory. Using the binomial probability formula (see appendix 5) the probability of completing 10 correct runs in a row is 0.001 and the probability of 14 correct responses in total out of 20 is 0.057, giving approximately a 5 % probability of 14 correct responses out of 20 occurring by chance. Testing on each task ended when the participant made 6 or more errors at any one level. At this point their maximum level of performance was recorded as the last correct level achieved. All tasks were presented on a 27cm by 20cm sized computer screen with a maximum task array size of 14 cm by 17cm.

Size JND task

In the size JND task the participant is presented with a single square on the computer screen for a period of one second (see figure 4.1, presentation phase). A blank screen is then presented for four seconds before a second square is presented in the recognition phase (see figure 4.1, recognition phase). The participant has to decide whether the square is the same size or a different size to the previous one, and respond with a key press (see appendix 15 for standardised instructions). The squares were

presented in ten different sizes ranging from 26 to 51 pixel side length. This task was carried out over a maximum of 6 levels of difficulty, with difficulty being determined by the percentage change in size. The percentage changes at each level were 50% for level one, 40% for level two, 30% for level three, 20% for level four, 10% for level five and 5% for level six. The use of a single shape should reduce the requirement for a complex representation and therefore should not require central executive processing. The passive retention of a visual factor such as shape size is considered to be a visual cache function (Logie, 1995).

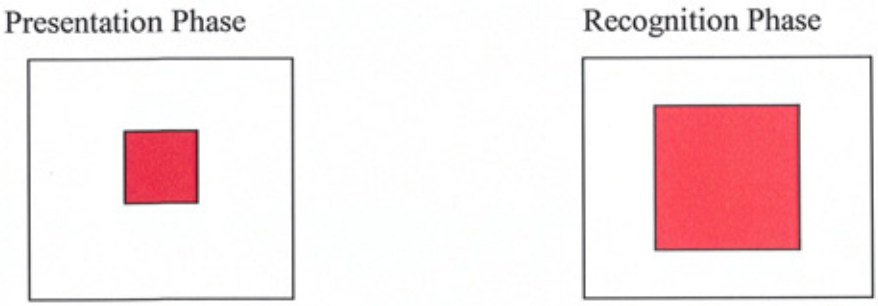


Figure 4.1: Size JND Task

Pattern Span Task

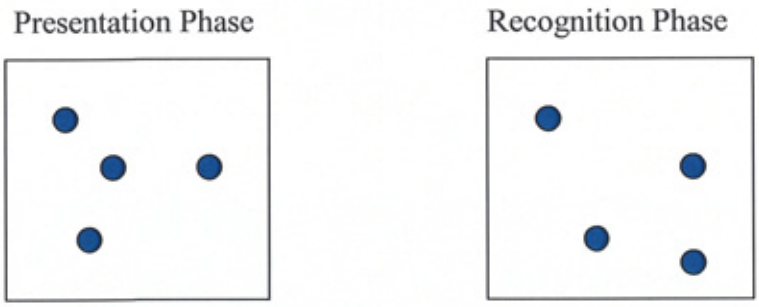


Figure 4.2: Pattern Span Task

The pattern span task involved the presentation of a number of spots (1 cm in diameter) in random locations on the computer screen (see figure 4.2, presentation phase). Spots were presented for 2 seconds. The participant has to remember the pattern or location of the spots. A masking pattern is then flashed onto the screen for 1 second to prevent after image (see appendix 16 for masking pattern, before a second pattern of spots is presented (see figure 4.2, recognition phase). The participant has to decide whether the second pattern of spots is the same or different to the first and respond by key press (see appendix 15 for standardised instructions). Difficulty

levels ranged from four to fourteen spots. Similar tasks requiring the recognition of complex patterns have been shown to rely not just on visual cache resources but also on central executive processes (Hamilton, Coates & Heffernan, 2003).

Trajectory JND task

In the trajectory JND task the participant has to remember the trajectory or angle at which a spot (1 cm in diameter) moves across the screen (see figure 4.3, presentation phase). The spot moves for approximately 2.8 seconds then disappears before reappearing approximately 3.4 seconds later, moving at either the same or a different trajectory (see figure 4.3, recognition phase). A blank screen is presented between the disappearance and reappearance of the spot. The participant has to decide whether the spot is travelling at the same trajectory angle as before or a different one and respond with a key press (see appendix 15 for standardised instructions). Participants were tested at six levels of difficulty. The easiest level having an angle difference of 27°: the remaining levels having 21°, 18°, 13.5°, 9° and 4.5° difference. Retention of spatial movement without sequential order is likely to make demands on the inner scribe component without utilising central executive resources (Phillips & Hamilton, 2001).

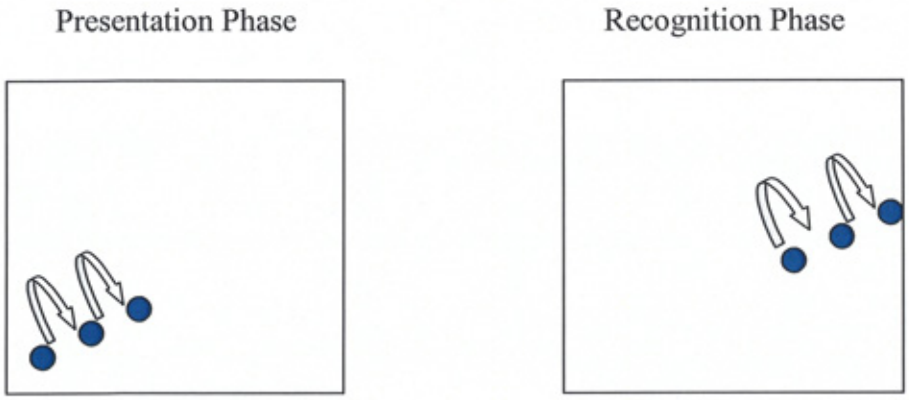


Figure 4.3: Trajectory JND Task

Sequence Span Task

The sequence span task involves the presentation of a sequence of spots (1 cm in diameter) on the computer screen (see figure 4.4). In the presentation phase the participant has to remember the sequence in which the spots appear (see figure 4, presentation phase). Spots are flashed onto the screen one at a time for 750 msec

before the next spot in the sequence appears. A masking pattern is then presented for 1 second before a second sequence of spots is presented in the recognition phase (see figure 4.4, recognition phase). The participant has to decide whether the sequence of spots is the same or different to the previous sequence and respond by key press (see appendix 15 for standardised instructions). The number of spots within the sequence increases from 3 to 10, to increase the difficulty level of the task.

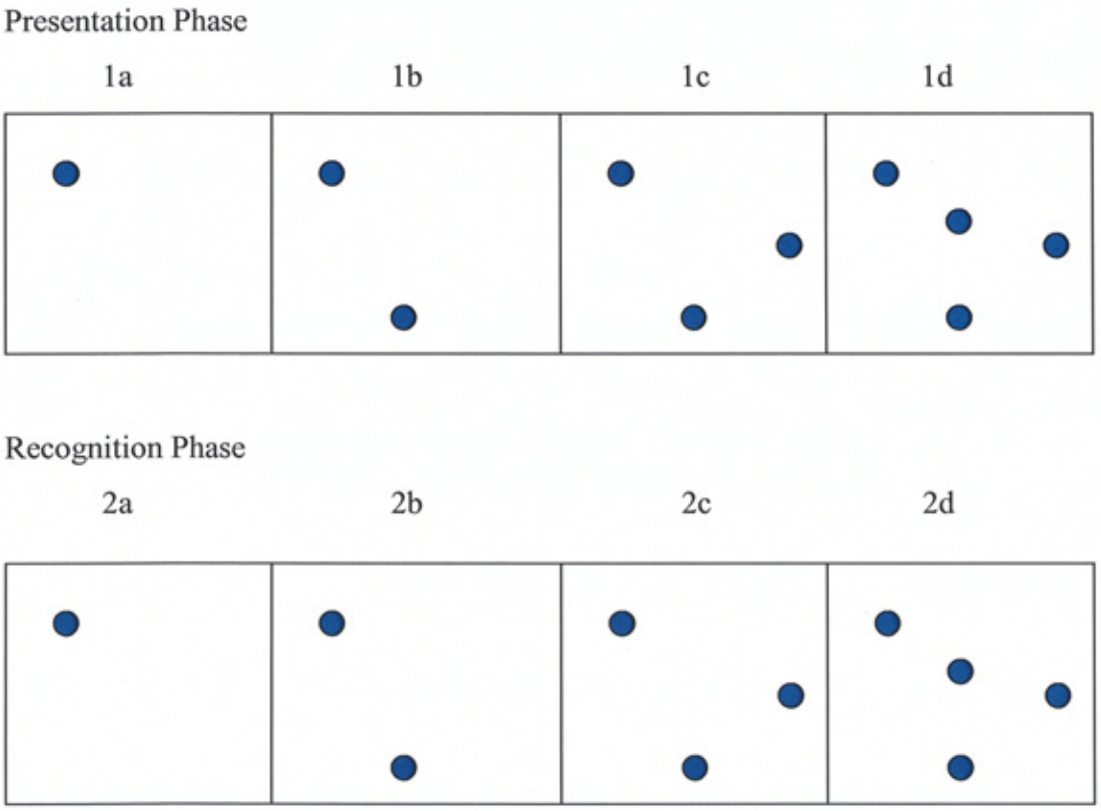


Figure 4.4: Sequence Span Task

Control Tasks

One potential criticism of the size JND and trajectory JND tasks is that performance on these tasks may be constrained by perceptual deficits rather than memory deficits. To identify whether this was indeed the case, a smaller sub-sample of 10 of the study participants took part in one of two control tasks relating to whichever experimental condition they had taken part in. The size JND control task was the same as the size JND task, except that to remove any memory component the two squares were presented at the same time and the participant had to determine whether they were the same or different. The scoring procedure and levels of difficulty were the same as for the original size JND task and performance was measured at the maximum level of

difficulty obtained on the size JND task. The trajectory JND control task was the same as the trajectory JND task, except that there was no delay between the first moving spot and the second moving spot. Participants had to decide whether the angle at which the second spot was travelling was the same or different to the first. Again the scoring and levels of difficulty were the same as in the original trajectory JND task. Performance on the control task was measured at the maximum level of performance achieved on the original trajectory JND task.

4.2.4: Procedure

Participants were tested individually either in their own homes or the establishment through which they were contacted. Participants were asked to self report any eyesight or medical problems and the MMSE and NART were completed first. Participants were then randomly allocated to either the visual or spatial conditions, with half of the participants in each group doing the spatial tasks and half the visual tasks. Those taking part in the visual condition were given the size JND and pattern span tasks, the order of which was counterbalanced between the participants. Tasks were explained and demonstrated by the experimenter and standardised instructions displayed on the screen at the start of each task. Participants were then given a practice on each task to ensure they understood the instructions. Participants then completed the tasks over two 45 minute sessions to reduce boredom and fatigue effects. Participants started at the easiest level for each task and progressed through each level until they either reached the error criteria for stopping (see section 4.2.3), or had completed all levels. Their score was then recorded. The same procedure was followed for those completing the spatial condition, using the trajectory JND and sequence span tasks. A sub-sample of participants was randomly selected to complete the appropriate control task, depending on whether they had taken part in the visual or spatial conditions. The control task was completed at the end of the testing procedure.

4.3: Results

4.3.1: Data Analysis

Mean and standard deviation scores for each age group were calculated for each of the experimental tasks and for MMSE and NART scores. To determine whether any of the changes in mean scores showed a significant difference between the age groups a

one way between subjects ANOVA was carried out for each task. To determine whether any significant effects found during the ANOVA analysis for the experimental tasks were due to differences in IQ or dementia the analysis was then repeated using one way between subjects ANCOVAs for each task, with IQ and MMSE as covariates. Post hoc analysis using Scheffe tests were then conducted for any significant ANOVA or ANCOVA results, to determine exactly where any significant differences occur. Results for each task will be considered separately. Control size JND and trajectory JND tasks were analysed using mean and standard deviation scores for each control measure and a one way between subjects ANOVA was carried out for each control task separately, to determine any age differences in control task performance.

4.3.2: IQ and Dementia Test Differences

The average MMSE and NART scores are shown in table 4.1. MMSE scores show that up to the age of 70 there is very little difference in MMSE score, with most participants performing close to ceiling level. Older elderly adults over the age of 70 show a slightly lower score than the other groups and this difference is significant ($F(3,104) = 12.386$, $p = 0.0001$), indicating that older elderly adults score lower on the dementia screening test than young, middle-age or young elderly adults. Older adults also show greater variability in their MMSE scores. Although older adults score significantly less than the other age groups, this score is above the cut off point of 26 (23 for over 85's), and therefore does not suggest evidence of dementia in this older elderly group.

Age Group	MMSE	NART IQ
20 – 30 years	29.7 (0.7)	111 (9.3)
40 – 50 years	29.4 (0.9)	114 (8.2)
60 – 70 years	29.0 (1.2)	111 (10.4)
70 + years	27.9 (1.7)	108 (8.1)

Table 4.1: Mean (standard deviation) MMSE and NART IQ scores for each age group

Average NART scores appear to be similar across the four age groups, with only a 6 point difference in the average IQ score between the highest and lowest scoring groups; this difference is not significant ($p>0.05$). There is some variability within

each age group; however, the average NART IQ scores suggest that the study population have a higher IQ than the average population for all age groups.

4.3.3: Control Task Results

ANOVA indicate no significant difference between the age groups for the size JND control task ($p>0.05$) and this can clearly be seen in the mean percentage change score for each age group for the size JND control task scores (see table 4.2). Similarly, ANOVA results and mean trajectory JND control scores (table 4.2) show no significant difference between the age groups in control trajectory JND task performance ($p>0.05$). The equivalent performance between the age groups in the control tasks suggests that performance on the size JND and trajectory JND task are not differentially constrained by perceptual limitations.

Age Group	Size JND Control Task	Trajectory JND Control Task
20 – 30 years	5.5 (1.5)	9.0 (2.0)
40 – 50 years	5.0 (0.0)	10.3 (2.2)
60 – 70 years	5.7 (1.9)	9.0 (0.0)
70 + years	5.0 (0.0)	9.0 (0.0)

Table 4.2: Mean (standard deviation) Control Size JND and Control Trajectory JND scores for each age group

4.3.4: Pattern Span Task Results

Age Group	Pattern span
20 - 30	13.2 (1.2)
40 – 50	12.5 (1.6)
60 – 70	10.3 (3.1)
70+ years	8.3 (2.2)

Table 4.3: Mean (standard deviation) pattern span scores for each age group

ANOVA results indicate a significant difference between the age groups in pattern span ($F(3,48) = 14.14$, $p = 0.0001$) and mean pattern span scores (see table 4.3) indicate a decline in pattern span with age. This effect of age on pattern span remains even when NART and MMSE scores are controlled for ($F(3,44) = 6.568$, $p = 0.001$). Post hoc analysis showed significant differences at the 0.05 level between the

following age groups: 20 – 30 years and 70+ years; 20 – 30 years and 60 – 70 years; 40 – 50 years and 70+. The two older age groups scored significantly lower than the young age group and the old elderly scored significantly lower than the middle-aged group, supporting the experimental hypothesis that older adults would have a lower pattern span score than the young adults.

4.3.5: Size JND Task Results

Mean scores for the size JND task show little difference between the age groups in the percentage size change detected. Although younger adults are able to detect slightly smaller percentage size changes than older adults (see table 4.4), this difference is small and there is a large amount of variability in scores within each age group. ANOVA results show no significant difference between the age groups in size JND task scores ($p>0.05$) and this remains non-significant when NART and MMSE scores are controlled for ($p>0.05$), indicating that age has no effect on cache task score.

Age Group	Percentage Size Change Score in mm
20 - 30	14.2 (8.9)
40 – 50	14.2 (7.6)
60 – 70	15.8 (7.0)
70+ years	16.2 (11.8)

Table 4.4: Mean (standard deviation) percentage size change score for each age group on the size JND task

4.3.6: Sequence Span Task Results

ANOVA results indicate that there is a significant effect of age on sequence span ($F(3,48) = 14.60$, $p = 0.0001$) and mean sequence span scores show that sequence span decreases with age (see table 4.5). This significant effect of age on sequence span remains when both NART and MMSE scores are controlled for ($F(3,46) = 10.723$, $p = 0.0001$). Post hoc Scheffe tests showed that significant differences occurred between the following age groups; 20 – 30 and 40 – 50 years; 20 – 30 and 60 – 70 years; 20 – 30 and 70+ years; 40 – 50 and 70+ years. Younger adults scored significantly higher than all other age groups and the middle-aged group scored significantly higher than the old elderly group, thus supporting the experimental hypothesis that older adults have smaller sequence span scores than younger adults.

Age Group	Sequence Span
20 - 30	7.0 (1.2)
40 – 50	5.4 (1.3)
60 – 70	5.1 (1.2)
70+ years	4.1 (0.9)

Table 4.5: Mean (standard deviation) sequence span scores for each age group

4.3.7: Trajectory JND Task Results

Little difference between the age groups on the trajectory JND task scores can be seen (table 4.6) and no significant effect of age is found in the ANOVA analysis ($p>0.05$). There remains no significant differences when NART and MMSE scores are controlled for ($p>0.05$).

Age Group	Trajectory Angle Change Score in degrees
20 - 30	13.9 (4.7)
40 – 50	16.2 (5.8)
60 – 70	16.5 (4.4)
70+ years	17.7 (5.6)

Table 4.6: Mean (standard deviation) trajectory angle change score for each age group on the trajectory JND task

4.4: Discussion

Overall, results from this study support the hypotheses put forward, in that the pattern span and sequence span tasks show a significant decline with increasing age, whereas performance on the size JND and trajectory JND tasks show no effect of age on performance. The pattern span and size JND tasks were both designed to make demands on the visual cache component of the VSSP; however, the pattern span task is also presumed to make demands on the central executive. Similarly, with the sequence span and trajectory JND tasks, both are designed to make demands on the inner scribe component of the VSSP, but the sequence span is also designed to tap central executive processes. It is therefore suggested that the poorer performance of older adults in comparison to young adults on the pattern span and sequence span tasks reflects the central executive demands of these tasks. The equivalent performance across the adult lifespan on the size JND and trajectory JND tasks suggests that the VSSP slave system is not impaired with age. These results are

consistent with the view that age differences in working memory are a consequence of an age-related decline in central executive functioning, rather than a decline in slave system functioning (Baddeley, 1986, Phillips & Hamilton, 2001). These results remained even after controlling for IQ and dementia test scores, suggesting that these factors cannot account for the age differences found.

Previous research looking at the effects of age on working memory has indicated a general working memory deficit, which has been attributed to either a storage capacity deficit (Foos, 1989), a processing capacity deficit (Craik, Morris & Gick, 1990), or a co-ordination deficit (Craik, 1983). The effects of age on pattern and sequence span in the current study are consistent with the reduced processing capacity view (Craik et al, 1990; Dobbs & Rule, 1989), in that age differences were found in tasks requiring active processing. However, rather than a general working memory impairment, the results specifically link the age-related deficit to the central executive component.

The lack of an age effect in the tasks designed to make demands on the visual cache and inner scribe components of VSWM is inconsistent with the notion of a storage deficit, and highlight the importance of isolating specific components within working memory, in order to determine the nature of any age differences found. One explanation for these differential findings may be that the central executive co-ordination function declines with age. In working memory span tasks, such as those used in the study by Foos (1989), storage and processing requirements of the task have to be co-ordinated, and it may be that the observed storage deficit reflects the requirement for co-ordination, rather than an age-related reduced storage capacity alone. When no co-ordination is required, as in the present study, no age effects will be found in passive storage.

The lack of an age effect on the size JND and trajectory JND tasks which make demands on the visual cache and inner scribe respectively, can also be compared to evidence from studies such as Belleville et al (1996) and Fisk & Warr (1996), which demonstrate no effect of age on tasks which make demands on phonological loop functioning. The current results suggest that this age equivalence in working memory slave systems is a general one rather than specific to the phonological loop.

Findings from the current study also suggest that age-related declines in visuo-spatial tasks are a consequence of central executive involvement on these tasks, rather than an age-related decline in visual cache or inner scribe functioning. This is consistent with the results of a number of previous studies that have found that older adults perform worse than young adults on visuo-spatial tasks that also make demands on the central executive (Libon et al, 1994, Parkin, Walter & Hunkin, 1995; Salthouse & Mitchell, 1990).

One explanation for the decline in performance on the sequence span task may be in relation to its requirement for the retention of sequential spatial order information. It has been argued that the retention of sequential or temporal order utilises central executive resources (Hamilton et al 2003; Klauer & Stegmeier, 1997; Pickering et al, 1998; Smyth & Scholey, 1996). An age-related decline in retention of sequential order has been shown by Parkin et al (1995), who found that whilst visuo-spatial tasks requiring the retention of temporal order declined with age, those requiring the retention of spatial information without any order component did not. Results from the current study show a similar pattern with an age-related decrement in the sequence span task, which requires the retention of serial order and age-equivalence in the scribe tasks, which requires the retention of spatial information without any sequential component.

The decline in pattern span with age is less easy to explain as there is no explicit requirement for the retention of sequential order in the pattern span task, as all the spots are presented at the same time. One alternative explanation may be that participants made use of some sort of voluntary strategy to help them retain the information. One such strategy may be to 'chunk' spots in close proximity to each other into patterns to reduce memory load, and then to integrate these 'chunks' into the whole pattern. The ability to integrate information within a visuo-spatial domain has been investigated by Libon et al (1994). They found that older adults showed a decline in integrational visuo-spatial tasks and that this decline was correlated with a decline in executive functioning. Similarly, Salthouse et al (1989) have also found evidence of an age related decline in tasks requiring active manipulation and integration of visuo-spatial information.

Results from this study also provide support for the view that executive processes decline with age. A number of previous studies have found evidence of an age-related impairment in central executive processing (Belleville et al, 1998; Fisk & Warr, 1996; Van der Linden et al, 1998). However, the relationship between age and central executive functioning is not straightforward as it has been suggested that the central executive can be fractionated into a number of separable functions (Baddeley, 1996) and not all of these functions may decline with age. The pattern span task and sequence span tasks used here do not clearly identify what executive function or functions they rely on, and as such, are limited in the conclusions that can be made regarding age-related decline in executive processing.

The results from the present study are also to some extent consistent with an alternative account of working memory (Cornoldi & Vecchi, 2000; Vecchi, Phillips & Cornoldi, 2001), which distinguishes between passive and active processes. Vecchi et al (2000) argue that age differences are likely to be determined by the amount of active processing required; tasks requiring active processing will show large age differences, whereas relatively passive tasks will show no differences with age. However problems in defining what is meant by active and passive processing (Phillips & Hamilton, 2001) make it difficult to draw firm conclusions. In this study, whilst the pattern span and sequence span tasks could be described as requiring active processing and the size JND task passive processing, it is less clear where the trajectory JND task would fit in to the continuum of passive to active processing.

A limitation of the conclusions from the present study is that it is difficult to rule out speed of processing as an explanation of the age differences found in the pattern and sequence span tasks. Older adults have been shown to have a slower speed of processing than younger adults (Cerella, 1985; Salthouse, 1982, 1996) and this slower rate of processing has been shown to account for age differences in central executive in the study by Fisk & Warr (1996). It may also be able to account for the age-related decline in pattern and sequence span in the present study. Salthouse (1994) has suggested that because similar effects of age are evident across both verbal and visuo-spatial domains, then there is likely to be a common factor such as speed of processing underlying them. However, given the differential effect of age in this study between tasks that make demands on central executive processing and those that

don't, it is difficult to see how a general factor such as speed of processing could account for the pattern of results. In order to rule out speed of processing as a complete explanation for age differences in tasks relying on central executive functioning, future research will need to control for the influence of speed of processing to see if age differences remain.

To conclude the current study suggests that age-differences in working memory are a consequence of an age-related decline in the central executive component rather than the slave system components. However, the findings are limited in that they do not take recent developments suggesting a fractionation of central executive functions into account; nor can they rule out age-related declines in speed of processing as an explanation of age differences in central executive processing. Further research is necessary to investigate the effects of age on different central executive functions, which also considers alternative explanations such as speed of processing. The next study is designed to address these issues and is designed to consider one of the central executive functions identified by Baddeley (1996), the strategic retrieval of information from long-term memory. One explanation for the age-differences found on the pattern span task in this current study, is that older adults may have difficulty in the use of strategies to integrate information into chunks; therefore the next study will concentrate on the use of strategy during retrieval, but within a different context, that of LTM retrieval. The use of strategic retrieval executive processes within tasks similar to the pattern and sequence span tasks used here has been demonstrated in a child development study by Hamilton et al (2003), who found that both visual and spatial span tasks showed interference effects from verbal fluency which is considered to make demands on executive strategic retrieval processes (Bryan, Luszcz & Crawford, 1997). The effects of aging will therefore be considered using verbal fluency tasks as measures of executive strategic retrieval in studies 2 & 3.

Chapter 5

Studies 2 & 3 - Verbal Fluency and Aging

5.1: General Rationale for Studies 2 & 3

The main conclusion from study 1 (chapter 4) was that age differences in working memory were more evident in tasks that made extensive demands on the central executive component of working memory, than those which utilised mainly slave system resources. The focus of studies 2 and 3 is to investigate the effects of age on central executive functioning further, by considering one specific central executive function, that of strategic retrieval. One possible explanation for the age differences found in the pattern span task in study 1, was that older adults may have greater difficulty in initiating effective strategies to aid recall. In relation to LTM a distinction between strategic and automatic retrieval has been made by Burgess (1997). Burgess (1997) argues that non-executive retrieval from LTM occurs as an automatic response to environmental cues or via well-learned associations, whereas executive LTM retrieval involves an active, strategic memory search, which is consciously planned and under voluntary control. Baddeley (1996) highlights retrieval from LTM as one of the main functions of the central executive component of working memory and it may be that it is this voluntary and effortful strategic aspect of retrieval that makes demands upon the central executive component, regardless of whether retrieval is from the short-term slave systems or LTM.

One paradigm which has been used extensively to investigate executive retrieval from LTM is fluency measures. Verbal and non-verbal fluency measures have been assumed to make demands upon frontal executive functions (Baddeley et al, 1997; Baldo & Shimamura, 1998; Benton, 1968) and versions of these tasks will be used in studies 2 and 3 to investigate the effects of age and central executive strategy use on retrieval. Studies 2 & 3 will investigate the effects of age on the executive function of strategic retrieval from LTM using verbal and non-verbal fluency tasks. Study 2 will be considered in sections 5.1 – 5.4 and study 3 in sections 5.5 – 5.8. Section 5.9 will conclude with a general discussion of the main findings from the two studies.

5.2: Study 2: Introduction

Study 2 aims to investigate the effects of age on executive strategic retrieval in letter and excluded letter fluency tasks. Both letter fluency (Moscovitch, 1995; Rosen, 1980) and excluded letter fluency (Bryan et al, 1997; Hughes & Bryan, 2002) are considered to make demands on executive processes of effortful strategic search and retrieval, although excluded letter fluency is likely to make greater executive demands than letter fluency (Bryan & Luszcz, 2000) given the requirement to inhibit responses that do contain the letter to be excluded.

Considering the assumption that executive processes decline with age (see section 3.5), an age-related decline in verbal fluency would be expected, particularly in letter fluency and excluded letter fluency tasks, which have been considered to place greater reliance upon executive processes. However, the empirical evidence is not wholly consistent with this view, with some studies finding that verbal fluency declines with normal aging (Bolla, Gray, Resnick, Galante & Kawas, 1998; Tombaugh, Kozak & Rees, 1999), some finding no effects of age (Bolla, Lindgren, Bonaccorsy & Bleeker, 1990) and some finding effects of age on some but not all measures of verbal fluency (Bryan et al, 1997; Kozora & Cullum, 1995).

One explanation for these differential findings is that it reflects differences in the type of fluency task used and it has been suggested that greater age difference are evident in category fluency, with only small or no age effects in letter fluency (Kozora & Cullum, 1995; Tomer & Levin, 1993). However, other studies have found similar age-related declines in letter fluency and category fluency (Bayles, Trosset, Tomeda, Montgomery & Wilson, 1993; Bolla et al, 1998; Gladsjo, Schuman, Evans, Peavy, Miller & Heaton, 1999).

One possible reason for the lack of age-related declines on some verbal fluency tasks may be that older adults have a greater verbal knowledge or verbal intelligence than younger adults and that this increased verbal ability could compensate for age related declines in the executive component of the task. The impact of verbal intelligence on fluency performance has been demonstrated in a number of studies (Bolla et al, 1990,

1998; Bolter, Long & Wagner, 1983; Phillips, 1999) who found evidence of a strong relationship between verbal intelligence and fluency performance in older adults.

Phillips (1999) found that intelligence predicts the use of retrieval strategies in fluency tasks; however, no relationship between age and strategy use was found in this study, suggesting that age and intelligence have separate influences on fluency performance and that letter fluency makes few demands on executive processes. The lack of a relationship between age and strategy use in the Phillips (1999) study however could be explained in terms of the measurement of strategy used. Strategy use was measured in terms of percentage strategy use, which gives a measure of the overall use of a particular strategy. It is likely that this is measuring non-executive retrieval similar to the concept of clustering discussed by Troyer et al (1997) (see section 2.4.3), rather than an executive process of generating or switching retrieval strategies. According to Troyer et al (1997) once a strategy has been initiated (within a cluster) then generation within that strategy will be automatic and rely on semantic memory. Like cluster size, percentage strategy use measures the number of words generated within a particular strategy and therefore is less likely to require executive processes. As such, the use of this method for measuring strategy use cannot rule out the influence of executive processes in initiating or switching strategies during letter fluency. The conclusion that letter fluency does not rely on executive processes can also be criticised for not taking into account the putative fractionation of the central executive. Only the executive process of strategy use during retrieval is considered, and it is not possible given the task used to determine the influence of other possible executive processes, such as inhibitory processing or the switching of retrieval strategies.

Although there appears to be a relationship between intelligence and fluency performance, Salthouse (1993) argues that it is unlikely that increased verbal intelligence in older adults can compensate for declines in other cognitive abilities, such as executive processing or speed of processing, which may also affect fluency performance. The influence of speed of processing on fluency performance has been highlighted in a number of studies, which have suggested that an age-related reduction in speed of processing can account for age differences in verbal fluency performance (Lindenberger, Mayr & Kliegl, 1993; Phillips, 1999; Salthouse, 1993;

Salthouse, Fristoe & Rhee, 1996). Phillips (1999) demonstrated that age-related declines in letter fluency were strongly related to a speed of processing measure, handwriting speed, and suggested that age-related variations in low-level motor speed can account for most of the age-related declines in letter fluency use. However, it could be argued that the requirement for a written response during the letter fluency task is responsible for the relationship between handwriting speed and letter fluency performance. The use of oral responses would reduce the reliance on motor speed at the response stage and allow for a more valid assessment of the relationship between letter fluency retrieval processes and speed of processing.

The limitations in the study by Phillips (1999) make it difficult to draw firm conclusions regarding the influence of executive processes, verbal intelligence and speed of processing on age differences in letter fluency. Another study which may provide a clearer picture of these influences is that by Bryan et al (1997). Bryan et al (1997) looked at the influence of verbal knowledge and speed of processing on letter and excluded letter fluency tasks among older adults, using oral generation. Excluded letter fluency is considered to rely on executive processes to an even greater extent than letter fluency, as it is unlikely that words are stored in memory on the basis of the absence of a letter, thus requiring the initiation of a strategic search (Hughes & Bryan, 2002). It is also likely that excluded letter fluency will require the active inhibition of words that do include the letter to be excluded and therefore will rely on executive inhibitory processes. Results from the study by Bryan et al (1997) indicated that excluded letter fluency showed a greater age-related decrement than letter fluency and that verbal knowledge was the best predictor of letter fluency performance, whereas speed of processing was the best predictor of excluded letter fluency performance. However, age differences in both letter and excluded letter fluency were mediated by speed of processing.

Findings from the Phillips (1999) and Bryan et al (1997) studies highlight the importance of verbal intelligence or knowledge and speed of processing to letter and excluded letter fluency performance as measured by the total number of words generated and suggest that any age differences evident can be explained mainly by speed of processing. However, it has been suggested that using strategy measures rather than just the number of words generated is a more useful method for

investigating verbal fluency performance (see section 2.4.3). Although the study by Phillips (1999) does examine the percentage strategy use, the limitations of this measurement make it difficult to draw firm conclusions.

In an investigation of age differences in clustering and switching strategies during letter and category fluency, Troyer et al (1997) found that in category fluency older adults switched less than young adults, whereas in letter fluency older adults produced larger clusters than young adults. However, Abwender et al (2001) argue that the method used by Troyer et al (1997) to calculate the number of switches does not adequately represent the processes it purports to. Troyer et al (1997) calculate switching as the number of transitions between adjacent clusters, including single-word clusters. It is questionable whether transitions between single words truly represents an ability to switch retrieval strategies as the generation of single word clusters may not be part of strategic retrieval, but merely the random retrieval of words that are randomly generated.

Using similar measures for clustering and switching, and two different measures, number of clusters and a cluster size/switch ratio, which are considered to measure the efficacy of strategic search processes, Hughes and Bryan (2002) investigated the effects of age and executive strategy use on initial and excluded letter fluency. The influences of verbal ability, speed of processing and executive functioning were also taken into account. Results indicated that age difference in excluded letter fluency could be accounted for by the number of clusters produced; no age differences were found on initial letter fluency. They also found that performance on both letter and excluded letter tasks was related to the number of switches and clusters. Verbal ability and speed of processing measures were found to be related to performance on both letter and excluded letter tasks. However, executive functioning, as measured by Stroop and self ordered pointing tasks, was only related to excluded letter fluency, suggesting that excluded letter fluency places greater reliance on executive processes than letter fluency.

So far, only limited research has been carried out investigating the effects of age on strategy measures of verbal fluency performance. The studies by Troyer et al (1997 and Hughes & Bryan (2002) suggest that clustering and switching between clusters is

related to performance on fluency tasks and that there are age differences in some of these measures. However, given the problems highlighted by Abwender et al (2001) it is clear that further research using more valid clustering and switching measures is needed to clarify the role of executive strategic retrieval in accounting for age differences in verbal fluency. The current study aims to investigate the underlying executive processes involved in strategic search by using a variety of strategy measures for both letter and excluded letter fluency tasks, as well as the more traditional measures of the number of words produced. It is predicted that for both tasks older adults will generate fewer words than young adults, but that this age difference will be greater in the excluded letter fluency task.

Despite the limitations in percentage strategy use discussed earlier, percentage strategy use of semantic, phonemic and alphabetic strategies will be measured, similar to Phillips (1999), so that task consistent and task discrepant strategy use can be identified and a total use of strategy calculated. Given the suggestion that excluded letter places greater demands upon executive resources than letter fluency, it is predicted that there will be a greater total percentage strategy use during excluded letter fluency compared to letter fluency. It is also predicted that older adults will show less use of strategy than young adults.

Given the criticisms of the strategy switching measure used by Troyer et al (1997), the method proposed by Abwender et al (2001) will be used, which differentiates between cluster switches and hard switches, alongside a new adaptation of the Troyer et al (1997) switching measure. According to Abwender et al (2001) cluster switches are transitions between two adjacent or overlapping clusters, which is presumed to be a measure of executively controlled strategic switching. Hard switches are transitions between either two non-clustered words or between a cluster and a non-clustered word and are considered to prepresent non strategic switching which will be dependent upon speed of processing rathe than executive control (Abwender et al, 2001). The new adapted measure includes words produced non-strategically, but rather than including switches between each individual non-strategy word, words produced non-strategically between two clusters will be grouped together so that the switching measures will include a switch from a strategically produced cluster, to a non-strategic group of words and vice versa. By not counting switches between each

individual non-strategy word, it is hoped that this method of measuring switches is a more appropriate measure of the switching concept in relation to strategy switches which are under executive control.

It is predicted that older adults will show fewer cluster switches than young adults because of the executive demands of the cluster switching measure, and that they will also show fewer hard switches, given the relationship between hard switches and speed of processing. Older adults will also be expected to show fewer switches on the new measure than young adults. Given that the excluded letter fluency task is considered to make greater demands on executive processes than initial letter fluency, it is predicted that older adults will be particularly impaired in the number of cluster switches and switches using the new measure on the excluded letter fluency task.

A measure of cluster size will also be taken. As cluster size is presumed to rely upon verbal ability it is likely that any age differences will favour older adults. Measures of verbal ability / intelligence and speed of processing will be taken and used as controls in the analysis, so that age differences in executive processes can be examined independently of speed of processing and verbal intelligence.

5.3: Study 2: Method

5.3.1: Design

A quasi-experimental mixed factorial design was used to investigate the effects of age and type of task on verbal fluency performance. The between subjects being age, with two levels (young adults aged 18 – 30 years and older adults aged 65 years plus), and the within subjects factor being type of task, with two levels (initial letter and excluded letter cues). Initial letter and excluded letter verbal fluency tasks were selected to make differential demands on central executive functions.

Verbal fluency performance was measured using a number of dependent variables. Firstly, performance was measured as the total number of permissible words generated after one, two and three minutes; and secondly, strategy use was measured for each task using percentage scores of phonemic, alphabetic, semantic and total strategy use, cluster size and number of switches, hard switches and cluster switches.

See appendix 3 for operational definitions of the strategies and how the strategy scores were calculated. Strategy measures as well as total number of words generated were used as performance indicators to provide a more complete picture of the underlying processes used during letter and excluded letter performance, given that a number of studies have shown that fluency tasks rely on a number of different executive and non executive processes (e.g. Bryan et al, 1997; Phillips, 1999; Rende et al, 2002; Troyer et al, 1997).

Control measures of verbal intelligence, speed of processing and dementia were also taken, given the possible reliance of fluency tasks on other processes such as verbal ability, intelligence and speed of processing (Phillips, 1997; 1999).

5.3.2: Participants

A convenience sample of twenty young adults (16 females and 4 males) aged 18-30 years (mean age 21.8 years, standard deviation 3.9) and twenty older adults (15 females and 5 males) aged 65 plus (mean age 73.6 years, standard deviation 6.5) was used. For this study and the remaining studies no middle-aged group was used, as results from study 1 indicate that there may be declines between young and middle aged adults on some tasks (e.g. the sequence span) but not other tasks (e.g. the pattern span), which make demands on central executive processes. The most consistent age differences were evident between the extreme (young and old adult) age groups and therefore only these groups will be used for the remaining studies. The sample of young adults was obtained from among undergraduate University students, University administration staff and nursing auxiliary staff from a local nursing home. The older adults sample was obtained from day centres and community centres for the over 65's and from a sheltered housing scheme.

Inclusion criteria for the study were that participants must fit into the specified age groups, be living independently in the community, and be healthy (determined by participants self report). All participants were screened for dementia using the MMSE dementia screening test and excluded from the study if they scored below the acceptable cut off point (see section 4.2).

MMSE scores for those included in the study showed a significant age difference ($t(38) = 2.54$, $p = 0.015$) with older adults showing a lower mean score than young adults (28.6 and 29.5 respectively). Older adults had a slightly higher verbal IQ than young adults (107 and 103 respectively); however, this difference was not significant ($t(38) = -1.40$, $p = 0.17$). There was a significant difference however between old and young adults in terms of speed of processing ($t(38) = -4.23$, $p = 0.0001$), with older adults being slower than young adults (0.30 and 0.21 seconds per word respectively).

5.3.3: Tasks

The initial letter fluency task was a shortened version of the Controlled Oral Word Association Test (Benton, 1968; Spreen & Benton, 1969), which requires participants to generate as many words as possible beginning with a particular letter. In this study participants were required to generate as many words as possible orally beginning with the letter 'a' over a three minute time period. Responses were tape recorded and recorded in written format by the experimenter.

The excluded letter fluency task was based on the one devised by Bryan et al (1997), where participants are required to generate as many words as possible that do not include a particular letter anywhere within them. In this study participants were asked to generate words orally over a three minute time period that do not include the letter 'a'. Responses were tape recorded and written down by the experimenter.

Dementia and verbal IQ were measured using the same tasks as in study 1 (MMSE and NART respectively; see section 4.2 for description of these tasks and scoring procedure). Speed of processing was measured using a speech articulation task. In this task participants are required to repeat the words 1-2-3-4-5 fifteen times as quickly as possible and the time taken to complete this is recorded in seconds. Within childhood development studies (Chuah & Maybery, 1999; Hamilton, Coates & Heffernan, 2003; Smyth & Scholey, 1996) and within adult aging studies (Bryan & Luszcz, 1996; Hughes & Bryan, 2002) this task has been assumed to reflect general speed of processing. One criticism of the speed of processing tasks highlighted in section 3.2, is that speed of processing measures also rely on other processes, such as perceptual and motor speed. The speech articulation rate task is likely to make minimal demands on perceptual and motor processes and therefore should provide a

purer measure of general cognitive slowing and it has been argued by Hughes & Bryan (2002, pp.651) that articulation rate "may reflect the speed at which basic verbal processes are carried out".

5.3.4: Procedure

Participants were tested on an individual basis. All participants completed the MMSE dementia screening test first, and any scoring below the cut off point were excluded from the study. The NART and speech articulation tasks were then completed. The speech articulation task was completed four times and the mean of these taken. The mean score was then divided by the number of words repeated in each trial of the task (75) to give the mean time per word, measured in seconds.

Participants were then asked to complete the initial letter and excluded letter fluency tasks, with half of each age group randomly allocated to complete the initial letter fluency task first and half the excluded letter fluency task first. In the initial letter fluency task participants were asked to generate as many words as possible beginning with the letter 'a' over a three minute time period. Participants were asked to generate the words orally to reduce the effects of motor speed on performance. Rules for the generation of words were the same as those used by Phillips (1999). No repetitions were allowed, no proper nouns and no variations of words stemming from the same word root. All the words generated by the participant were recorded on a tape recorder and in written form by the experimenter. The initial letter fluency score was calculated as the total number of permissible words generated after 1 minute, 2 minutes and 3 minutes. A similar procedure was used for the excluded letter fluency task, participants were asked to generate orally as many words as possible that did not include the letter 'a' anywhere within them. Rules for generating words, recording and scoring procedure were the same as for the initial letter fluency task.

Strategy measurement for both the initial letter and excluded letter fluency tasks was measured in a number of different ways. Percentage strategy use was measured for total strategy, phonemic strategy, alphabetic strategy and semantic strategy types using a similar procedure to that described by Phillips (1999), (see appendix 3 for definitions of the different types of strategy measured and how percentage strategy use was calculated). In this study very few participants made use of a strictly

alphabetic strategy and it tended to be used as part of an overall phonemic strategy, therefore for analysis purposes alphabetic strategy use was combined with phonemic strategy use. Strategy use was also measured in terms of clustering and switching, using similar definitions and calculation to those used by Troyer et al (1997), (see appendix 3 for description and calculation of clustering and switching strategies).

5.4: Study 2: Results

5.4.1: Data Analysis

Mean and standard deviation scores for all dependent variables and for MMSE, NART and speech articulation rate measures were calculated for young and old adult age groups. To determine the effects of age and type of task on the number of words generated and the strategy measures, a series of two factor mixed ANOVAs were carried out. Two factor mixed ANCOVA analyses were also undertaken using IQ and speed of processing as covariates, separately and together. Post hoc analysis of significant interactions used Bonferroni corrected one way ANOVAs and ANCOVAs, with a corrected p value of 0.0125 or less indicating a significant simple effect. Only ANOVA and ANCOVA analyses with both covariates will be reported and discussed in detail in the results and discussion sections. ANCOVA and post hoc analyses with only IQ or speed of processing as covariates will be included in appendix 4 and specific points of interest referred to in the discussion section. All results were analysed for scores after 1, 2 and 3 minutes however as little difference was evident in ANOVA results between the different time intervals only results for the 3 minute time interval are reported within the thesis.

5.4.2: Number of Words Generated during Verbal Fluency

ANOVA analysis indicated no significant effect of age on the mean number of words produced during verbal fluency ($p>0.05$). However, a significant effect of type of task ($F(1,38) = 51.40$, $p = 0.0001$) and a significant interaction between task and age ($F(1,38) = 23.753$, $p = 0.0001$) were evident. Mean scores (see table 5.1) suggest that young and old adults produce a similar number of words in the letter fluency task, whereas young adults are able to produce a much greater number of words than old adults on the excluded letter fluency task. Post hoc analysis of the ANOVA interaction indicated a significant difference between young and old adults in the

excluded letter fluency task ($F(1,38) = 9.941$, $p = 0.003$), but not between young and old adults in the letter fluency task ($p>0.0125$), thus supporting the hypothesis that age differences would be greater in the excluded letter than the initial letter fluency task. No simple effect of task type was found for older adults ($p>0.0125$), but younger adults showed a much larger number of words generated in the excluded compared to the letter fluency task ($F(1,19) = 76.962$, $p = 0.0001$).

	Letter Fluency	**Excluded Letter Fluency**
Young adults	18.60 (6.54)	34.60 (8.15)
Older adults	20.80 (10.39)	23.85 (12.89)

Table 5.1: Mean (standard deviation) number of words generated for Young and Old Adults on Letter and Excluded Letter Fluency Tasks

The same pattern of significance is evident in the ANCOVA analysis controlling for speed of processing and IQ with no significant effect of age ($p>0.05$), but significant effects of type of task ($F(1,34) = 6.957$, $p = 0.013$) and a significant interaction between age and type of task ($F(1,34) = 4.719$, $p = 0.037$). The interaction effect can be seen in figure 5.1. Post hoc analysis of the ANCOVA interaction showed no significant simple effects at the 0.0125 level of significance.

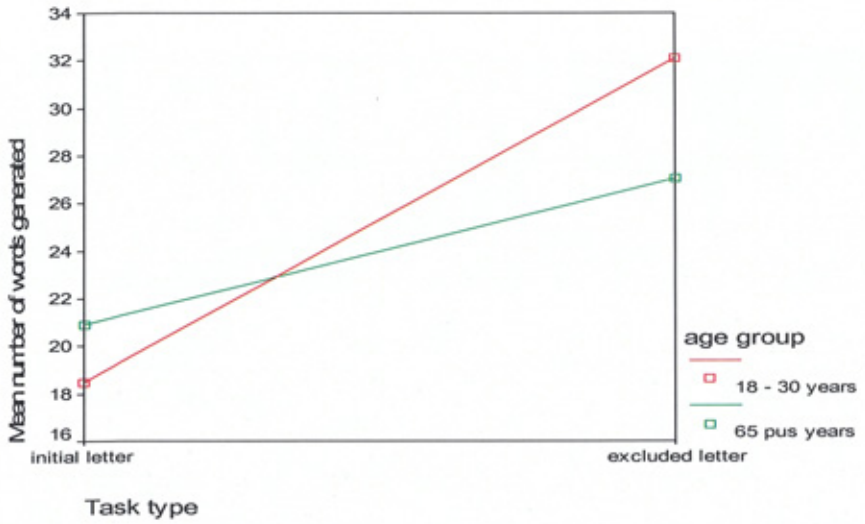


Figure 5.1: Interaction between Age and Task Type on the Number of Words Generated (controlling for speed of processing and IQ)

5.4.3: Strategy Use during Verbal Fluency

Total percentage strategy use appears to be much greater for the excluded letter than the initial letter fluency task (see table 5.2) and ANOVA analysis indicates that this difference is significant ($F(1,38) = 50.179$, $p = 0.0001$), supporting the hypothesis that there will be a greater use of strategy during excluded letter fluency. No significant main effects of age ($p>0.05$) or interaction between age and type of task ($p>0.05$) were evident. ANCOVA analysis using speed of processing and IQ as covariates removes the significant main effect of task type ($p>0.05$), suggesting that differences in total strategy use can be accounted for by speed of processing and IQ. No significant main effect of age or interaction between age and task type ($p>0.05$) are evident when speed of processing and IQ are controlled for.

	Letter Fluency			**Excluded Letter Fluency**		
	Total Strategy %	**Phonemic Strategy %**	**Semantic Strategy %**	**Total Strategy %**	**Phonemic Strategy %**	**Semantic Strategy %**
Young Adults	13.50 (16.95)	11.50 (15.05)	2.00 (5.12)	54.60 (26.07)	11.80 (21.98)	41.00 (25.56)
Older Adults	29.50 (30.51)	29.50 (30.51)	0.00 (0.00)	58.65 (32.88)	39.30 (37.36)	20.20 (25.46)

Table 5.2: Percentage Strategy Use for Young and Old Adults during Letter and Excluded Letter Fluency Tasks

Use of a phonemic strategy appears to be greater among older adults than young adults in both the letter and excluded letter fluency tasks (see table 5.2), and the ANOVA analysis shows that this main effect of age is significant ($F(1,38) = 9.908$, $p = 0.003$). No significant effect of task type ($p>0.05$) or interaction between age and task type ($p>0.05$) are evident however. ANCOVA analysis controlling for speed of processing and IQ shows no significant main effects of age, type of task, or interaction between age and task type ($p>0.05$), suggesting that the effect of age on phonemic strategy use can be accounted for by speed of processing and IQ.

ANOVA analysis of semantic strategy use shows a significant main effect of age ($F(1,38) = 7.462$, $p = 0.010$), a significant main effect of task type ($F(1,38) = 55.748$, $p = 0.0001$) and a significant interaction between age and task type ($F1,38) = 5.622$, $p = 0.023$). Mean figures indicate that use of a semantic strategy appears to be limited

during letter fluency in both young and old adults, with older adults showing no use of semantic strategy at all in the letter fluency task. Both age groups make some use of a semantic strategy during excluded letter fluency, with young adults making a much greater use of a semantic strategy than older adults (see table 5.2).

However, the significant main effects of age, type of task and the interaction between them found in the ANOVA analysis are eliminated when both speed of processing and IQ are controlled for, with the ANCOVA showing no significant main effect of age, no significant effect of task type and no significant interaction ($p>0.05$), suggesting that the effects of age and type of task on semantic strategy use can be accounted for by speed of processing and IQ.

5.4.4: Clustering and Switching During Verbal Fluency

In relation to the size of clusters ANOVA analysis found: a significant main effect of task ($F(1,38) = 11.201$, $p = 0.002$), with slightly larger clusters in the excluded letter task compared to the initial letter task (see table 5.3); and a significant main effect of age ($F(1,38) = 4.849$, $p = 0.034$), with older adults producing slightly larger clusters than young adults (see table 5.3). No significant interaction between age and task type was found though ($p>0.05$). When speed of processing and IQ were controlled for in the ANCOVA analysis the significant main effect of age remained ($F1,34) = 4.164$, $p = 0.049$); however, the effect of task type was removed ($p>0.05$). No interaction between age and task type was found ($p>0.05$). These results suggest that whilst differences in cluster size between the two tasks can be accounted for by speed of processing and IQ, age differences in cluster size are independent of speed of processing and IQ.

	Letter fluency Cluster size	**Excluded letter fluency Cluster size**
Young Adults	1.11 (0.57)	2.11 (0.92)
Old Adults	2.04 (1.62)	2.67 (1.76)

Table 5.3: Mean (standard deviation) Clustering scores for Young and Old Adults during Letter and Excluded Letter Fluency Tasks

ANOVA analysis of the number of switches found a significant main effect of type of task ($F(1,38) = 21.794$, $p = 0.0001$), with more switches made in the excluded letter compared to the initial letter fluency task (see table 5.4); a significant main effect of age ($F(1,38) = 10.433$, $p = 0.003$), with young adults making more switches than older adults (see table 5.4); and a significant interaction between age and task type ($F(1,38) = 11.052$, $p = 0.002$).

	Letter Fluency			Excluded Letter Fluency		
	Number of switches	**Number of hard switches**	**Number of cluster switches**	**Number of switches**	**Number of hard switches**	**Number of cluster switches**
Young Adults	6.00 (3.32)	8.55 (4.08)	1.50 (1.70)	11.65 (3.41)	7.00 (4.61)	5.15 (2.89)
Old Adults	5.70 (3.26)	7.60 (5.69)	1.60 (2.04)	6.65 (3.67)	3.25 (2.63)	3.55 (4.35)

Table 5.4: Mean (standard deviation) Switching Scores for Young and Old Adults during Letter and Excluded Letter Fluency

When controlling for speed of processing and IQ in the ANCOVA analysis the significant main effect of age remains ($F(1,34) = 4.357$, $p = 0.044$). However, the main effect of type of task and the interaction between age and task type are no longer significant ($p>0.05$), suggesting that the effect of task but not the effect of age can be accounted for by speed of processing and IQ.

In terms of the number of hard switches made, older adults appear to make fewer hard switches than young adults, and there are fewer hard switches during excluded letter compared to initial letter fluency (see table 5.4). This difference between the age groups and the two tasks is found to be significant in the ANOVA analysis with a significant main effect of task type ($F(1,38) = 7.526$, $p = 0.009$), and a significant main effect of age ($F(1,38), = 7.129$, $p = 0.011$), but no significant interaction ($p>0.05$): thus supporting the hypothesis that older adults will make fewer hard switches than young adults. However, controlling for speed of processing and IQ in the ANCOVA analysis eliminates all significant effects ($p>0.05$), suggesting that differences in the number of hard switches can be accounted for by differences in speed of processing and IQ between young and old adults.

As expected a significant difference in the number of cluster switches between initial letter and excluded letter fluency tasks is evident ($F(1,38) = 38.012$, $p = 0.0001$), with a larger number of cluster switches made during excluded letter fluency than initial letter fluency (see table5.4). However, no significant effects of age or interaction between age and task type were found ($p>0.05$), which does not support the hypothesis that older adults will make fewer cluster switches than young adults. No significant differences were found in the ANCOVA analysis when speed of processing and IQ were controlled for ($p>0.05$).

5.5: Study 2: Discussion

5.5.1: Number of Words Generated

The pattern of results for the number of words generated during the verbal fluency tasks provides partial support for the hypothesis that older adults will produce fewer words than young adults, particularly in the excluded letter fluency task. The significantly greater age-related declines in the number of words generated in excluded letter fluency compared to initial letter fluency supports the hypothesis and is consistent with previous literature (such as Bryan & Luszcz, 2000; Bryan et al, 1997; Hughes & Bryan, 2002). No significant age-related declines were found in the number of words generated in the letter fluency task however. Previous research investigating age-related changes in letter fluency has been inconsistent and the extent to which initial letter fluency makes demands on executive processes has been questioned (Phillips, 1999).

5.5.2: Strategy Use

To clarify the underlying processes involved in initial letter fluency and account for the age-equivalent performance, results from the strategy measures need to be considered alongside the number of words produced. One particularly interesting result which may be able to explain the lack of age effects on the initial fluency task is that older adults made more use of a phonemic strategy than young adults. If strategy use depends on executive processes then older adults would be expected to make less use of strategy than young adults if executive retrieval processes decline with age. The effect of age on phonemic strategy use is therefore the opposite of that expected. These contradictory results can be explained in two ways – either the executive

processes involved in the use of the phonemic strategy do not decline with age, or phonemic strategy use does not make demands on executive processes. Burgess (1997) distinguished executive retrieval from non-executive retrieval in terms of the voluntary, planned use of a strategic search for executive retrieval and an automatic response to environmental cues for non-executive retrieval. The phonemic nature of the initial letter cue used to guide retrieval during letter fluency may prompt the use of a phonemic strategy, therefore making the search more dependent on an automatically generated strategy rather than a voluntary, planned strategy, thus reducing the executive demands of the task. A similar view has also been put forward by Abwender et al (2001) who distinguish between task-consistent and task discrepant clustering during verbal fluency. They argue that phonemically related clusters of words on letter fluency are task-consistent, whereas, semantically related words would be task-discrepant and that it is task–discrepant clustering which reflects the voluntary or intentional use of strategy during executive retrieval, rather than task-consistent clustering. The use of a percentage phonemic strategy measure during initial letter fluency in the present study is similar in concept to the task-consistent cluster measure used by Abwender et al (1997) and therefore may reflect non-executive retrieval rather than an intentional executive strategic search.

Although this conceptualisation of the phonemic strategy use during initial letter fluency can explain why older adults do not make less use of a phonemic strategy, it does not adequately account for the opposite pattern of results found, with older adults making more use of a phonemic strategy than young adults during initial letter fluency. If phonemic strategy use during letter fluency does not rely on executive processes, what processes does it rely on? Two possible sources of the underlying processes responsible for the age differences in phonemic strategy use are either speed of processing or verbal IQ. Results from the present study show that the effect of age on phonemic fluency is removed when speed of processing and IQ are controlled for. To separate out the influences of speed of processing and IQ on phonemic strategy use the ANCOVA analyses with these as separate covariates needs to be considered (see appendix 4, section 4.2.2). In the separate ANCOVA's the effect of age remains when speed of processing is controlled for, but goes when IQ is controlled for, suggesting that the age differences in phonemic strategy use can be accounted for by differences in verbal IQ, rather than by speed of processing differences. The

relationship between verbal fluency and verbal IQ has been demonstrated in a number of studies (Bolla et al, 1990; 1998) and Phillips (1999) found evidence of a relationship between intelligence and the use of retrieval strategies during letter fluency.

However, results from the present study differ from those by Phillips (1999) in that Phillips (1999) found no relationship between age and strategy use. This difference may be due to differences in strategy measurement; in the Phillips (1999) study a combined strategy measure was taken which included both phonemic (task-consistent) and semantic (task-discrepant) strategies, whereas the current study separates out the two types of strategy. A total strategy use score similar to that used in the Phillips (1999) study was taken in the current study however and the pattern of age differences remained the same as those of the phonemic strategy use. In the current study among the older adults the use of a semantic strategy in either of the two tasks was so small (non-existent in the initial letter fluency), that the total strategy use score is very similar for the older adults to that of phonemic strategy use. Indeed the complete lack of a task discrepant semantic strategy in the initial letter fluency, which is likely to rely on executive processes, supports the previously discussed conclusion that initial letter fluency does not utilise an intentional executive retrieval strategy, but mainly relies on non-executive retrieval from LTM. This provides support for the argument put forward by Phillips (1997; 1999) that letter fluency is not a valid measure of executive processing.

Alternatively, the different findings may be due to age and intelligence differences between the two samples. Phillips (1999) examined the effects of age in a sample of adults between the ages of 56 to 61 with a low negative correlation between age and intelligence score, whereas the sample in the present study consists of adults aged 20 – 30 compared to older adults aged 65 – 87, with no difference in intelligence score between young and old adults. This wider age range and different relationship between age and IQ in the current study compared to the Phillips study may explain the different findings.

If the lack of age differences in initial letter fluency can be accounted for in terms of the use of a task-consistent strategy which makes demands on verbal intelligence

rather than executive processes, can the age-related decline in excluded letter fluency be accounted for in terms of the voluntary or intentional use of a task-discrepant strategy which relies on executive processes? Hughes & Bryan (2002) have suggested that excluded letter fluency requires the use of executive strategic search abilities and it is these abilities which decline with age. This view is supported to some extent in the current study. The total percentage strategy use is greater in the excluded letter fluency task than the initial letter fluency task and young adults make a much greater use of semantic strategy compared to older adults, particularly in the excluded letter fluency task. Older adults continue to make greater use of a phonemic strategy than young adults in the excluded letter fluency task. The pattern of strategy use in the excluded letter fluency tasks suggests that young adults are able to voluntarily utilise a task-discrepant semantic strategy, which is likely to rely on executive processes of strategic search, whereas the older adults continue to use a task-consistent strategy. The phonemic cue in the excluded fluency task, similarly to the cue used in the initial letter fluency is likely to prompt the use of a phonemic strategy; however, in the excluded letter task this may be a less effective strategy. Young adults are able to make use of executive processes to intentionally switch to a more effective task-discrepant task and therefore produce a greater number of words. The lower use of a task-discrepant strategy among older adults compared to young adults in the excluded fluency task may be a consequence of reduced executive resources, alternatively it may be accounted for by either speed of processing or verbal IQ differences. When both speed of processing and verbal IQ are controlled for, the age difference in the use of a semantic strategy goes. When this result is broken down further, neither speed of processing nor verbal IQ alone can remove the effect of age on semantic strategy use (see appendix 4, section 4.2.3), but when both are taken into account no age effects remain, suggesting that both speed of processing and verbal IQ contribute to semantic strategy use during initial and excluded letter fluency performance.

5.5.3: Switching of Retrieval Strategies

The voluntary use of a task-discrepant strategy may indicate the involvement of executive processes of strategic retrieval from LTM. However, this is only one potential executive function and given the putative fractionation of the central executive (Baddeley, 1996) it is also important to consider the contribution other

potential executive processes, such as the ability to switch retrieval strategies and the ability to inhibit task irrelevant responses, make to verbal fluency performance. The ability to switch retrieval strategies was examined in the present study through the use of three different switching measures. The general switching measure and cluster switching are presumed to reflect executive processes utilised during switching of retrieval strategies, whereas hard switching, which is switches between non-strategy words, is thought to rely more on speed of processing than executive processing (Abwender et al, 2001).

Results from the present study show that older adults made fewer hard switches than young adults, particularly in the excluded letter fluency task and this age-difference was removed when speed of processing and verbal IQ were controlled for. When the influences of speed of processing and verbal IQ were separated out, speed of processing alone removed the effect of age, whereas the effect of age remained when verbal IQ was controlled for (see appendix 4, section 4.3.3). This supports the views of Abwender et al (2001) that the number of hard switches is dependent on speed of processing rather than central executive resources and suggests that the reduced number of hard switches in the older adults compared to the young adults can be accounted for by their slower speed of processing.

The general switching measure and cluster switching were both assumed to reflect executively demanding switches between clusters of words. However, the pattern of results between the two measures is different, suggesting that they may not both measure the same concept. As predicted, results from the general switching measure indicate that whilst the number of switches made in the letter fluency task is similar for young and old adults, in the excluded letter fluency task young adults make more switches than the older adults, the effect of age remains when both speed of processing and IQ are controlled for. These results suggest that excluded fluency performance makes greater use of executively demanding strategy switching processes than letter fluency, thus providing further support for the conclusion of Bryan et al (1997), that excluded letter fluency is a more executively demanding task than initial letter fluency. The age difference found in the number of switches made on the excluded letter fluency suggests that the central executive process, switching of retrieval strategies, declines with age. However, results from the cluster switch

measure, which is also assumed to be a measure of central executive strategy switching processes, shows no decline with age.

The differing results from different switching measures are not easy to account for in terms of a single executive switching process and seem to indicate that switching relies on a number of different processes. It is also clear that the concept of 'switching' needs to be more clearly defined, in order to develop a measure which more accurately reflects the underlying process. Within a verbal fluency paradigm switching is conceptualised as the ability to alternate from one strategy cluster of words to another (Abwender et al, 2001; Troyer et al, 1997); however, what is not clear is whether switching includes alternating to non-clustered words and between non-clustered words making it difficult to identify an accurate measure of switching and the processes underlying it. Given the limitations in the interpretation of the switching measures used, it is difficult to draw firm conclusions regarding the effects of age on switching and the executive processes underlying switching performance.

In order to clarify the effects of age on the executive process of switching a clearer definition and more valid measure of the concept needs to be developed. An alternative definition of switching which is utilised within a task switching paradigm is that switching reflects the ability to alternate between two simple tasks, which is presumed to rely on executive processes of voluntary control (Rogers & Monsell, 1995) and is measured as the increased time taken to switch from one task to another compared to repeating the same task. The task switching paradigm appears to provide a much clearer definition of the concept of switching and therefore is likely to be a useful method for investigating age-related changes in the executive process of switching. The reliance on executive processes of voluntary control is also consistent with the use of a task-discrepant strategy in the excluded letter fluency task, which relies on the intentional or voluntary use of a strategy to generate words.

5.5.4: Inhibitory processes

An alternative explanation for the greater use of a task-discrepant strategy by young adults in the excluded fluency task, is that young adults may be more able than older adults to actively inhibit the use of an ineffective phonemic strategy, that is prompted by the excluded letter cue. In order to voluntarily switch to a more effective strategy,

a task-consistent, but ineffective, strategy will first have to be inhibited. There is a large body of research indicating that effective inhibitory processing declines with age (Hasher & Zacks, 1988; May, Hasher &Kane, 1999; McDowd & Shaw, 2000). However, the role of inhibitory processing within a verbal fluency paradigm has not been explicitly investigated. The excluded fluency task however seems to be a task that is likely to require inhibitory processing. The excluded letter cue may automatically activate words that include the letter to be excluded and these will need to be actively inhibited and a voluntary strategy to produce appropriate words initiated. The inhibition of automatic or habitual responses to a familiar cue has been highlighted by Hasher et al (2001) as one of three inhibitory functions and is consistent with the notion of executive control (Burgess, 1997). Age differences in excluded letter fluency performance may therefore reflect an age-related decline in the executive process of inhibition of prepotent or automatic responses. Older adults may be less able to inhibit automatically produced irrelevant responses and therefore produce fewer correct words than young adults during excluded letter fluency. Although not undertaken in this study, an examination of the number and nature of incorrect words may be a useful way of determining the extent of inhibitory processing during excluded letter fluency.

An alternative task that has been used to investigate inhibition of automatically generated responses is random generation (Baddeley, 1986). Few studies have investigated the effects of age on random generation; however, Van der Linden, Beerten & Pesenti (1998) have found an age-related decline on some measures of randomness during random generation, but not others. This task may therefore be a useful tool to investigate further the effects of age on executively mediated inhibitory processing.

5.5.5: Clustering

In both initial letter and excluded letter fluency older adults produced larger clusters than young adults. This is consistent with the findings by Troyer et al (1997). Cluster size is considered to reflect automatic retrieval from LTM, rather than executive strategic search processes (Troyer et al, 1997; Hughes & Bryan, 2002), thus suggesting that automatic retrieval from LTM is not impaired with age, but may be enhanced. One explanation for the larger cluster size in the older age group may be

that clustering relies on verbal IQ processes and that the increased cluster size in the older age group is a consequence of their slightly higher verbal IQ than the young adults. However, the effect of age remains when both verbal IQ and speed of processing are controlled for, indicating that verbal IQ differences cannot wholly account for the age differences in cluster size.

5.5.6: Conclusion

Results from study 2 suggest that excluded letter fluency is a more executively demanding task than letter fluency and as such shows a greater decline with age. Age differences are also evident in some of the strategy measures such as the use of a task discrepant strategy, general switching and hard switching which may account for excluded letter fluency performance. However the executive demands of these measures, particularly the switching measures, is difficult to determine because of limitations in the conceptualisation of switching and its operationalisation. This is evident by the inconsistency in results between the different switching measures. An additional limitation of the results is that they may only apply to the verbal domain, a replication of these results using similar non-verbal measures would strengthen the conclusion that age differences in fluency performance are a consequence of modality free executive resources.

5.6: Study 3: Introduction

The purpose of study 3 is to replicate the findings of study 2 within a non-verbal modality. Results from study 2 support previous research (such as Bryan et al, 1997), which suggest that excluded letter fluency places greater demands upon central executive processes than letter fluency, in particular, the executive ability to switch retrieval strategies. Given that the central executive is assumed to be modality free, age-related declines in performance on non-verbal fluency tasks should show similar patterns to those of verbal fluency.

Design fluency (Jones-Gotmann & Milner, 1977) and figural fluency (Ruff, Light & Evans, 1987) are considered to be non-verbal equivalent tasks to verbal fluency. The design fluency task requires the generation of as many unique and un-nameable drawn designs as possible within a given time period. Studies of design fluency performance

in patients with frontal lobe deficits show similar patterns of deficits to verbal fluency, with frontal lobe patients generating fewer designs and making more perseverative errors than normal controls (Jones-Gotmann & Milner, 1977; Tranel, Anderson & Benton, 1994), suggesting that design fluency makes demands on executive processes. Ruff et al (1987) however, have criticised the design fluency task because of the subjectivity of the scoring and the difficulty in interpreting the scoring criteria. They developed the Ruff figural fluency task, which requires the participants to connect dots together on dot matrices in as many unique ways as possible within a given time period. Figural fluency has also been shown to be correlated to performance on verbal fluency tasks (Demarkis & Harrison, 1997).

The effect of age on non-verbal fluency performance has been investigated by a number of researchers. Daigneault, Braun & Whitaker (1992) found no age differences in the number of designs produced, but that older adults made more perseverative errors than young adults, suggesting that it is the monitoring of responses rather than the ability to generate strategies that declines with age. The lack of age effects in the number of designs produced, in the Daigneault et al (1992) study, may have been due to the age groups used. Their older adults were aged 45 – 65 years and it is likely that fluency performance does not decline until later in life than this. The majority of studies using older ages have found that performance does decline with age; with older adults producing fewer designs than young adults (Keys & White, 2000; Mittenberg, Seidenberg, O'Leary & Di Guilio, 1989; Phillips, 1999; Ruff et al, 1987). Phillips (1999) suggests that this decline in non-verbal fluency performance with age is due to the inability of older adults to generate and make use of effective retrieval strategies and argues that because of this it is a more valid measure of executive functioning than verbal fluency.

Both the design fluency and the figural fluency tasks involve the generation of novel, unique designs and appear to make demands on the central executive in terms of strategy generation and monitoring of responses. However, in terms of strategic retrieval they cannot be considered to be non-verbal equivalents to verbal fluency. Whereas verbal fluency requires the retrieval of words from LTM, the design and figural fluency tasks require the generation of new designs. For the purpose of the present study, these tasks are therefore not suitable as non-verbal equivalents to the

letter and excluded letter fluency task and new tasks were therefore designed to place demands on the executive process of strategic retrieval from LTM, but requiring non-verbal rather than verbal strategies. Two new tasks were developed to meet this purpose – shape and excluded shape fluency.

The shape fluency task required the verbal generation of as many objects as possible of a particular shape (in this case rectangular or cube shaped) within a set time period of 3 minutes. The task was designed to be equivalent to the letter fluency task in study 2 apart from a cue with non verbal properties (shape) being given rather than a verbally based cue. The use of a cue based on the non-verbal properties of the objects to be produced was hoped to encourage participants to use executive non-verbal strategies to generate words, as words are not likely to be stored in LTM on the basis of their shape. The excluded shape fluency task requires the generation of as many object words as possible that are not of a given shape (in this case not rectangular or cube shaped) within three minutes. This task was designed to be equivalent to the excluded letter fluency task in all respects, apart from the use of a non-verbal cue, instead of a verbally based cue. Similarly to the excluded letter task the excluded shape task is likely to place greater reliance on executive processes of strategic retrieval and inhibition.

The same measures of fluency performance will be used in study 3 as those in study 2: the number of words generated; percentage total phonemic and semantic strategy use; size of clusters; number of switches; number of hard switches; and number of cluster switches. Additionally, participants will be asked to indicate if they have used any strategy to help them generate words, and if so, what. This is to identify any new strategies used with the use of a non-verbal cue.

The aims of study 3 are to investigate the effects of age and task demands on performance in the shape and excluded shape fluency tasks. In particular, the effects of age and task demands will be examined in terms of the number of words generated and the use of strategic retrieval. As these tasks have not been used before, precise predictions regarding the tasks is difficult, however a similar pattern of results is expected to those in study 2.

5.7: Study 3: Method

5.7.1: Design

A quasi-experimental mixed factorial design was used to examine the effects of age and type of retrieval cue on non-verbal fluency performance. The between subjects factor being age, with two levels (young adults, aged 18 – 30 years and older adults 65 plus years), and the within subjects factor being type of retrieval cue and having two levels (shape and excluded shape cues).

A number of dependent variables were used to measure fluency performance. Firstly, the total number of words generated was measured after one minute, two minutes and three minutes. Secondly, strategy use during shape and exclude shape fluency was measured in terms of total, phonemic, alphabetic and semantic percentage strategy use, cluster size and switches between strategies were also measured. These strategy measures are the same as those used in study 2 (see appendix 3 for definitions and strategy use calculations).

Control measures of dementia, speed of processing and verbal intelligence were also taken, so that their effects on shape and excluded shape fluency performance could be determined and controlled for during the analysis.

5.7.2: Participants

A convenience sample of 20 young adults and 20 older adults (same participants as those used in study 2) was taken. See section 5.3.2 for description of sample.

5.7.3: Tasks

Measures of dementia (MMSE), speed of processing (speech articulation rate) and verbal intelligence (NART) were the same as those used in study 2 (see section 5.3.3 for details).

The experimental tasks of shape and excluded shape fluency were developed to measure central executive processes involved in the strategic retrieval from LTM, using cues based on non-verbal information, but otherwise equivalent to the verbal fluency tasks used in study 2. In the shape fluency task participants are required to

generate orally as many objects as possible that have a given shape (in this case rectangular or cube shaped) over a three minute time period. For the excluded shape task participants are required to generate orally as many objects as possible that are not of the given shape (rectangular or cube shaped) over a three minute time period.

5.7.4: Procedure

All participants were tested individually within the same testing session as study 2. As the same participants were used, scores for the control measures of MMSE, NART and speech articulation rate taken in study 2 were used. Half of the participants within each age group were then randomly allocated to complete the shape fluency task first and half to complete the excluded shape fluency task first. Rules for the generation of words were the same as study 2; no repetitions, no proper nouns and no variations of words stemming from the same word root. The words generated by the participant were recorded using a tape recorder and written down by the experimenter.

After the two tasks were completed, participants were asked what if any strategies they had used to help them generate words. This was to identify if any new strategies were used that were specific to these newly developed tasks. The most common strategy stated by participants was the use of visualisation, e.g. visualising objects in rooms around their home. In practice, the words generated using this strategy were very difficult to distinguish from the semantic strategy used in the verbal fluency tasks and therefore the visualisation strategy was classed along with the semantic strategy for analysis purposes. Apart from this strategy, measurement was the same as in study 2 (see appendix 3 for details).

5.8: Study 3: Results

5.8.1: Data Analysis

Mean and standard deviation scores for young and old adults were calculated for the total number of words produced in the shape and excluded shape fluency tasks and for all strategy, clustering and switching measures for both tasks. As the same participants were used as those in study 2, MMSE, NART and speech articulation rate scores were used from study 2. The effects of age and type of task on the number of words generated on the various strategy, clustering and switching measures were

investigated using two factor mixed ANOVAs. Two factor mixed ANCOVA's using NART and speech articulation scores as covariates, both separately and together, to control for IQ and speed of processing respectively, were also conducted. Post hoc analysis used Bonferroni corrected one way ANOVAs and ANCOVAs, with a corrected p value of 0.0125 or less to identify simple effects. As for study 2, only results from the ANOVAs and ANCOVAs controlling for both speed of processing and IQ are reported within the results section. Results relating to ANCOVA analyses controlling for speed of processing and IQ individually are included in appendix 4 and any specific points of interest from these will be discussed within the discussion section. Scores for all measures were taken after 1, 2 and 3 minutes; however, as little difference in the effects of age and task type were found during ANOVA analysis, only results for 3 minute scores are reported within the thesis.

5.8.2: Number of Words Generated during Shape Fluency

The number of words produced appears to be slightly more in the excluded shape fluency task than the shape fluency task (see table 5.5) and ANOVA analysis indicates that this difference is significant, with a main effect of task type ($F(1,38) = 8.902$, $p = 0.005$). No significant main effect of age and no significant interaction between age and task type were found ($p>0.05$). This does not support the hypothesis that older adults will show a poorer performance on the excluded shape fluency task.

	Shape Fluency	**Excluded Shape Fluency**
Young Adults	22.65 (8.63)	26.55 (8.82)
Older Adults	18.30 (8.53)	21.40 (11.51)

Table 5.5: Mean (standard deviation) number of words generated for Young and Old Adults on Shape and Excluded Shape Fluency Tasks

ANCOVA analysis controlling for speed of processing and IQ shows no significant main effects of task type, age, or interaction between age and task type ($p>0.05$), which again is inconsistent with the expectation of an age effect in the excluded shape fluency task.

5.8.3: Strategy Use during Shape Fluency

ANOVA analysis, showed no significant main effects of task type, age, or interaction ($p>0.05$). Older adults appear to have a lower total strategy use than young adults in the shape fluency task, but a greater total strategy use in the excluded shape fluency task; however, there is wide variation in scores within each age group (see table 5.6) and these differences are shown to be non-significant in the ANOVA.

	Shape Fluency			**Excluded Shape Fluency**		
	Total Strategy %	**Phonemic Strategy %**	**Semantic / Visualisation Strategy %**	**Total Strategy %**	**Phonemic Strategy %**	**Semantic / Visualisation Strategy %**
Young Adults	57.30 (22.81)	0.75 (3.35)	54.05 (25.41)	49.30 (31.55)	2.40 (6.03)	44.05 (28.75)
Older Adults	45.25 (27.66)	1.70 (5.48)	43.55 (28.55)	53.80 (24.43)	1.35 (4.82)	51.30 (22.70)

Table 5.6: Percentage Strategy Use for Young and Old Adults During Shape and Excluded Shape Fluency Tasks

ANCOVA analysis controlling for both speed of processing and IQ does show a significant interaction between age and task type ($F(1,34) = 6.386$, $p = 0.016$), with older adults having a greater total percentage strategy use in the excluded shape fluency task compared to the shape fluency, and young adults having a greater percentage total strategy use in the shape fluency tasks compared to the excluded shape fluency task (see figure 5.2). Post hoc analysis however found no significant simple effects ($p>0.0125$) for all comparisons. These results are inconsistent with the hypotheses that there will be differences in total strategy use both between the age groups and between the two tasks.

Very little use of a phonemic strategy was made by either age group during shape and excluded shape fluency tasks (see table 5.6) and ANOVA analysis showed no significant main effects of task type, age, or interaction between age and task type ($p>0.05$). Similarly, ANCOVA analysis controlling for speed of processing and IQ also showed no significant main effects of task type, age, or interaction ($p>0.05$). Again this is inconsistent with the hypotheses that that there will be differences in strategy use between the two age groups and the two tasks.

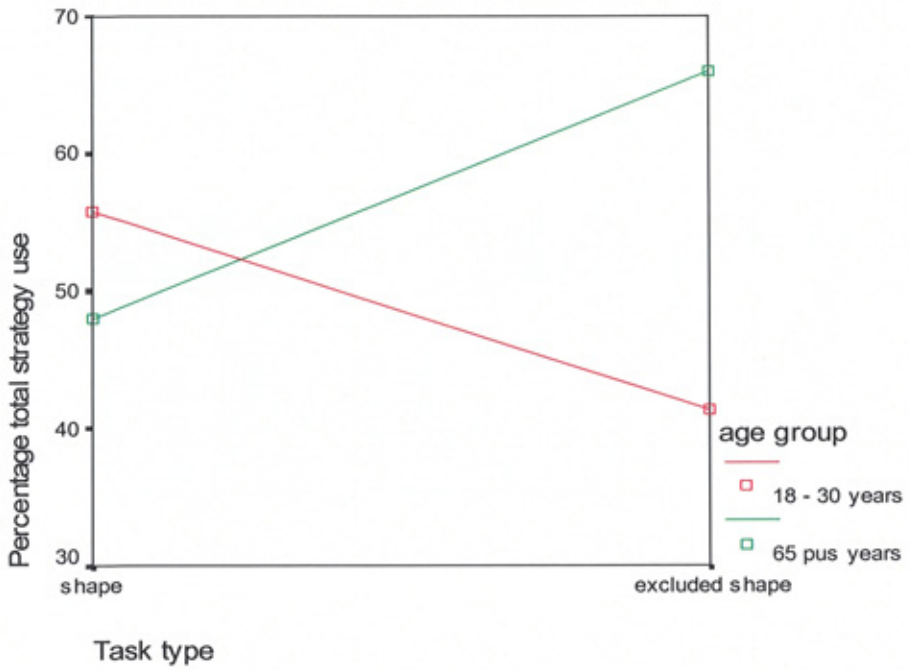


Figure 5.2: Interaction between Age and Task Type on Total strategy Use (controlling for speed of processing and IQ)

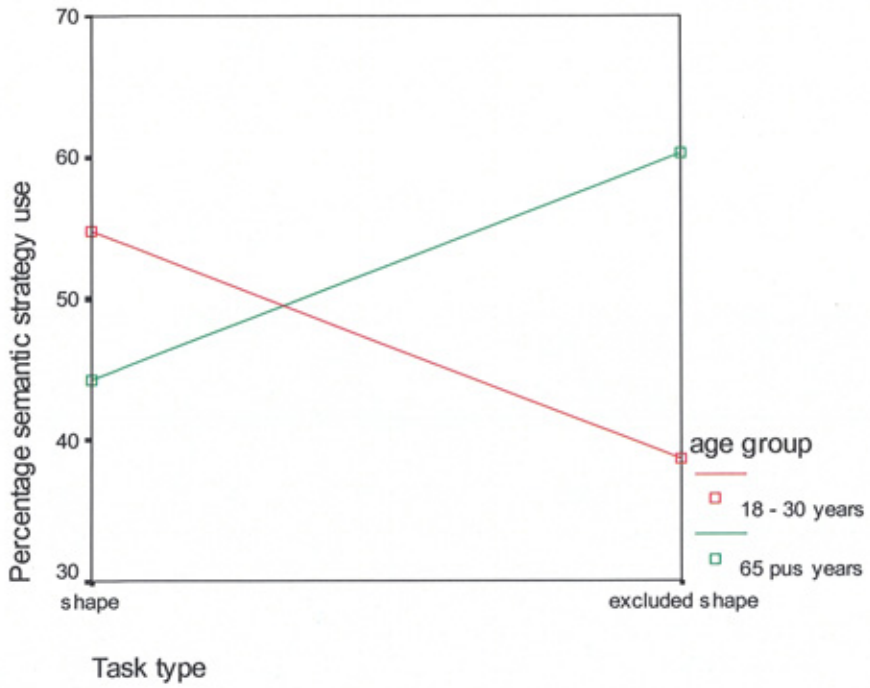


Figure 5.3: Interaction between Age and Task Type on Semantic/ Visualisation Strategy Use (controlling for speed of processing and IQ)

The pattern of semantic / visualisation strategy use is very similar to that of total strategy use with ANOVA analyses showing no significant main effects of task type,

age, or interaction (p>0.05). ANCOVA analysis controlling for speed of processing and IQ also found no significant main effects of task type or age (p>0.05), although a significant interaction between age and task type was evident ($F(1,34) = 6.518$, $p = 0.015$), with a much greater difference in semantic / visualisation strategy use between the age groups during excluded shape fluency compared to shape fluency (see figure 5.3). The interaction graph also suggests that older adults make more use of a semantic / visualisation strategy compared to young adults during excluded fluency, but less use than young adults during shape fluency. However, post hoc analysis shows no significant simple effects of either age or task type in any of the comparisons (p>0.0125).

5.8.4: Clustering and Switching during Shape Fluency

No significant main effects of task type, age, or interaction between age and task type (p>0.05) were evident in the ANOVA analysis for cluster size. This lack of differences in cluster size between the age groups and tasks can be seen in table 5.7 and is inconsistent with the hypothesis that older adults will have a larger cluster size than young adults during fluency tasks. A similar lack of age or task differences was also found in the ANCOVA analysis when controlling for speed of processing and IQ, with no significant main effect of task type, age, or interaction (p>0.05).

	Shape Fluency Cluster size	**Excluded Shape Fluency Cluster size**
Young Adults	2.22 (1.30)	2.01 (0.92)
Older Adults	1.68 (0.58)	2.10 (0.57)

Table 5.7: Mean (standard deviation) Clustering Scores for Young and Old Adults during Shape and Excluded Shape Fluency

There also appears to be little difference in the number of switches between the age groups or between the shape and excluded shape tasks (see table 5.8) and the ANOVA analysis shows no significant main effect of task type, age, or interaction (p>0.05). ANCOVA analysis controlling for speed of processing and IQ also shows no significant main effect of task type, age, or interaction (p>0.05). This pattern of

results does not support the hypothesis that older adults will switch less often than young adults, particularly in the excluded shape fluency task.

	Shape Fluency			Excluded Shape Fluency		
	Number of switches	**Number of hard switches**	**Number of cluster switches**	**Number of switches**	**Number of hard switches**	**Number of cluster switches**
Young Adults	7.25 (3.70)	6.30 (4.03)	2.55 (1.91)	8.45 (3.78)	7.15 (3.47)	3.25 (2.20)
Older Adults	6.25 (3.16)	4.80 (3.33)	2.40 (2.35)	6.80 (4.25)	4.95 (2.37)	2.30 (1.98)

Table 5.8: Mean (standard deviation) Switching Scores for Young and Old Adults during Shape and Excluded Shape Fluency

ANOVA analysis of the number of hard switches found a significant main effect of age ($F(1,38) = 5.880$, $p = 0.020$) with older adults making fewer hard switches than young adults in both the shape and excluded shape fluency tasks (see table 5.8). This supports the hypothesis that older adults will be able to make fewer hard switches than young adults. No significant main effect of task type or interaction between age and task type ($p>0.05$) were evident. The effect of age on the number of hard switches found in the ANOVA was no longer evident in the ANCOVA analysis when controlling for speed of processing and IQ ($p>0.05$), thus suggesting that age differences in the number of hard switches can be accounted for by speed of processing and IQ. ANCOVA analysis also showed no significant main effect of task type, or interaction between age and task type ($p>0.05$).

No significant main effects of task type, age, or interaction between age and task type ($p>0.05$) were found for the number of cluster switches. This lack of significant effects remained when controlling for speed of processing and IQ in the ANCOVA analysis, with no significant main effects of task type, age, or interaction ($p>0.05$).

5.9: Study 3: Discussion

5.9.1: Number of Words Generated

Results from the present study show no age differences in either the shape or excluded shape fluency task, this is inconsistent with the results from study 2 which found an

age-related decline in excluded letter fluency. The lack of age effects in the shape and excluded shape fluency tasks may be a consequence of the task demands. Although the tasks were designed to be non-verbal equivalents to the letter and excluded letter fluency tasks, it may be that they rely on automatic retrieval using a task-consistent strategy rather than a more executively demanding task-discrepant strategy.

5.9.2: Strategy Use

In both shape and excluded shape fluency the task cue is likely to lead to the use of a visualisation strategy. In terms of measurement of a separate visualisation strategy within the present study, it was extremely difficult to distinguish between words produced through a semantic strategy and those produced through a visualisation strategy, therefore the use of a semantic / visualisation strategy would be considered to be task-consistent, whereas a phonemic strategy would be task-discrepant. Results show that the majority of participants used a task–consistent strategy for both tasks, with very little use of a task-discrepant phonemic strategy. The similar amount of a task-consistent strategy used throughout both shape and excluded shape tasks suggests that both tasks rely on non-executive automatic retrieval processes and this may explain the lack of an age-related decline.

5.9.3: Switching of Retrieval Strategies

Results relating to the general and cluster switching measures also support the conclusion that retrieval during both the shape and excluded shape fluency tasks does not make demands on executive processes. No age differences were found in either the general or cluster switching measures which are presumed to rely on executive resources.

The number of hard switches however did decline with age in both tasks. Abwender et al (2002) has suggested that hard switching depends on speed of processing rather than executive resources and results from this study provide further evidence for this view. Results showed that the effect of age on hard switching was eliminated when both speed of processing and IQ were controlled for during the analysis, and when analysis controlling for speed of processing and IQ separately is examined, (see appendix 4, section 4.6.3), it can be seen that controlling for IQ alone does not remove the effect of age on the number of hard clusters, whereas controlling for speed

of processing alone does remove the age effects. This supports the conclusion that age–related declines in the number of hard switches during fluency performance can be accounted for by age-related differences in speed of processing. However, given that there is no corresponding age-related decline in the number of words during the shape and excluded shape fluency tasks, this suggests that the number of hard switches does not influence the total number of words generated.

5.9.4: Conclusion

Results from the non-verbal fluency study have failed to replicate the findings from the verbal fluency study, with no age differences evident apart from in the hard switching measure. The most likely explanation for this lack of age differences is that the shape and excluded shape fluency tasks do not make demands on executive processes of voluntary strategic search or switching of retrieval strategies, but instead rely on the use of a relatively automatic task-consistent strategy of visualisation.

5.10: Studies 2 & 3: General Conclusion

From the results of study 2 it can be concluded that letter fluency is not a valid measure of executive processing. No age differences in letter fluency were found and performance seemed to rely on the use of an automatic task consistent strategy rather than an executively mediated task discrepant strategy.

Excluded letter fluency does however seem to make greater demands on executive processes. Age differences were evident both in the number of words produced and on a number of measures presumed to rely on executive processing. Previous research by Bryan et al (1997) has suggested that speed of processing can account for most of the age differences evident in excluded letter fluency performance. However, the results from this study provide evidence that not all of the age-related decline in excluded fluency measures can be accounted for by speed of processing. From study 2 results it can be concluded that speed of processing is responsible for age differences in the number of hard switches, but cannot wholly account for the age related decline in the number of words produced, or the number of executively mediated switches.

Although results from study 2 suggest that older adults show poorer performance on excluded letter fluency because of a decline in executive function, it is unclear precisely which executive processes are responsible for this age-related decline in excluded letter fluency performance. Age differences were found in the use of a task discrepant strategy which is assumed to rely on executive retrieval strategies that are under voluntary control and were also found on one measure of retrieval strategy switching. However, interpretation of the results is difficult as a second measure of retrieval strategy switching showed no age differences. Excluded letter fluency is also likely to rely on the executive process of inhibition and therefore the results could also be explained in terms of an age-related decline in inhibitory processing. Whilst the excluded letter fluency task is likely to rely on executive processes, the complex nature of the task makes it difficult to draw firm conclusions regarding the effects of age on the different executive functions. Further research examining age differences in executive processes will need to make use of tasks that allow the different executive processes to be separated out. This will allow for the investigation of age differences within the framework of a fractionated working memory model such as that by Baddeley (1996).

No age differences were found in the measures presumed to rely on executive resources for either the shape or the excluded shape fluency tasks used in study 3. This suggests that the verbal fluency and non-verbal fluency measures may utilise domain specific executive processes, not all of which decline with age. However, results from study 3 are ambiguous given the difficulty in differentiating between the use of a visual and a semantic strategy, making it difficult to determine the underlying processes for both of the non-verbal fluency tasks. Given the limitations of the non-verbal fluency tasks, firm conclusions regarding the nature of executive processing within these tasks cannot be made and further research is required to investigate the effects of age on executive processes, both within a verbal and a visuo-spatial domain.

Studies 4 and 5 (chapter 6) will address the need for further research examining the effects of age on the different executive processes within both a verbal and visuo-spatial domain using the random generation paradigm. Random generation is considered to make demands on a number of executive and non-executive processes (Baddeley et al, 1998; Towse & Valentine, 1997). The measurement of randomness

is problematic (Wagenaar, 1972); however, a number of different measures of randomness have been developed, which are presumed to reflect different underlying processes (Towse, 1998), thus providing a useful tool for the investigation of the different central executive processes within a fractionated central executive model. Random generation can also be measured under both verbal and visuo-spatial conditions in the form of oral and keypress random generation, thus allowing the investigation of executive processing within the different modalities. Studies 4 & 5 will therefore use both oral and keypress random generation tasks to investigate the effects of age on central executive executive processing.

Chapter 6
Study 4 - Random Generation and Aging

6.1: General Rationale for Studies 4 & 5

Findings from studies 1, 2 and 3 have suggested that within the framework of a fractionated working memory model (e.g. Baddeley, 1986, 1996, 2000; Baddeley & Hitch, 1974), older adults show a decline in performance on tasks which are likely to make demands on the central executive component. However, because of the complex nature of the tasks used in these previous studies it is difficult to determine precisely which executive processes decline with age. The effect of age on the excluded letter task could be explained in terms of an age-related deficit in either task switching processes or inhibitory processes and age–related declines were also found in the use of retrieval strategies under voluntary executive control. The excluded letter fluency task is likely to rely on all of these processes and it is difficult to separate these out to determine which are affected by age. Previous research (e.g. Fisk & Warr, 1996; Van der Linden, Bredart & Beerten, 1994) has also suggested that older adults have impaired central executive processing; however, similar task constraints have made it difficult to draw firm conclusions as to the precise nature of these central executive deficits.

Studies 4 and 5 aim to investigate the effects of age on some of the central executive processes further, by using a random generation task, which is presumed to make demands on a number of executive processes (Baddeley et al 1998; Towse & Valentine, 1997). This chapter will discuss the two studies investigating the effects of age on random generation: section 6.2 - 6.5 will discuss study 4 and sections 6.6 – 6.9 will discuss study 5. Section 6.10 will present a general discussion section for both studies 4 and 5.

6.2 Study 4: Introduction

Random generation is a complex task that is presumed to rely on a number of executive processes, which are differentially affected by manipulations such as response speed (Baddeley et al, 1998), set size (Spatt & Goldenberg, 1993) and

generation modality (Towse, 1998) (see chapter 2 discussion). Random generation can be measured in a number of different ways and Towse (1998) suggests that different measures of randomness reflect different underlying task processes. The use of different measures of randomness and different task manipulations will allow the underlying task processes to be separated out and examined in greater isolation, thus providing purer measures of the different central executive processes. To date, little research has been undertaken examining the effects of age on random generation efficacy and investigating differential effects of age on random generation measures and the interactions between age and various task manipulations is likely to provide a valuable insight into the possible fractionation of central executive resources.

Van der Linden, Beerten & Pesenti (1998) have found a decline with age on some measures of randomness, such as the stereotypical production of digrams, but not others, i.e. zero order redundancy and the RNG index. They interpreted these results as indicating that older adults have a difficulty in inhibiting over-learned schemas, but their ability to store items, monitor responses and shift between strategies is not reduced. This is consistent with the notion of a fractionated central executive, with some processes declining with age and others remaining intact. Under dual task conditions however, Van der Linden et al (1998) found that all measures of randomness showed a significant decline with age, which they interpreted as indicating that older adults have an overall reduction of central executive resources, along with a specific deficit in the ability to inhibit well learned response strategies.

Although the findings of Van der Linden et al (1998) appear to indicate that age-related declines in random generation can be explained in terms of a deficit in central executive processing, Fisk & Warr (1996) found that controlling for speed of processing largely eliminated age-related declines in random generation performance, suggesting that a reduction in speed of processing may be able to account for age differences in random generation. However, the study by Van der Linden et al (1998) found that performance declined in the older adults even at very slow speeds of response (4 seconds), suggesting that speed may not be the only factor involved.

More specifically, study 4 will examine the interaction between response rate, modality and age during a random generation task for set sizes of 5 and 10, using a

number of different randomness measures which are expected to make demands on different processes. Results from set sizes 5 and 10 will be analysed separately, as the number of response alternatives will affect baseline measure values of several of the randomness measures (see Towse & Neil, 1998). Although direct comparisons will not be possible, by including both set size 5 and 10, it will be possible to determine if there are differential age-related patterns of results.

Response rates of 1 item per second and 1 item per two seconds will be used to manipulate the demands on the limited capacity central executive system. If older adults have a reduced central executive capacity, then they will be expected to show poorer random generation performance compared to young adults, particularly during the faster response rate. Random generation performance will be measured under both oral and keypress conditions to investigate the effect of response modality on random generation performance. Oral random generation will use a number generation task using responses 1 – 5 inclusive, or 1 – 10 inclusive, depending on the set size condition. Random keypress generation will use a series of either 5 or 10 horizontally adjacent keys. The use of horizontally adjacent keys will ensure that a comparison between the two modalities is not influenced by baseline adjacency differences. Participants will use their index finger of the dominant hand to respond, rather than all fingers, to prevent additional motor co-ordination effects from influencing performance. The modality manipulation will allow the investigation of age effects in the ability to generate candidate items.

Randomness will be measured using a range of randomness measures, which are presumed to reflect the use of different strategies and underlying processes. The RNG index and NSQ measures will be used as general non-specific measures of random generation performance. Redundancy and coupon measures will be used as measures of the executive ability to monitor and update information within working memory. Adjacency and runs measures will be used as measures of the executive ability to inhibit stereotypical responses and the turning point index (TPI) will be used as a measure of the ability to switch strategies, (see section 6.3.1 and appendix 6 for a more detailed description of the different measures of randomness used). It is expected that older adults will show poorer performance on all randomness measures,

in particular those making demands on inhibitory processes (adjacency and runs measures).

The potential influence that age differences in both speed of processing and IQ may have on random generation performance will also be considered, to determine whether any changes in the executive measures of randomness are independent of speed of processing and IQ differences.

6.3: Study 4: Method

6.3.1: Design

A quasi-experimental mixed factorial design was used to investigate the effects of age, modality and response rate on random generation performance. The between subjects factor was age, with two levels (young adults aged 18 – 30 and old adults aged 65 plus). The within subjects factors were modality, with two levels (oral random number generation and keypress random generation); and response rate, with two levels (fast and slow). The fast response rate required random generation at a rate of one item per second and the slow response rate one item per two seconds. Both age groups undertook all random generation tasks using two different response set sizes (5 items and 10 items).

Randomness was measured using seven different randomness measures using the RGCalc program devised by Towse & Neil (1998). Two general measures of randomness were used: the RNG index (Evans, 1978) which is a measure of sequential response bias and Guttmann's (Guttmann, 1967, cited in Brugger et al, 1996) null score quotient (NSQ) which indicates the number of digram possibilities that the participant does not use. The RNG index is a measure of sequential response bias which examines the distribution of response pairs or digrams. It looks at how often one response follows any other response. Scores can range from 0 to 1 where 0 indicates a perfectly equal distribution and 1 indicates complete predictability of pair sequences. The NSQ measure indicates the number of digram possibilities that the participant does not use. NSQ scores are given as a percentage of the maximum number of digram possibilities not used, with 100% indicating the use of 1 digram repeatedly and 0% all possible digrams used.

Two measures of monitoring and updating were used: redundancy (R) , which looks at the frequency of individual response alternatives and coupon (Ginsburg & Karpiuk, 1994), which measures the mean number of responses produced before all possible response alternatives are given. The redundancy measure examines the frequency of response alternatives generated and compares that to the selection of responses with equal frequency. R scores are given as a percentage where 0% indicates equality of response alternatives (no redundancy) and 100% indicates the same response used repeatedly (complete redundancy). Coupon measures the mean number of responses produced before all the response alternatives are given. It looks at the specific strategy of cycling (working through the set of all possible responses). Sequences where a strategy of cycling is used will produce a low coupon score.

Two measures of the inhibition of prepotent stereotypical responses were used: adjacency, which is the proportion of responses that are adjacent items in an ordinal sequence and runs (Ginsburg & Karpiuk, 1994), which describes the variability in interval length between two turning points. Adjacency (A) measures a specific type of stereotyped score, i.e. the proportion of adjacent items from an ordinal sequence, rather than all possible response pairings as in the RNG index. It is calculated as a combined score for both ascending and descending adjacent pairs and is expressed as a percentage, with scores of 0% indicating no adjacent pairs and 100% indicating a response which is entirely made up of adjacent pairs. The runs measure describes the variability in interval length between 2 turning points. It is measured as the variance of ascending sequence lengths. A high runs score indicates greater variation in the length of ascending sequences.

One measure of the ability to switch between different strategies was also used: the turning point index (TPI) reported by Kendal (1976), which identifies the number of turning points, or changes from ascending to descending sequences, compared to a theoretically determined ideal number of turning points. TPI scores are given as a percentage, with scores of 100% indicating the expected number of turning points, those greater than 100% indicating too many turning points and less than 100% too few turning points.

Control measures of verbal intelligence (using NART), speed of processing (using speech articulation rate) and dementia (using MMSE) were also taken.

6.3.2: Participants

A convenience sample of 20 young adults (15 females 5 males) aged 18 – 30 years (mean age 22.0 years, standard deviation 3.8) and 20 older adults (17 females and 3 males) aged 65 plus (mean age 73.2 years, standard deviation 6.8) was used. The sample of young adults was obtained from University students and administration staff, and nursing auxiliary staff from a local nursing home. The older adults sample was obtained from community and day centres for the over 65's and from a sheltered housing scheme. Inclusion and exclusion criteria were the same as for studies 2 & 3 (see section 5.3.2).

MMSE scores for those included in the study showed no significant difference between young and old adults ($t(32.54) = 1.628$, $p = 0.113$). However, significant differences were found between the age groups in NART score ($t(37) = -2.257$, $p = 0.030$), with older adults showing a higher NART score than young adults (110 and 103 respectively). A significant difference between the age groups was also found for speed of processing ($t(25.49) = -2.995$, $p = 0.006$), with older adults showing a slower articulation rate than young adults (0.27 and 0.21 seconds per word respectively).

6.3.3: Tasks

During the random number generation task participants were required to generate numbers randomly at a rate of either one per second or one per two seconds in time to a metronome set at the required rate. Numbers were generated either with a set size of 5 (numbers 1 – 5 inclusive) or with a set size of 10 (numbers 1 – 10 inclusive). Similarly to previous research, participants were instructed to produce random numbers by imagining that they were drawing a number from a hat, saying that number out loud, replacing it, picking another number out and so on, so that each time a response is made every number in the hat has an equal chance of being selected. The task continued until a total of 100 numbers had been generated. Response were recorded on a tape recorder and written down by the experimenter.

The random keypress task followed a similar procedure. Participants were requested to randomly press keys arranged in a horizontal line at the rates of either one per second or one per two seconds in time to the metronome. The horizontal number keys on a standard keyboard were used, with the numbers covered with tape to prevent participants from generating according to the numbers. Random generation was either with a set size of 5 keys (horizontal number keys 1 – 5 inclusive) or a set size of 10 keys (horizontal number keys 1 – 0 inclusive). Similar instructions to the oral number generation were given, with participants being asked to press keys randomly from the marked set, keeping in time with the metronome, using their index finger. Responses were recorded on the computer as the numbers corresponding to the particular key presses, thus allowing equivalent analysis to the oral random number generation task. Participants were not able to see their responses on the screen.

Dementia, verbal intelligence and speed of processing were measured using the same tasks as in studies 2 and 3 (see sections 4.2.3 and 5.3.3 for descriptions of these tasks and scoring procedure).

6.3.4: Procedure

All testing was undertaken on an individual basis. Participants first completed the MMSE dementia screening test and any participant scoring below the cut off point (see section 4.2.3 for procedure and scoring) was excluded from the study. Participants then completed the NART and speech articulation rate tasks (see sections 4.2.3 for NART procedure and scoring and section 5.3.3 for speech articulation rate procedure).

Participants then commenced the random generation procedures under the different modality, rate and set size conditions. The order of completion for the different conditions was counterbalanced within each modality, with half of the participants in each age group responding at the fast rate first and half responding at the slow rate first. The order of modality was also counterbalanced, and similarly the order of set size was also counterbalanced.

At the start of each condition participants were instructed to randomly produce either numbers or keypresses according to the required rate and set size. Before

commencing each condition participants listened to the rate at which the metronome would beep, and were allowed to practice generating either numbers or keypresses in time with the beep until they felt comfortable with the task. Participants were instructed that if a response was missed, or they lost time with the metronome beep, to ignore the mistake and carry on generating numbers in time with the next beeps as best they could. Data collection began immediately after the practice for each condition and participants were allowed to rest for a couple of minutes between each condition, during which time instructions were given for the next task condition. Participants continued to generate responses in each condition until 100 responses for that condition were given.

Responses for each task condition were entered into the RGCalc program (Towse & Neil, 1998) to calculate the randomness measures. Responses from the keypress conditions were coded according to the corresponding number for the key pressed. A keypress response of the 0 key was recoded as 10 so that the equivalent number sequence followed the ordinal sequence of the keys.

6.4: Study 4: Results

6.4.1: Data Analysis

Mean and standard deviation scores for all dependent variables and for MMSE, NART, and speech articulation rate measures were calculated for young and old adults. To determine the effect of age, modality and response rate on each of the random generation measures a series of three factor mixed ANOVAs were carried out. Three factor mixed ANCOVAs were also undertaken using IQ and speed of processing as covariates, separately and together. Post hoc analysis of significant interactions used Bonferroni corrected one way ANOVAs and ANCOVAs. These analyses were carried out separately for set size 5 and set size 10 results. Only ANOVA, ANCOVA and post hoc analyses with no covariates and both covariates together will be reported and discussed in the results. ANCOVA and post hoc analysis with only IQ or speed of processing alone as covariates will be included in appendix 7 and specific points of interest referred to in the discussion section.

6.4.2: RNG index

RNG index - Set Size 5 Results

ANOVA results showed a significant main effect of age ($F(1,38) = 6.47$, $p = 0.015$) with older adults showing higher RNG scores than young adults (see table 6.1), indicating that older adults are less random than young adults in both oral and keypress tasks. A significant main effect of modality was also evident ($F(1,38) = 10.56$, $p = 0.002$) with higher RNG scores for keypress generation compared to oral generation (see table 6.1), suggesting that randomness is poorer for random keypress generation than for oral random number generation. No significant main effect of response rate was evident ($p>0.05$) and no significant interactions were found ($p>0.05$). The ANCOVA analysis controlling for both speed of processing and IQ found no significant main effects or interactions ($p>0.05$), suggesting that differences in the RNG measure of randomness can be explained by individual differences in speed of processing and/or IQ. ANCOVA analysis looking at the effects of speed of processing and IQ separately indicates that it is controlling for speed of processing that removes the main effects of both age and modality, whereas controlling for IQ only removes the main effect of modality (see appendix 7, section 7.1.1).

Condition	Young Adults	Older Adults
Oral Fast	0.493 (0.004)	0.503 (0.007)
Oral Slow	0.486 (0.002)	0.511 (0.005)
Keypress Fast	0.496 (0.003)	0.549 (0.005)
Keypress Slow	0.516 (0.004)	0.553 (0.008)

Table 6.1: Mean (standard deviation) RNG Scores for Set Size 5

RNG index – Set Size 10 Results

A significant main effect of age ($F(1, 38) = 5.56$, $p = 0.024$) was found, with older adults showing higher RNG scores than young adults and therefore being less random (see table 6.2). A significant main effect of response rate was also evident ($F(1,38) = 5.56$, $p = 0.033$) in the ANOVA analysis, with higher RNG scores at the faster response rate compared to the slow response rate (see table 6.2), suggesting that randomness declines at faster response rates. No significant main effect of modality was evident ($p>0.05$) and no significant interactions were found ($p>0.05$). ANCOVA analysis controlling for both speed of processing and IQ showed no significant main effects and no significant interactions ($p>0.05$) suggesting that the effects of response

rate and age can be accounted for by either speed of processing or IQ, or both. ANCOVA analysis examining the covariates separately found that speed of processing removed the main effects of both age and modality, whereas IQ only removed the main effect of modality (see appendix 7, section 7.1.2).

Condition	Young Adults	Older Adults
Oral Fast	0.275 (0.054)	0.284 (0.061)
Oral Slow	0.243 (0.063)	0.257 (0.073)
Keypress Fast	0.254 (0.059)	0.316 (0.144)
Keypress Slow	0.246 (0.047)	0.306 (0.094)

Table 6.2: Mean (standard deviation) RNG Scores for Set Size 10

6.4.3: NSQ Measure

NSQ - Set Size 5 Results

A significant main effect of age was evident ($F(1,38) = 7.54$, $p = 0.009$), with older adults showing higher NSQ scores than young adults (see table 6.3), indicating that randomness is poorer in older adults than young adults. ANOVA analysis also found a significant main effect of modality on the NSQ measure ($F1,38) = 16.33$, $p = 0.0001$), with higher NSQ scores in the keypress modality compared to the oral modality (see table 6.3), suggesting that random generation under keypress conditions is less random than under oral conditions. No significant main effect of response rate or interactions were evident ($p>0.05$).

Condition	Young Adults	Older Adults
Oral fast	19.17 (8.27)	21.67 (10.52)
Oral slow	18.75 (5.49)	23.96 (9.74)
Keypress fast	22.50 (9.74)	29.37 (10.16)
Keypress slow	24.79 (8.24)	29.97 (12.02)

Table 6.3: Mean (standard deviation) NSQ Scores for Set Size 5

When both speed of processing and IQ are controlled for in the ANCOVA analysis no significant main effects or interactions remain ($p>0.05$), suggesting that the effects of modality and age on the NSQ measure can be accounted for by speed of processing, IQ or both. ANCOVA analysis controlling for speed of processing and IQ separately, found that controlling for either speed of processing or IQ alone removed the main effect of modality but not the main effect of age (see appendix 7, section 7.2.1).

NSQ – Set Size 10 Results

A significant main effect of age was found in the ANOVA analysis ($F(1,38) = 6.032$, $p = 0.019$) with older adults demonstrating higher NSQ scores than young adults (see table 6.4), suggesting that older adults are less random than young adults. A significant main effect of response rate ($F(1,38) = 5.624$, $p = 0.023$) was also evident, with higher NSQ scores in the faster response rate compared to the slow response rate (see table 6.4), indicating the randomness decreases at faster response rates. No significant main effect of modality was evident ($p>0.05$). However, the interaction between modality and rate was significant ($F(1,38) = 4.393$, $p = 0.043$).

Condition	Young Adults	Older Adults
Oral fast	60.56 (3.73)	61.42 (3.69)
Oral slow	57.83 (4.03)	59.65 (3.71)
Keypress fast	58.79 (3.49)	62.63 (6.81)
Keypress slow	59.10 (3.76)	61.92 (5.25)

Table 6.4: Mean (standard deviation) NSQ Scores for Set Size 10

ANCOVA analysis controlling for speed of processing and IQ found no significant main effects and no significant interactions ($p>0.05$) and further analysis controlling for speed of processing and IQ separately, showed that it is the speed of processing covariate that removes both the main effect of age and the interaction, whereas IQ alone can only account for the interaction (see appendix 7, section 7.2.2).

6.4.4: Redundancy Scores

Redundancy - Set Size 5 Results

ANOVA results found no significant main effects of age, modality or response rate and no significant interactions ($p>0.05$). See table 6.5 for mean figures showing little difference in redundancy between the different conditions. When controlling for both speed of processing and IQ in the ANCOVA analysis no significant main effects and no 2 way interactions were found ($p>0.05$). However, the 3-way interaction between modality, response rate and age was significant ($F(1,34) = 6.73$, $p = 0.014$). Post hoc analysis showed no significant simple effects with the Bonferroni corrected p value ($p>0.004$).

Condition	Young Adults	Older Adults
Oral fast	0.76 (0.62)	0.94 (0.91)
Oral slow	0.93 (0.98)	0.87 (0.67)
Keypress fast	0.89 (0.76)	0.79 (0.61)
Keypress slow	0.83 (0.77)	1.20 (0.96)

Table 6.5: Mean (standard deviation) Redundancy Scores for Set Size 5

Redundancy – Set Size 10 Results

ANOVA analysis showed no significant main effects of age, modality or response rate ($p>0.05$). The 2-way interaction between modality and response rate was significant ($F(1,38) = 9.324$, $p = 0.004$). No other 2 or 3-way interactions were significant ($p>0.05$).

Condition	Young Adults	Older Adults
Oral fast	2.61 (1.22)	2.01 (1.12)
Oral slow	1.58 (0.73)	1.73 (1.42)
Keypress fast	2.20 (1.25)	1.75 (0.84)
Keypress slow	2.58 (1.59)	2.27 (1.34)

Table 6.6: Mean (standard deviation) Redundancy Scores for Set Size 10

When controlling for both speed of processing and IQ in the ANCOVA analysis the interaction between modality and response rate is removed, but a significant main effect of response rate ($F(1,34) = 7.462$, $p = 0.010$) is evident, with higher redundancy scores at the fast rate compared to the slow rate, demonstrating less randomness at faster rates of generation (see table 6.6). No other significant main effects or interactions were found ($p>0.05$).

6.4.5: Coupon Scores

Coupon – Set Size 5 Results

No significant main effects of age, modality or response rate and no significant interactions were found ($p>0.05$) for the coupon measure with a set size of 5. Mean figures for the different conditions show similar low coupon measures (see table 6.7), suggesting that a strategy of cycling is used by both age groups at both fast and slow rates for both oral and keypress random generation. ANCOVA analysis controlling for both speed of processing and IQ, also showed no significant main effects, or interactions, for modality, response rate or age ($p>0.05$).

Condition	Young Adults	Older Adults
Oral fast	6.59 (0.89)	6.83 (1.15)
Oral slow	6.82 (0.78)	6.77 (0.99)
Keypress fast	6.77 (1.06)	6.62 (0.49)
Keypress slow	6.68 (0.74)	6.63 (0.82)

Table 6.7: Mean (standard deviation) Coupon Scores for Set Size 5

Coupon – Set Size 10 Results

ANOVA analysis showed that no significant main effects of age, modality or response rate were evident ($p>0.05$). This can be seen by the similar high coupon scores for all random generation tasks (see table 6.8), which suggest that for a response set size of 10 there is little use of a cycling strategy in any of the tasks by either young or older adults. However, the 2-way interaction between modality and response rate was significant ($F(1,38) = 4.431$, $p = 0.042$). ANCOVA analysis controlling for both speed of processing and IQ removed this interaction, and found no significant main effects, and no significant interactions ($p>0.05$).

Condition	Young Adults	Older Adults
Oral fast	21.27 (5.75)	19.83 (9.15)
Oral slow	20.40 (5.95)	17.00 (4.08)
Keypress fast	18.83 (5.95)	18.23 (5.16)
Keypress slow	20.19 (5.56)	20.06 (5.76)

Table 6.8: Mean (standard deviation) Coupon Scores for Set Size 10

6.4.6: Adjacency Scores

Adjacency – Set Size 5 Results

ANOVA analysis found no significant main effect of age ($p>0.05$). However, a significant main effect of modality was evident ($F(1,38) = 20.01$, $p = 0.0001$), with higher adjacency scores in the oral modality compared to the keypress modality (see table 6.9). This indicates that there is a greater reliance on stereotypical response in the oral generation tasks. The main effect of rate was also significant ($F(1,38) = 15.37$, $p = 0.0001$), with higher adjacency scores at the fast response rate compared to the slow response rate (see table 6.9), indicating more stereotypical responses at faster rates of generation. A significant 2-way interaction between response rate and age was evident ($F(1,38) = 4.45$, $p = 0.042$) and the 3-way interaction between age, response rate and modality was also significant ($F(1,38) = 6.20$, $p = 0.017$).

Condition	Young Adults	Older Adults
Oral fast	46.67 (8.84)	37.50 (13.19)
Oral slow	37.30 (7.84)	37.07 (16.51)
Keypress fast	36.16 (10.39)	31.95 (16.56)
Keypress slow	32.83 (13.72)	26.57 (18.91)

Table 6.9: Mean (standard deviation) Redundancy Scores for Set Size 5

ANCOVA analysis controlling for both speed of processing and IQ found no significant main effects of modality, response rate or age, and no significant 2-way or 3-way interactions ($p>0.05$), suggesting that the 3-way interaction between modality, response rate and age can be accounted for by differences in either speed of processing, IQ or both. Additional ANCOVA analysis controlling for speed of processing alone, found that controlling for speed of processing removed the main effect of modality and the interactions, but not the main effect of response rate, whereas the interactions remained when IQ was controlled for alone (see appendix 7, section 7.5.1). This suggests that speed of processing can account for the effects of age on adjacency.

Adjacency – Set Size 10 Results

ANOVA analysis found no significant main effect of age ($p>0.05$). However, a significant main effect of modality ($F(1,38) = 16.852$, $p = 0.001$) was evident, with higher adjacency scores in the oral modality compared to the keypress modality (see table 6.10), indicating that there are more stereotypical responses made in the oral modality. A significant main effect of response rate was also evident ($F(1,38) = 13.371$, $p = 0.001$), with higher adjacency scores at the fast rate compared to the slow rate (see table 6.10), indicating that stereotypical responding increases at faster response rates. No significant 2 way or 3-way interactions were evident ($p>0.05$). ANCOVA analysis controlling for speed of processing and IQ showed no significant main effects of modality, response rate or age and no significant 2 way or 3-way interactions ($p>0.05$).

Condition	Young Adults	Older Adults
Oral fast	32.49 (11.57)	31.22 (16.14)
Oral slow	26.67 (10.53)	29.40 (15.51)
Keypress fast	19.58 (12.21)	25.00 (18.91)
Keypress slow	16.38 (12.48)	21.33 (16.56)

Table 6.10: Mean (standard deviation) Adjacency Scores for Set Size 10

6.4.7: Runs Scores

Runs – Set Size 5 Results

Both ANOVA analysis and the ANCOVA controlling for speed of processing and IQ showed no significant main effects of age, response rate or modality, and no significant 2 way or 3-way interactions. Runs scores were similar for both age groups across all tasks (see table 6.11).

Condition	Young Adults	Older Adults
Oral fast	0.77 (0.32)	0.60 (0.31)
Oral slow	0.73 (0.26)	0.76 (0.35)
Keypress fast	0.54 (0.27)	0.67 (0.44)
Keypress slow	0.58 (0.25)	0.66 (0.53)

Table 6.11: Mean (standard deviation) Runs Scores for Set Size 5

Runs – Set Size 10 Results

ANOVA analysis showed no significant main effect of age ($p>0.05$). However, a significant main effect of modality was evident ($F(1,38) = 7.035$, $p = 0.012$), with higher runs scores in the oral modality compared to the keypress modality (see table 6.12), suggesting that there is greater variability in interval lengths between turning points in oral random generation than in keypress random generation. A significant main effect of response rate was also found ($F(1,38) = 6.193$, $p = 0.017$) with higher runs scores at faster response rates than slow response rates (see table 6.12), suggesting that there is greater variability in interval length between two turning points at the fast generation rate. No significant 2 way or 3-way interactions were evident ($p>0.05$).

ANCOVA analysis controlling for both speed of processing and IQ found no significant main effects of modality, response rate or age, and no significant 2-way or 3-way interactions ($p>0.05$), suggesting that the effects of modality and response rate can be accounted for by speed of processing, IQ, or both. Further ANCOVA analysis controlling for speed of processing and IQ separately showed no significant main effects or interactions (see appendix 7, section 7.6.2), suggesting that both speed of processing and IQ can account for the effects of modality and response rate.

Condition	Young Adults	Older Adults
Oral fast	1.44 (0.73)	1.71 (1.01)
Oral slow	1.32 (0.63)	1.60 (0.89)
Keypress fast	0.54 (0.27)	0.67 (0.44)
Keypress slow	0.99 (0.60)	1.30 (1.36)

Table 6.12: Mean (standard deviation) Runs Scores for Set Size 10

6.4.8: TPI Scores

Turning Point Index Set Size 5 Results

ANOVA analysis found no significant main effects of age or response rate; however, a significant main effect of modality ($F(1,38) = 29.34$, $p = 0.0001$) was evident, with higher TPI scores in the keypress modality than in the oral modality (see table 6.13). TPI scores indicate that the number of turning points is close to the theoretically determined average of 100% for the oral modality and more than average for the keypress modality, indicating that in the keypress modality participants make a greater number of switches between ascending and descending sequences. No significant 2 way or 3-way interactions were found ($p>0.05$)

Condition	Young Adults	Older Adults
Oral fast	94.27 (13.41)	98.62 (14.24)
Oral slow	100.43 (12.41)	100.27 (20.11)
Keypress fast	114.12 (14.78)	106.55 (17.52)
Keypress slow	111.85 (13.42)	108.06 (20.40)

Table 6.13: Mean (standard deviation) TPI Scores for Set Size 5

ANCOVA analysis controlling for both speed of processing and IQ also found a significant main effect of modality ($F(1,34) = 4.17$, $p = 0.049$), with higher TPI scores in the keypress than the oral modality, suggesting that there is a greater tendency to switch between ascending and descending sequences in the keypress modality compared to the oral modality, and that this effect cannot be accounted for by speed of processing and IQ.

Turning Point Index Set Size 10 Results

ANOVA analysis found a significant main effect of age ($F(1,38) = 7.795$, $p = 0.008$) with older adults showing significantly lower TPI scores than young adults (see table 6.14), indicating that older adults switch between ascending and descending

sequences less frequently than young adults. A significant main effect of modality was also evident ($F(1,38) = 7.539$, p 0.009), with lower TPI scores in the oral modality compared to the keypress modality (see table 6.14). Both oral and keypress TPI scores were lower than the theoretically determined average number of switches between ascending and descending sequences, with significantly fewer switches made during oral generation. The main effect of response rate was also significant ($F(1,38) = 6.261$, $p = 0.017$), with lower TPI scores at the fast rate compared to the slow rate (see table 6.14), indicating that participants switch less frequently between ascending and descending sequences at the faster response rate. The 2-way and 3-way interactions were not significant ($p>0.05$).

Condition	Young Adults	Older Adults
Oral fast	86.74 (15.16)	70.32 (18.60)
Oral slow	87.41 (11.12)	81.12 (20.98)
Keypress fast	95.34 (25.64)	80.77 (27.06)
Keypress slow	101.41 (16.70)	82.21 (24.01)

Table 6.14: Mean (standard deviation) TPI Scores for Set Size 10

ANCOVA analysis controlling for speed of processing and IQ found no significant main effects of modality or response rate and no significant 2-way or 3-way interactions ($p>0.05$). However, the main effect of age remained significant ($F(1,34) = 5.35$, $p = 0.027$), with older adults having lower TPI scores than young adults and therefore making less frequent switches between ascending and descending sequences. This effect of age cannot be accounted for by speed of processing and IQ. Post hoc analysis of this age effect indicated that no simple effects of age were present in any of the conditions using the Bonferroni corrected p value ($p>0.013$), although the simple effect of age in the oral task at the fast response rate was approaching significance ($F(1,34) = 6.273$, $p = 0.017$).

6.5: Study 4: Discussion

6.5.1: General Measures of Randomness

A significant main effect of age was found in both the general measures of randomness (RNG and NSQ) in both set size 5 and set size 10 conditions, with older adults being less random than young adults. Given that random generation

performance may reflect the limited capacity of the central executive (Baddeley, 1986; Towse, 1998), one explanation for these age differences may be that older adults have impaired central executive processing. However, further analysis controlling for speed of processing and IQ differences indicated that the effect of age is removed when both of these are controlled for; and ANCOVA analysis looking at the separate influence of speed of processing and IQ, indicated that it is speed of processing differences rather than IQ differences which eliminates the effect of age on the RNG and NSQ measures (see appendix 7, sections 7.1 and 7.2). This suggests that the effects of age on general measures of random generation can best be accounted for by age differences in speed of processing. This is consistent with the findings of Fisk & Warr (1996), who found that controlling for speed of processing eliminated age differences in random generation.

Results from the RNG and NSQ measures provide little support for the notion of an age-related decline in central executive processing explanation of random generation performance. However, the general nature of the measures means that they rely on a number of different resources (Towse & Neil, 1998) and therefore it is difficult to draw firm conclusions regarding the effects of age on central executive processing from these measures alone, as some underlying processes may decline or be influenced by speed of processing and others may not. This view is supported by Van der Linden et al (1998), who found no effects of age on randomness in the RNG measure, but age effects on other measures of randomness. Effects of age on other measures of randomness will be considered later in the discussion section.

An effect of response rate was found for both the RNG and NSQ measures in the set size 10 conditions, with randomness being poorer at the faster response rate. No effect of response rate was found for set size 5 conditions. The effect of response rate with a set size of 10 is to some extent consistent with the findings of Towse (1998), who concluded that the RNG measure of randomness was sensitive to both set size and speed and Van der Linden et al (1998) who found an effect of response rate on RNG performance. Towse (1998) used set sizes of 10 and 15 items and found an effect of response rate across both set sizes, concluding that the effects of response rate and set size were independent of each other. Van der Linden et al (1998) use random letter generation and therefore a set size of 26. In the present study however

no effect of response rate was found with the smaller set size of 5. One explanation for these different findings may be that when the set size exceeds memory capacity (i.e. set sizes of 10 or more), this will place a greater strain on the limited capacity of the central executive and make the effect of rate more evident. The use of a set size of 5 items is likely to be more easily retained and monitored and therefore places less demands on the limited capacity central executive.

The effect of response rate however is eliminated when both speed of processing and IQ together are controlled for and when speed of processing or IQ alone are controlled for (see appendix 7, sections 7.1 and 7.2), suggesting that the effect of response rate can best be accounted for in terms of the demands made on both speed of processing and IQ.

In the current study the effect of response rate in set size 10 was found for both oral and keypress generation, which supports the conclusions of Baddeley et al (1998) who argue that similar patterns of response rate and set size for both oral and keypress generation suggest that they rely on similar resources. Specifically looking at effects of modality an effect of modality was found in set size 5 but not set size 10, with randomness being poorer in keypress conditions. The effect of modality is removed when both speed of processing and IQ are controlled for and when either speed of processing or IQ alone is controlled for, suggesting that the effect of modality can best be accounted for by differing demands on speed of processing or IQ.

This pattern of results is consistent with previous research by Baddeley et al (1998), who found that whilst a difference in randomness between oral and keypress generation was evident, there was no interaction between the effect of modality and response rate, suggesting that they rely on similar underlying processes. However, an interaction between modality and response rate was found for the NSQ measure in set size 10. The interaction showed an effect of response rate in the oral modality but not in the keypress modality, which goes against the argument of Baddeley et al (1998) by indicating that whilst oral random generation is dependent on the response rate, keypress random generation is not. The interaction found in the NSQ results supports the suggestion put forward by Towse (1998) that oral and keypress random generation are not equivalent and that they rely on different underlying processes. The

inconsistency of modality effects and interactions in the RNG and NSQ measures makes it difficult to draw firm conclusions regarding the equivalence of processes underlying oral and keypress random generation.

6.5.2: Monitoring / Updating Measures of Randomness

Results from the redundancy and coupon measures showed no significant effects of age apart from a 3-way interaction between modality, rate and age in the set size 5 redundancy measure when speed of processing and IQ are both controlled for. Post hoc analysis of this interaction revealed no significant simple effects however, suggesting that any differences between the age groups or experimental conditions were minimal. The lack of age effects is consistent with the findings of Van der Linden et al (1998), who found no effects of age on their measure of zero order redundancy. Redundancy, as a measure of the frequency with which each individual item is produced is considered to make demands on working memory monitoring and updating processes, therefore, the findings from this study and that of Van der Linden et al (1998) suggest that the ability to monitor and update information within working memory remains intact in older adults. This is only partially consistent with previous research on working memory and age differences.

Whilst a number of previous studies have suggested that passive storage of items within phonological memory does not decline with age (Belleville et al, 1996; Dobbs & Rule, 1989; Wiegersma & Meertse, 1990), other studies looking at memory updating have found evidence of an age-related decline (Dobbs & Rule, 1989; Morris & Jones, 1990; Van der Linden et al, 1994). The memory updating function of working memory is considered to rely on central executive processes, thus a decline with age is expected, whereas passive storage is considered to be the role of the slave systems. The lack of age differences in the results of this study therefore suggest that redundancy relies more on passive storage of previous responses, rather than a continuous executively demanding updating process. An alternative explanation may be that the monitoring demands of the task are not sufficient to detect small age-related changes in passive memory storage within the phonological loop, therefore, further research which increases the monitoring and memory demands of the task would be useful to clarify the role of the central executive in monitoring during random generation.

The coupon measure is presumed to indicate reliance on a strategy of cycling through each potential response within the permissible series and as such depends on the ability to monitor previous responses. If a strategy of cycling is used then it would be expected that the coupon score should be similar in value to the number of items within the set. The set size 5 results show coupon scores of around 6 or 7 (only slightly higher than the number of items in the set) indicating that both young and old adults are not only able to monitor their previous responses equally well, but also that they both make use of this strategy to produce random sequences. Coupon scores are much higher for the set size 10 results, around 18 – 21 in value, which is much higher than the number of items within the set. Although no direct comparison can be made between the set size 5 and set size 10 results, this suggests that both young and old adults place less reliance on a cycling strategy when the set size is greater, perhaps because 10 items is beyond the monitoring capacity of working memory. The implication of this is that the type of strategy used during random generation may vary as a consequence of the task constraints and consequently the processes underlying random generation performance may also be different depending on task constraints such as set size, making it difficult to compare findings from studies using different task manipulations and parameters and difficult to determine and generalise the processes underlying performance on random generation tasks.

Effects of response rate and modality were evident for both redundancy and coupon measures under set size 10 conditions, but not set size 5 conditions, in the form of a two way interaction between modality and rate. The redundancy measure interaction showed an effect of response rate in the oral generation task, with higher redundancy at faster response rates. This effect of response rate remains when both speed of processing and IQ are controlled for, although as a main effect rather than an interaction. Keypress generation showed no difference in redundancy between fast and slow response rates, with no controls. Firstly, the different effects of response rate on oral and keypress random generation supports the argument by Towse (1998) that oral and keypress random generation are not equivalent and suggests that they my be different in terms of their demands on monitoring processes. The provision of an external aid to monitoring in the form of the keys during keypress random generation may make it easier to not only generate potential responses, as suggested by Towse

(1998), but also to monitor those responses, either by providing a visual representation or by allowing memory for movement to act as an aid to monitoring.

Similarly to the redundancy measures, coupon scores also showed an interaction between modality and response rate for set size 10. However, post hoc analysis showed no significant simple effects, and controlling for speed of processing and IQ removed the interaction effect altogether. The weaker interaction for the coupon measure may reflect the previously discussed difference in the use of the cycling strategy. If there is less reliance on the cycling strategy in the set size 10 random generation task then the coupon measure is less likely to be affected by other task parameters, such as response speed and modality.

6.5.3: Inhibitory Measures of Randomness

No effects of age were found on either the adjacency or runs measures of randomness. Both of these measures are presumed to reflect the ability to inhibit prepotent or stereotypical responses, thus suggesting that the ability to inhibit stereotypical responses does not decline with age. This finding is inconsistent with that of Van der Linden et al (1998), who found that older adults showed higher adjacency scores on a random letter generation task, compared to young adults. It is also inconsistent with previous studies suggesting a decline in inhibitory processing with age (e.g. Hasher & Zacks, 1988; McDowd & Shaw, 2000). One possible explanation for the difference between the results of this study and those finding a decline in inhibitory processing with age, is that they may be measuring different inhibitory processes, only some of which decline with age. The notion of separable inhibitory processes has been suggested by Hasher et al (1999) and Hasher et al (2001) who propose three separable inhibitory processes (see section 3.3). However, this explanation cannot account for the different findings between this study and the Van der Linden et al (1998) study, as both use a measure of random generation that looks at the use of prepotent or stereotypical responses.

An alternative explanation may be that the potency of the response stereotypy may determine how well it can be inhibited. Van der Linden et al (1998) used a random letter generation task, whereas this study uses random number and random keypress generation tasks, and it could be argued that alphabetic stereotypes in the letter

generation task are more potent than consecutive number and consecutive keypress stereotypes and therefore more difficult to overcome. The letter generation tasks may therefore be a more inhibitory demanding task than random number or random keypress generation tasks and be more likely to pick up small deficits in inhibitory processing than the less demanding tasks. However, there is little evidence to suggest that alphabetic stereotypes are more potent than number or keypress stereotypes. Further research would be useful to investigate the effects of age on inhibitory processing further, particularly by manipulating the inhibitory load to determine whether a greater inhibitory demand will lead to evidence of age differences.

Main effects of modality were evident for the set size 10 conditions for both the adjacency and runs measures, with more stereotypical responses produced in the oral compared to the keypress conditions. This suggests that oral number generation relies more heavily on central executive inhibitory processes than keypress generation. An effect of response rate was also found for both oral and keypress tasks on both the adjacency and runs measures, which indicates that although the oral and keypress tasks may differ in the degree of their demands on inhibitory processing, the lack of interaction with response rate means that they both show a similar pattern of increased stereotypical responses with an increase in response rate. This would appear to support the argument of Baddeley et al (1998) that both tasks rely on a common limited capacity central executive component that acts to inhibit over-learned stereotypical responses. The faster the response rate the greater the demands on the central executive and the more stereotypical responses are made.

However, both the effect of modality and the effect of response rate on adjacency and runs measures are eliminated when speed of processing and IQ are controlled for. Both speed of processing and IQ, when controlled for alone, remove the main effects. For the adjacency measure an interaction between response rate and modality remains when speed of processing is controlled for alone; however, none of the simple effects are significant. This suggests that differences in speed of processing and IQ can best account for differences in the production of stereotypical responses during random generation. A number of studies have suggested that age differences in inhibitory processing can be wholly accounted for by age differences in speed of processing (Earles et al, 1997; Salthouse & Meinz, 1995; Shilling et al, 2002). However, it is

puzzling that age differences in the current study are evident in speed of processing but not inhibitory processing. If a speed of processing account of the age differences in inhibitory tasks is assumed then age differences in inhibitory measures would be expected alongside the age differences in speed of processing measures. However, this does not occur, thus casting doubt on a purely speed of processing account of age-related differences in inhibition. It may be that whilst both speed of processing and inhibitory processing influence age-related performance on tasks that are presumed to make demands on inhibitory processes, their influence is separate and that the relationship between these processes and age is complex.

6.5.4: Switching Measures of Randomness

A significant effect of aging was found for the TPI measure in set size 10 analysis, with older adults showing a much lower TPI score than young adults. The TPI measures how frequently participants switch between ascending and descending sequences and as such is presumed to reflect the ability to switch between strategies. Results from this study therefore suggest that older adults are less able to switch strategies to maintain randomness. This effect of age remains when both speed of processing and IQ are controlled for, suggesting that the age-related decline in switching cannot be accounted for by either speed of processing or IQ differences between the age groups. The age-related decline in the TPI measure is consistent with the view that it is the central executive component of working memory that declines with age and supports the proposal by Baddeley (1996) and Miyake et al (2000) that the ability to switch strategies is a function of the central executive. However, no effect of age on the TPI measure was found in the set size 5 results. Based on results from their study, Van der Linden et al (1998) also concluded that the ability to switch between strategies does not decline with age.

The difference between the current findings and those of Van der Linden et al (1998) can be explained in terms of the different measures of randomness used. The current study uses a specific measure of switching, the TPI measure, whereas Van der Linden et al (1998) base their conclusion of no age differences in switching during random generation on the use of the RNG measure. The RNG measure however, is considered to be a non-specific measure of randomness (Brugger et al, 1996) and to rely on a number of different processes (Towse & Neil, 1998), and therefore the age

equivalence may be a consequence of other underlying processes apart from switching strategies.

The differential effects of age on the TPI measure between the set size 5 and set size 10 findings may be a consequence of the variation in the number of candidate responses, which may act as an external control for switching between ascending and descending strategies. A smaller set size of 5 will constrain the potential to switch between ascending and descending sequences to a greater extent than a larger set size of 10. When this high degree of external control is lacking as in the set size 10, the extent to which participants switch strategies between ascending and descending sequences will be more dependent on the internal voluntary control of the central executive, rather than under external control. A decline in the executive ability to switch strategies is therefore more likely to be apparent under task conditions which maximise the need for this process and minimise external control. The idea that tasks requiring self initiated or voluntary control show greater decline with age than those which depend on external or environmental support, has recently been suggested by a number of researchers using different task paradigms (Anderson et al, 1998; Hasher et al, 2001; Humphrey & Kramer, 1999), and the TPI results are consistent with this view.

The age-related decline in the TPI measure of switching during random generation does seem to indicate that an impaired ability to switch strategies may be able to account for age differences in random generation tasks. However, given the findings of age equivalence in set size 5, further research will be necessary to determine whether the effect of age on switching is replicable and under what task conditions it occurs. The task switching paradigm (Rogers & Monsell, 1995) which attempts to isolate the voluntary control processes involved in task switching from other task demands may provide a useful approach to investigate the effects of age on switching processes.

Significant effects of modality and response rate were also evident for the TPI measure in set size 10, with lower TPI scores in the oral conditions compared to the keypress conditions and lower TPI scores at the faster rate compared to the slower response rate. The lower TPI score for the random number generation task suggests

that whilst random number generation is likely to be more executively demanding than random keypress, the lack of interaction with response rate indicates that the two tasks rely on the same executive processes, but to a differing extent as both tasks are influenced in a similar way by task manipulations such as response rate. This supports Baddeley et al's (1998) argument that random number generation and random keypress both rely on similar working memory processes. However, both the effect of modality and the effect of response rate are eliminated when both speed of processing and IQ are controlled for, or when either speed of processing or IQ alone are controlled for (see appendix 7). This suggests that the effects of modality and response rate on TPI index can best be accounted for by differences in the demands on both speed of processing and IQ, rather than differences in the demands for executive processes.

6.5.5: Conclusion

The results from study 4 highlight a number of important issues that need to be considered further. Firstly, the results provide additional evidence relating to the equivalence of oral and keypress random generation tasks. Whilst it appears that the tasks differ in their relative demands on the underlying central executive processes as demonstrated by the effects of modality on the measures of randomness, on the whole they respond in a similar fashion to the manipulation of response rate, suggesting that both tasks rely on the same underlying executive processes albeit to a differing extent. This conclusion will be considered further in study 5.

No effects of age were found on either the measures of inhibition or the monitoring and updating measures of randomness. One explanation for the lack of age effects on the monitoring and updating measures may be that these measures rely on passive storage within the phonological loop, rather than central executive updating processes, and therefore age differences would not be expected. However, the current study could be limited in terms of the extent of the task demands on passive monitoring processes and that if greater demands were made then age differences would be evident. Study 5 will address this issue by increasing the working memory demands of the task to determine whether this will lead to a different pattern of age effects. The lack of age effects on the inhibitory measures is inconsistent with previous research (e.g. Van der Linden et al, 1998), making it difficult to draw firm

conclusions. It could be argued that the lack of age effects may be a consequence of limited demands on inhibitory processing within the task, or that inhibitory processes do not decline with age. Further research regarding the nature of inhibitory processing within random generation will be undertaken in study 5, to determine whether increasing the inhibitory load within the random generation task will lead to the detection of age differences in randomness. This will help clarify the nature of age-related differences in inhibitory processing.

The most important issue for this thesis to consider is the age-related decline in random generation on the TPI measure of randomness. Studies 6 and 7, to be discussed in chapter 7) will investigate this effect of age on task switching further, to determine whether the effects of aging on switching is a general effect or is determined by specific task constraints.

6.6: Study 5: Introduction

Study 4 results found no age differences in monitoring / updating measures or inhibitory measures of random generation. Previous research has suggested that the ability to inhibit stereotypical responses is one of the functions of the central executive component of working memory (Baddeley, 1996) and that this ability to inhibit prepotent responses declines with age (Earles et al, 1997; Salthouse & Meinz, 1995; Shilling et al, 2002; Van der Linden et al, 1998), although this decline in inhibitory processing with age may be accounted for by an age-related decline in speed of processing (Earles et al, 1997; Salthouse and Meinz, 1995; Shilling et al, 2002). The lack of age–related decline in the inhibitory processing measures of randomness in study 4, coupled with the effects of age on inhibitory processing found in this previous research is difficult to explain and warrants further investigation.

Similarly, the lack of age effects in the monitoring and updating measure of randomness is inconsistent with the previous literature. Whilst passive memory for previous responses is likely to be reliant upon the phonological loop, the updating required to continuously monitor the previous responses and make use of this, in the form of a cycling strategy, is likely to make demands on the central executive component of working memory. This updating function of the central executive has

been found to decline with age (Van der Linden et al, 1994). The lack of age effects on the coupon and redundancy measures found in study 4 and the lack of age differences found in redundancy during random generation by Van der Linden et al (1998), suggests that the ability to monitor previous responses may rely on passive storage rather than central executive processes. However, further research to determine the role of passive memory processes during random generation is necessary to clarify this.

One criticism of the previous study is that the random generation tasks may not have been sufficiently demanding, in terms of memory and inhibitory processing requirements, to identify any small age-related declines in these processes. The aim of study 5 therefore is to replicate the random generation tasks in the previous study, but also include an inhibitory and a memory load, to clarify whether increasing the memory and inhibitory demands of the task leads to any age-related declines in these processes.

The effects of concurrent memory and inhibitory loads on random generation performance has been examined by Towse & Valentine (1997, exp. 2). Concurrent memory load was manipulated by requiring participants to remember two responses of the potential response set and indicate that they had remembered these responses by tapping the desk when they were generated within the random sequence. The inhibitory load was manipulated by requiring participants to inhibit and not produce two potential responses from the specified response set. The effects of concurrent memory and inhibitory load were examined on four measures of randomness, RNG, R, A, and a measure similar to TPI. They found no effects of either the memory or inhibitory load on redundancy, an effect of both memory and inhibitory load on the RNG index and the measure similar to TPI, and an effect of inhibitory load but not memory load on adjacency. From this Towse & Valentine (1997) concluded that both memory and inhibitory requirements are important for the production of random sequences and that increasing the memory and inhibitory load leads to a decrement in randomisation performance. The lack of effect of either inhibitory or memory load on redundancy is consistent with the conclusion drawn from study 4, that monitoring measures such as redundancy do not rely on executive processes, but rather on passive

storage within the working memory slave systems and that a memory load of two additional items is not sufficient to overload the phonological loop capacity.

The Towse & Valentine (1997) study however uses a young adult population and it would be interesting to use a similar paradigm within an aging context to examine the effects of memory and inhibitory load on random generation in an elderly population. The current study intends to use a similar concurrent load paradigm to that used by Towse & Valentine (1997) and to extend their findings by investigating the interaction between concurrent load and aging on a more comprehensive range of random generation measures, in both oral and keypress random generation. Investigating the effects of inhibitory and memory load on both oral and keypress random generation will provide further evidence regarding the underlying processes involved in both of the tasks and add to current knowledge relating to the effects of age on executively demanding tasks. The same measures of randomness will be used as in study 4.

Based on the findings from the previous study and from the Towse & Valentine (1997) study it is predicted that: there will be an effect of concurrent load (memory load and inhibitory load) on all measures, apart from the redundancy and coupon measures; there will be a greater effect of inhibitory load compared to memory load on the adjacency and runs measures; there will be a greater effect of concurrent load among older adults compared to young adults; and there will be a greater effect of concurrent load in oral compared to keypress random generation.

6.7: Study 5: Method

6.7.1: Design

A quasi-experimental mixed factorial design was used to investigate the effects of age, concurrent load and modality on random generation performance. Age was the between subjects factor, with two levels (young adults, aged 18 – 30 years and older adults aged 65 plus years). The within subjects factors were concurrent load, with three levels (no load, memory load and inhibitory load) and modality, with two levels (oral and keypress modalities). The dependent variable, randomness was measured using the same seven measures of randomness as in study 4 (RNG & NSQ, presumed

to be general measures of randomness relying on a number of executive process; redundancy & coupon, presumed to make demand on monitoring and updating processes; adjacency & runs, presumed to rely on inhibitory processes; and TPI, presumed to rely on the executive process of switching) (see appendix 6 for more detailed description). These were calculated through the use of the RGCalc program (Towse & Neil (1998). Control measures of verbal intelligence (using NART), speed of processing (using speech articulation rate) and dementia (using MMSE) were also taken.

6.7.2: Participants

The same convenience sample of 20 young adults and 20 older adults as in study 4 was used (see section 6.3.1).

6.7.3: Tasks

Throughout the oral random number generation task participants were required to generate numbers randomly at a rate of one per two seconds in time to a metronome, using a set size of 10. In the no load condition participants were asked to produce numbers from a response set of numbers 1 – 10 inclusive. The memory and inhibitory load tasks for the oral random generation followed a similar procedure to that used by Towse & Valentine (1997). In the memory load task the same response set of 1 – 10 inclusive was used, however participants also had to remember the numbers 2 and 7. To indicate that they had remembered the specified numbers participants were asked to tap the desk each time they generated either of those particular numbers. Participants were also instructed to use these numbers no more and no less than any other numbers in the potential set of numbers. In the inhibitory load task participants were requested to remember the numbers 2 and 7, but not to include them in their responses. In order to keep the set size to 10, the possible range of responses was increased to 1 – 12 inclusive.

Similarly to the previous study participants were instructed to produce numbers randomly by imagining that they were drawing a number out of a hat, saying the number out loud, replacing it and then picking another number and so on, so that each time a response is made every number in the hat has an equal chance being selected. Participants were required to produce 100 responses verbally and responses were

recorded on a tape recorder and written down by the experimenter. Error responses for the memory load and inhibitory load conditions were also recorded: an error being classified as a missed memory response to the specified numbers in the memory load condition and an incorrect response of 2 or 7 in the inhibitory load condition.

The random keypress tasks followed a similar pattern. Participants were required to press keys arranged in a horizontal line in a random order at the rate of one keypress per second in time to a metronome, using a set size of 10 keys. For the no load condition the keys 1 – 0 inclusive were used. For the memory load task the same set of keys were used, but participants were also required to remember the 2nd key and the 7th key in the horizontal sequence. To indicate that they had remembered these specific keys, participants were required to say "now" each time they pressed either of the two specified keys. Participants were also instructed to use these keys no more and no less than any other key in the potential set. In the inhibitory load condition participants were requested not to press the 2nd and 7th key in the horizontal sequence when generating keypresses. To maintain a set size of 10 the potential keys ranged from number key 1 to the = key on a standard keyboard, excluding keys 2 and 7. For all tasks the keys in use were covered with tape to prevent participants generating according to the visual numbers on the keys. Responses were recorded on the computer as the numbers and symbols corresponding to the particular key presses and then recoded to form a sequence of 1 – 10, with the left-most permitted key being coded as 1, the next as 2 etc (allowing for the excluded keys in the inhibitory load condition), thus allowing equivalent analysis to the oral random generation task. Participants were not able to see their responses on the screen. Error scores were also recorded for the memory and inhibitory load conditions in the same way as for the oral generation tasks.

Dementia, verbal intelligence and speed of processing were measured using the tasks as in studies 2, 3 and 4 (see sections 4.2.3 and 5.3.3 for descriptions of these tasks and scoring procedure).

6.7.4: Procedure

Participants completed all tasks on an individual basis. MMSE, NART and speech articulation scores from study 4 were used as all participants undertook both studies.

The order of completion for the different conditions was counterbalanced across modalities, so that half of each age group undertook the oral random generation tasks first and half undertook the keypress generation tasks first. Within each modality participants undertook the no load condition first, then the order of the memory and inhibitory load tasks was counterbalanced within each age group, so that half undertook the inhibitory load conditions first and half completed the memory load conditions first.

At the start of each condition participants were given the specific instructions according to that task, allowed to listen to the rate of the metronome before starting, and then practice generating numbers or keypresses from the response set in time with the beep, until they felt comfortable with the task. For all task conditions participants were instructed that if a response was missed, or they lost time with the beep of the metronome, to ignore the mistake and carry on generating numbers in time with the remaining beeps as best they could. For the memory load task conditions participants were also instructed that if they missed either tapping the desk during oral generation, or saying "now" during the keypress generation when they responded with one of the items to be remembered, that they would be reminded that they should remember this number or key press, by the experimenter giving the required response (desk tap for oral or "now" for keypress). For the inhibitory load conditions a reminder was given if an incorrect response of 2 or 7 in the oral tasks or 2nd or 7th key in the keypress conditions was given, by the experimenter saying "no".

Responses for each task condition (recoded responses for the inhibitory conditions) were then entered into the RGCalc program (Towse & Neil, 1998) to calculate the different measures of randomness.

6.8: Study 5: Results

6.8.1: Data Analysis

Mean and standard deviation scores are presented for each measure of randomness separately for each load condition for both young and old adults. Mixed 3 factor ANOVAs were conducted to determine the effects of age, modality and load and the interaction between these factors, for each measure of randomness. ANCOVA

analyses using the same factors as the ANOVA, but also including speed of processing and IQ measures as covariates were also carried out for each measure of randomness, to determine the influence of speed of processing and intelligence on any effects of age. ANCOVAs using both speed of processing and IQ as covariates are presented within the results section. ANCOVAs using speed of processing alone and IQ alone as covariates are presented in appendix 8. Post hoc analysis utilises Bonferroni corrected one way ANOVAs. Additionally, error scores were also analysed using a mixed 3 factor ANOVA to determine the effect of age, load and modality on error scores. Results from the error analysis are reported in appendix 8, section 8.8 and are discussed in the discussion section of this chapter.

6.8.2: RNG Scores

ANOVA analysis found no significant effect of age or modality ($p>0.05$). However, a main effect of load was evident ($F(2,76) = 3.212$, $p = 0.046$), with higher RNG scores in both load conditions compared to the no load condition (see table 6.15). No 2-way or 3-way interactions were significant ($p>0.05$).

Condition	Young Adults	Older Adults
Oral no load	0.243 (0.063)	0.257 (0.073)
Oral memory load	0.272 (0.056)	0.295 (0.090)
Oral inhibitory load	0.264 (0.038)	0.315 (0.093)
Keypress no load	0.246 (0.038)	0.306 (0.094)
Keypress memory load	0.359 (0.390)	0.324 (0.096)
Keypress inhibitory load	0.248 (0.051)	0.346 (0.127)

Table 6.15: Mean (standard deviation) RNG Scores

ANCOVA analysis removed the main effect of load; however, the 2-way interaction between load and age was significant ($F(2,68) = 4.360$, $p = 0.017$) when both speed of processing and IQ were controlled for. Trends suggested that older adults showed higher RNG scores and were therefore less random in the inhibitory load task compared to no load and memory load tasks, whereas young adults showed higher RNG scores and were therefore less random in the memory load task compared to the no load and inhibitory load tasks (see figure 6.1). However, post hoc analysis showed that these trends were not significant using the Bonferroni corrected p value ($p>0.005$).

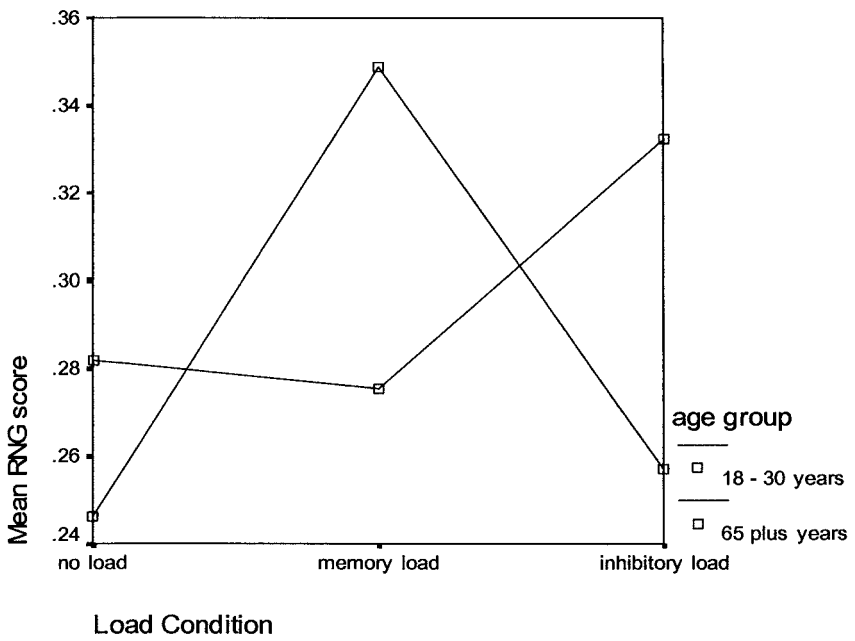


Figure 6.1: Load x Age Interaction (controlling for speed of processing and IQ) for RNG Results

6.8.3: NSQ Scores

ANOVA analysis showed a significant main effect of age ($F(1,38) = 10.314$, $p = 0.003$) with older adults showing higher NSQ scores than young adults (see table 6.16), suggesting that the older adults are less random than young adults. A main effect of load was also evident ($F(2,76) = 9.509$, $p = 0.0001$), with higher NSQ scores on the memory and inhibitory load tasks compared to the no load tasks (see table 6.16). A significant 2-way interaction between load and age was also apparent ($F(2,76) = 3.419$, $p = 0.038$). No significant main effect of modality and no other significant 2-way or 3-way interactions were evident ($p>0.05$). ANCOVA analysis controlling for speed of processing and IQ removed the significant main effect of load and the significant interaction between load and age. However, the main effect of age was almost significant ($F(1,34) = 4.108$, $p = 0.051$), suggesting that whilst speed of processing and IQ can account for the effects of load on NSQ performance, the effect of age is attenuated, but not completely removed by controlling for both speed of processing and IQ. Post hoc analysis of the effect of age within the different tasks conditions shows a significant simple effect of age in the keypress task under an inhibitory load ($F(1,34) = 8.491$, $p = 0.006$), but no other task conditions showed any simple effects of age using the Bonferroni adjusted p value ($p>0.008$).

Condition	Young Adults	Older Adults
Oral no load	57.83 (4.03)	59.65 (3.71)
Oral memory load	61.37 (3.98)	61.97 (5.18)
Oral inhibitory load	59.55 (2.63)	62.98 (5.86)
Keypress no load	59.10 (3.76)	61.92 (5.25)
Keypress memory load	60.31 (3.67)	63.74 (5.25)
Keypress inhibitory load	58.74 (3.03)	64.55 (6.11)

Table 6.16: Mean (standard deviation) NSQ Scores

6.8.4: Redundancy Scores

No significant main effects of age or modality were found in the ANOVA analysis ($p>0.05$). The main effect of load however was significant ($F(2,72) = 13.780$, $p = 0.0001$), with higher redundancy scores in the load conditions compared to the no load conditions, particularly in the memory load tasks (see table 6.17). The 2-way interaction between modality and age ($F(1,38) = 4.916$, $p = 0.033$) and the 3-way interaction between age, modality and load ($F(2,76) = 4.858$, $p = 0.010$) was also significant. No other 2-way interactions were significant ($p>0.05$).

Condition	Young Adults	Older Adults
Oral no load	1.58 (0.73)	1.73 (1.42)
Oral memory load	3.60 (1.93)	2.27 (1.31)
Oral inhibitory load	2.70 (1.70)	2.12 (1.68)
Keypress no load	2.55 (1.55)	1.95 (0.97)
Keypress memory load	2.86 (1.76)	4.14 (3.43)
Keypress inhibitory load	2.10 (1.03)	2.64 (1.78)

Table 6.17: Mean (standard deviation) Redundancy Scores

ANCOVA analysis controlling for speed of processing and IQ showed no significant main effects and no significant 2 or 3-way interactions ($p>0.05$), suggesting that the effects of age, modality and load can be accounted for by either speed of processing and / or IQ. Further ANCOVA analysis controlling for speed of processing alone and IQ alone found that the effect of load remained in both cases, when either speed of processing or IQ is controlled for alone (see appendix 8, sections 8.3). This suggests that both speed of processing and IQ attenuate the effects of load, but neither speed of processing or IQ alone can wholly account for the effects of load on redundancy.

6.8.5: Coupon Scores

No significant main effects of age or modality were found in the ANOVA analysis ($p>0.05$). However, a significant main effect of load was evident ($F(2,76) = 3.143$, $p = 0.049$), with higher coupon scores in both the memory and inhibitory load condition compared to the baseline condition (see table 6.18). A significant 2-way interaction between age and modality was also evident ($F(1,38) = 6.094$, $p = 0.018$). No other 2-way or 3-way interactions were apparent ($p>0.05$).

Condition	Young Adults	Older Adults
Oral no load	20.40 (5.95)	17.00 (4.08)
Oral memory load	24.69 (9.21)	20.15 (6.34)
Oral inhibitory load	23.13 (12.89)	21.56 (10.41)
Keypress no load	20.19 (5.56)	20.06 (5.76)
Keypress memory load	20.86 (6.83)	24.50 (11.01)
Keypress inhibitory load	19.45 (4.76)	24.62 (12.13)

Table 6.18: Mean (standard deviation) Coupon Scores

ANCOVA analysis controlling for speed of processing and IQ showed no significant main effects or interactions ($p>0.05$), suggesting that speed of processing and / or IQ can account for the effects of age, modality and load. ANCOVA analysis controlling for speed of processing and IQ individually found that controlling for speed of processing eliminated the main effect of load, whereas controlling for IQ eliminated the interaction between age and modality (see appendix 8, section 8.4).

6.8.6: Adjacency Scores

ANOVA analysis showed a significant main effect of age ($F(1,38) = 4.170$, $p = 0.048$), with older adults showing higher adjacency scores than young adults (see table 6.19), suggesting that older adults are less random than young adults. A significant main effect of load ($F(2,76) = 15.596$, $p = 0.0001$) and a significant main effect of modality ($F(1,38) = 20.104$, $p = 0.0001$) were also evident. The 2-way interaction between load and age was also significant ($F(2,76) = 4.534$, $p = 0.014$). No other 2 way or 3-way interactions were significant ($p>0.05$). ANCOVA analysis controlling for speed of processing and IQ removed the main effects of age, modality and load; however, the interaction between age and load remained significant ($F(2,68) = 3.780$, $p = 0.028$). Post hoc analysis showed no significant simple effects using the

Bonferroni corrected p value (p>0.005), although non-significant trends indicated larger effects of age in both the memory and inhibitory load conditions compared to the no load condition (see figure 6.2).

Condition	Young Adults	Older Adults
Oral no load	26.67 (10.53)	29.40 (15.51)
Oral memory load	28.42 (8.47)	33.17 (18.62)
Oral inhibitory load	32.88 (11.01)	37.43 (18.01)
Keypress no load	16.38 (12.48)	21.33 (16.56)
Keypress memory load	16.81 (12.22)	32.48 (18.78)
Keypress inhibitory load	17.38 (9.69)	31.08 (19.36)

Table 6.19: Mean (standard deviation) Adjacency Scores

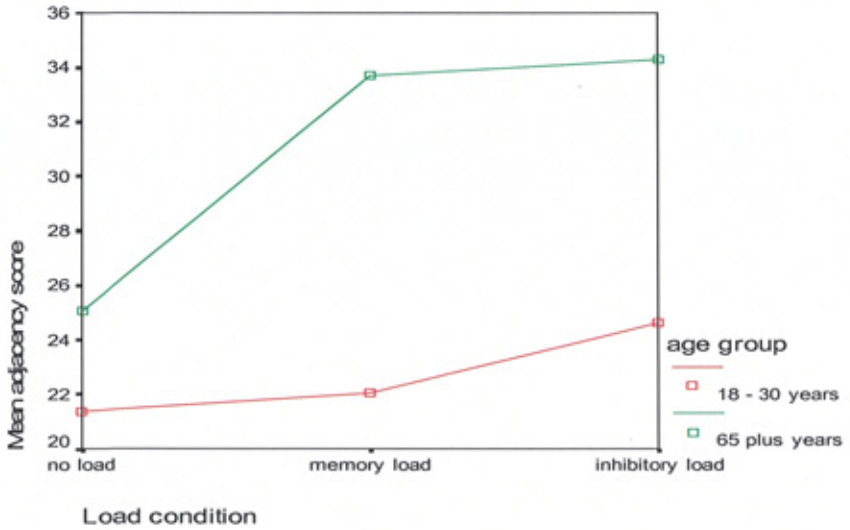


Figure 6.2: Age x Load Interaction (controlling for speed of processing and IQ) for Adjacency Results

6.8.7: Runs Scores

ANOVA analysis found a significant main effect of age ($F(1,38) = 6.602$, $p = 0.014$) with older adults showing higher runs scores than young adults (see table 6.20), suggesting that older adults are less random. Significant main effects of load ($F(2,76) = 14.671$, $p = 0.0001$) and modality ($F(1,38) = 8.318$, $p = 0.006$) were also evident. The 2-way interaction between age and load was also significant ($F(2,76) = 6.359$, $p = 0.003$). However, ANCOVA analysis controlling for speed of processing and IQ found no significant main effects or interactions (p>0.05), suggesting that the effects of age, load and modality can be accounted for by speed of processing and / or IQ. Further ANCOVA analysis indicated that controlling for speed of processing alone removed all main effects, but the interaction between load and age remained; whereas

when IQ was controlled for alone the main effect of age and the interaction between age and load remained (see appendix 8, section 8.6). This suggests that whilst speed of processing and IQ both attenuate the effects of age and load, neither can completely account for age-related differences in runs scores.

Condition	Young Adults	Older Adults
Oral no load	1.32 (0.63)	1.60 (0.89)
Oral memory load	1.36 (0.48)	1.89 (1.12)
Oral inhibitory load	1.50 (0.56)	2.80 (2.16)
Keypress no load	0.90 (0.60)	1.30 (1.36)
Keypress memory load	1.01 (0.52)	1.78 (1.53)
Keypress inhibitory load	1.13 (0.64)	2.11 (1.72)

Table 6.20: Mean (standard deviation) Runs Scores

6.8.8: TPI Scores

ANOVA analysis found a significant main effect of age ($F(1,38) = 11.078$, $p = 0.002$) with older adults showing lower TPI scores than young adults, suggesting that older adults switch between ascending and descending strategies less frequently than young adults (see table 6.21). Significant main effects of load ($F(2,76) = 11.078$, $p = 0.002$) and modality ($F(1,38) = 10.366$, $p = 0.0001$) were also evident. No 2-way or 3-way interactions were significant ($p>0.05$).

Condition	Young Adults	Older Adults
Oral no load	87.41 (11.12)	81.12 (20.98)
Oral memory load	83.70 (12.69)	74.83 (21.04)
Oral inhibitory load	82.77 (13.83)	63.88 (27.99)
Keypress no load	101.40 (16.70)	82.21 (24.01)
Keypress memory load	96.76 (15.99)	80.14 (24.01)
Keypress inhibitory load	95.60 (17.01)	75.34 (24.06)

Table 6.21: Mean (standard deviation) TPI Scores

When speed of processing and IQ were controlled for in the ANCOVA analysis, the main effects of load and modality were removed ($p>0.05$), but the main effect of age remained ($F(1,34) = 8.192$, $p = 0.007$), suggesting that the age-related decline in switching between ascending and descending sequences cannot be accounted for by either speed of processing or IQ. Post hoc analysis of the effect of age on the TPI

measures under different task conditions revealed no significant simple effects using the Bonferroni corrected p value ($p>0.008$).

6.9: Study 5: Discussion

6.9.1: General Measures of Randomness

No significant main effect of age was found in the RNG measure, however the main effect of load was significant. This main effect of load was removed when both speed of processing and IQ were controlled for and a significant interaction between age and load became evident. Although post hoc analysis showed no significant simple effects, the pattern in the interaction graph (see figure 6.1) suggested that whilst young adults were less random with a memory load, older adults were less random with an inhibitory load. A similar interaction pattern was also evident with the NSQ measure, however this interaction was removed when controlling for speed of processing and IQ. ANCOVA analysis controlling for speed of processing and IQ showed no significant differences; however, the main effect of age was approaching significance, and post hoc analysis of the simple effects of age showed that older adults were less random than young adults under inhibitory load conditions for the keypress task only. The effect of load found in these general measures is partially consistent with the findings of Towse & Valentine (1997), who demonstrated an effect of memory and inhibitory load on the RNG measure of randomness. However, results from the current study extend these findings in two ways.

Firstly, the effects of memory and inhibitory loads on RNG performance do not appear to be equivalent as suggested by Towse & Valentine (1997), given the interaction between age and load. Using a young adult sample Towse & Valentine (1997) found that both a memory and inhibitory load reduced randomness on the RNG index. However, by using older adults as well as young adults, the results from the current study add to this finding by demonstrating that whilst young adults appear to be impaired more by a memory load, older adults are impaired more by an inhibitory load. One explanation for this may be that young and older adults utilise different strategies when undertaking random generation, which in turn make demands on different underlying processes. An alternative explanation may be that both young and old adults utilise a range of different processes during random

generation, but that older adults are more impaired by an inhibitory load because they have reduced inhibitory resources available. However, this explanation cannot account for the impairment of young but not old adults in the memory load condition. Whilst there is some evidence to suggest age-equivalence in memory resources (Belleville et al, 1996; Dobbs & Rule, 1989), there is little to suggest that older adults have greater memory resources. The results from this study are therefore more consistent with the different strategies explanation of age differences in random generation, which has been put forward by Phillips & Hamilton (2001).

Secondly, the effect of load on these general measures of randomness appears to be mediated, but not completely accounted for, by both speed of processing and IQ, adding to the debate regarding the effects of speed of processing on cognitive aging. Neither speed of processing nor IQ alone completely removes the interaction effects between age and load in the RNG measure, although the size of the interaction is reduced. This suggests that general resource theories, such as speed of processing, cannot wholly account for age-related differences in random generation performance, other underlying processes must also be important.

6.9.2: Monitoring / Updating Measures of Randomness

Neither the redundancy or the coupon measures showed a main effect of age; however, both showed a two-way interaction between modality and age and the redundancy measure showed a three-way interaction between age, modality and load; all of which are removed by speed of processing and IQ. The lack of a consistent effect of age supports the findings from study 4 and suggests that both of these measures rely on passive memory storage to monitor items, rather than executive memory updating processes. This is consistent with the idea that older adults will show a decline in performance on tasks which require active executive processing and age equivalence on tasks that require passive storage (e.g. Dobbs & Rule, 1989; Gick et al, 1988; Morris et al, 1988). The elimination of the age by modality interaction effects by controlling for speed of processing is also consistent with previous research on aging and passive storage, which have found that a reduced speed of processing, as indicated by a slower articulation rate, may account for age differences in passive storage tasks such as word span (see Kynette, Kemper, Norman & Cheung, 1990; Phillips & Hamilton, 2001). Whilst the findings from studies 4 & 5 suggest that

passive memory processes do not decline with age, further research looking at the role of more executively demanding memory updating processes would be useful to clarify the role of memory processes in age differences on executive tasks.

Both the redundancy and coupon measures also showed significant effects of load with poorer randomness in both the memory and the inhibitory load conditions. Again however, the effects of load are removed by speed of processing and IQ. The effect of both a memory and inhibitory load on redundancy and coupon measures is inconsistent with the previous findings of Towse & Valentine (1997), who found no effect of a concurrent load on redundancy. One explanation for the different findings may be the inclusion of older adults with a slower speed of processing in the current study, compared to the use of a young adult sample in the Towse & Valentine (1997) study. In the current study the effect of load was removed by controlling for speed of processing, suggesting that speed of processing may differentially affect the no load and load conditions, particularly among older adults with a slower speed of processing. Speed of processing was not measured in the Towse & Valentine (1997) study; however, given the use of a purely young adult sample, it is unlikely that speed of processing differences will limit performance in the more demanding load conditions.

6.9.3: Inhibitory Measures of Randomness

Both the adjacency and runs measures showed significant main effects of age and load and a significant interaction between age and load. However, all of these effects, apart from the interaction between age and load for the adjacency measure, were removed when both speed of processing and IQ were controlled for. Additional ANCOVA analysis (see appendix 8) indicated that on the whole it is controlling for speed of processing, rather than IQ that eliminates the main effects of age and load. These results suggest that whilst speed of processing may be able to account for some of the effects of age and load on randomness measures, it cannot wholly account for them, given that the interaction for the adjacency measure is still present.

Post hoc analysis of the interaction between age and load for the adjacency measure found non-significant trends, indicating that whilst young adults only show a marginal decrement in randomness with a memory or an inhibitory load, older adults show a

much greater decrement under both a memory and inhibitory load. In contrast to the results of study 4 this suggests that older adults do show a reduced ability to inhibit stereotypical responses, but only under increased memory or inhibitory load conditions. The effect of load is only partially consistent with the results of Towse & Valentine (1997), who found that an inhibitory load increased adjacency scores, whereas a memory load did not. One explanation that again may account for the differences between the findings of this study and those of Towse & Valentine (1997), is that Towse & Valentine (1997) used only young adults, whereas the current study uses young and old adults. However, no effects of either memory or inhibitory load were found in the young adults sample from this study. Procedural differences may also account for the different results. Towse and Valentine (1997) used a faster rate of random generation and used oral random generation only, compared to the current study, which used a slower rate of generation and both oral and keypress generation. The use of a faster rate of generation is likely to have increased the central executive demands of the task, making it more difficult to inhibit stereotypical responses at a faster rate. This effect of response rate on adjacency scores has been demonstrated by a number of studies (Baddeley et al, 1998; Towse, 1998).

The effect of both the memory and inhibitory load on adjacency scores in the older adult group is interesting. Given that the adjacency measure reflects inhibitory processes, a greater decrement in performance would be expected with the inhibitory load compared to the memory load on these inhibitory measures. A possible explanation for the influence of both a memory and inhibitory load on performance is that older adults have a deficit in general working memory or executive resources. This argument has also been put forward by Van der Linden et al (1998) to explain their results on age differences in random generation. They suggested that older adults have a specific deficit in inhibitory processing as well as a reduction in general central executive resources.

Although the results from both the current study and study 4 do not support the idea of a specific inhibitory deficit among the older adults, a general working memory resource deficit may be able to account for the adjacency results from this study. A number of researchers support the view that a reduction in general working memory resources can account for age differences on a range of tasks (Cherry & Park, 1993;

Craik & Byrd, 1982; Dobbs & Rule, 1989). However, similarly to these previous studies which have concluded that older adults have a reduction in general working memory resources, it is unclear from the current study whether this deficit is a consequence of a reduced storage capacity, a reduced processing capacity, or a reduced ability to co-ordinate both storage and processing; a criticism which has been highlighted previously for reduced general working memory resource theory of adult age differences (Brebion et al, 1997; Foos, 1995). Given the results from both this study and study 4 demonstrating that older adults are not impaired on the monitoring measures, it is unlikely that a reduced storage capacity can account for the general working memory resource deficit. However, the results would be consistent with either a reduction in processing resources, or an impaired ability to combine storage and processing. Although a reduction in general working memory resources with age can account for the adjacency results in this study, the general effect of load has not been consistent across all measures of randomness and further research is necessary to clarify under what task constraints age differences caused by a reduced general working memory capacity will occur.

A significant main effect of modality was also evident for both the adjacency and runs measures; however, this effect of modality was removed when speed of processing and IQ were controlled for, in particular, further ANCOVA analysis indicated that controlling for speed of processing removed the effect of modality (see appendix 8). The main effect of modality, coupled with the lack of interactions between modality and either load or age, suggests that whilst randomness is poorer under oral generation conditions compared to keypress generation conditions, they make demands on the same underlying processes, supporting the argument put forward by Baddeley et al (1998) that the tasks are equivalent in terms of the processes they rely on, but differ in the amount of these processes they require.

6.9.4: Switching Measures of Randomness

A significant effect of age was evident on the TPI measure of randomness, with older adults showing much lower TPI scores than young adults, suggesting that older adults are less able to switch between ascending and descending strategies than young adults. This effect remains when both speed of processing and IQ are controlled for, indicating that the age-related change in switching cannot be accounted for by age-

related changes in either speed of processing or IQ. Given that the TPI measure is presumed to reflect an executively controlled strategy switching process, results suggest that it is the central executive component which declines with age, in particular the strategy switching function of the central executive. This supports the conclusions of study 4.

The results from the TPI measure suggest that older adults appear to have a specific deficit in the ability to switch strategies which cannot be accounted for by general factors, such as speed of processing, inhibitory or passive memory factors. This age-related decline in strategy switching is consistent with the findings of a number of previous studies using tasks such as the WCST, which have also suggested that older adults are less able to switch between strategies (e.g. Daigneault et al, 1992; Libon et al, 1994; Parkin et al, 1995).

Significant main effects of load and modality were also found for the TPI measure, with lower TPI scores in both load conditions compared to the no load conditions and lower TPI scores during oral random generation compared to keypress random generation. However, these effects of load and modality were both eliminated when speed of processing and IQ were controlled for. Further ANCOVA analysis indicated that both speed of processing or IQ alone removed the effects of load and modality, suggesting that the effects of load and modality can best be accounted for in terms of the different demands the load and modality conditions make on speed of processing and IQ.

6.9.5: Error Scores

The main data analysis has concentrated on the different measures of randomness as indicators of a decline in performance on the random generation tasks. However, an alternative measure is to look at the number of errors made under the load conditions as this may also indicate an impaired task performance. During the memory load task participants may make errors in omitting to remember the two responses they had to remember, whilst in the inhibitory load condition participants may show intrusions of the two responses to be omitted.

Analysis of the error scores indicates that older adults show more errors than young adults, even when speed of processing and IQ are controlled for (see appendix 8). Whilst speed of processing removes the effect of age in some of the measures of randomness discussed previously, the decline in performance with age is not removed by speed of processing when errors are examined. This is inconsistent with a general slowing hypothesis such as that proposed by Salthouse (1996) and suggests that older adults have greater difficulty than young adults on random generation tasks under both memory and inhibitory load conditions. One explanation for this may be that older adults have an impaired ability to co-ordinate both the random generation and load components of the tasks within working memory, leading to a decline in performance which is evident in terms of the number of errors made. A number of studies have suggested that under certain circumstances older adults show a decline in dual task performance (Chen, 2000 & Phillips et al, 2003).

6.10: General Conclusion for Studies 4 & 5

Studies 4 and 5 have highlighted a number of important issues that need to be considered. Firstly, they have added to the evidence from previous studies relating to the discussion of the equivalence of oral and keypress random generation. Results from both studies 4 and 5 show that whilst there are differences in randomness between the two modalities, there are few interactions between modality and either other task manipulations or age. This provides further evidence supporting the argument put forward by Baddeley et al (1998), that oral and keypress random generation do rely on the same underlying processes, but that they differ in the extent of their demands on these processes, with oral random generation making greater demands on central executive processes than keypress random generation.

Although the oral and keypress random generation tasks appear to rely on the same processes, the differing effects of response rate within the set size 5 and set size 10 results, suggests that random generation with different set sizes is likely to make demands on different processes. Although the results were analysed separately for the two set sizes and therefore a direct comparison is not possible, generally response rate effects occurred for set size 10, but not set size 5, suggesting that set size 10 random generation relies on executive resources, whereas set size 5 random generation may

not. It is argued that one possible explanation for this may be that the greater requirement for strategies under voluntary control in set size 10 requires the involvement of central executive processes, whereas performance on the set size 5 task is determined more by external task constraints. Firm conclusions regarding this explanation however are limited, as the study was not specifically designed to test this and further research is necessary to investigate whether the degree of voluntary control required can determine the effects of age on a variety of cognitive tasks.

Secondly, no consistent effects of age on inhibitory processing were evident and those age differences in inhibitory measures that were found in study 5 with the increased load conditions, were generally eliminated when speed of processing was controlled for. It could be argued that the results from studies 4 and 5 indicate age equivalence in inhibitory processing. However, this argument is not supported by previous research demonstrating age differences in inhibitory processes (Hasher & Zacks, 1988; McDowd & Shaw, 2000; Van der Linden et al, 1998), and some age differences were found for the inhibitory measures in study 5 under both memory and inhibitory load conditions. A more likely explanation is that whilst inhibitory processes decline with age, this decline is only small and therefore only evident under more demanding task conditions, as in study 5 load conditions. It can also be concluded from the results that these small age differences in inhibitory processing may be accounted for by age differences in more general resources, such as speed of processing and general working memory resources. Taking into consideration that a number of previous studies have found evidence that speed of processing can account for age differences on inhibitory measures (e.g. Earles et al, 1997; Salthouse & Meinz, 1995; Shilling et al, 2002) and given the results of studies 4 and 5, it is unlikely that investigating age differences in inhibitory processes will provide a fruitful method for investigating age differences in central executive processing.

A third important issue to consider is the effects of age on memory processes during random generation. Both studies found no consistent effects of age on the redundancy and coupon measures of randomness and those effects that were evident under load conditions were eliminated by speed of processing. It is assumed that these measures reflect the ability to monitor previously generated items, and as such, are likely to rely on passive storage within working memory slave systems. The results therefore

support previous research suggesting that these passive, slave system working memory processes do not decline with age (e.g. Dobbs & Rule, 1989, Phillips & Hamilton, 2001). Although the monitoring measures presumed to rely on passive memory storage showed no decline with age; some effects of a memory load on age-related performance on other measures of randomness, such as the inhibitory measures, were evident in study 5. This can be interpreted in terms of an age-related deficit in general working memory resources and is likely to reflect either active processing within working memory, or the co-ordination of storage and processing aspects of memory, both of which are considered functions of the central executive. Given the differing effects of memory load on the different measures of randomness it is difficult to draw firm conclusions regarding the effects of age on executively controlled memory processes and therefore further research looking at age differences in more executively demanding general working memory resources is necessary.

The most important issue to discuss is the finding of an age-related deficit in the TPI measure of randomness which cannot be explained by speed of processing or IQ differences. This effect of age on the TPI measure was evident in both studies 4 and 5 and suggests that the executive function of strategy switching declines with age. Although an effect of load was found on the TPI measure in study 5, no interaction was present, which suggests that the executive strategy switching function is not affected by either general working memory resources or inhibitory processes. This separability of the executive switching function from other potentially executively controlled processes provides some support for a fractionated model of the central executive (e.g. Baddeley, 1996, Miyake et al, 2000) and warrants further investigation.

However, the effect of age on strategy switching does not appear to be consistent across all task manipulations. No age differences in the switching measure were evident in the set size 5 results in study 4. One explanation that may account for the differing effects of age on the switching measure may be in terms of the amount of internal voluntary control required for the switch between ascending and descending strategies. During set size 5 random generation switching between ascending and descending strategies will be determined to a large extent by the task constraints, as the small set size will force a switch after a small number of generated items, whereas

with a larger set size such as 10, switching between ascending and descending strategies is less constrained by the task set size demands and therefore there is greater potential for switching to be controlled by internal voluntary processes. Although this account may plausibly explain the differing findings between set size 5 and 10 on the switching measure of random generation, the amount of voluntary control required was not specifically manipulated and no direct comparison between set size 5 and 10 results was made, therefore it is difficult to draw firm conclusions. Further research is necessary looking specifically at task switching and the specific situations in which age differences occur; in particular, it would be interesting to directly manipulate the requirement for internal voluntary control when switching, to determine whether this may account for age differences in the executive switching function.

Studies 6 & 7 (chapter 7) will further investigate the effects of age on the executive function of switching. One paradigm which can be used to investigate executive switching processes is the task switching paradigm, originally developed by Jersild (1927). The task switching paradigm compares response time for the repeated performance of a simple task to the response time for alternation between two simple tasks: the increased response time when alternating between tasks is known as the switch cost. This task has the advantage of being able to isolate higher level executively controlled processes from lower level task specific processes and therefore is likely to be a purer and more valid measure of executive switching processes than other more traditional executive switching tasks such as the WCST and random generation (Meiran, 1996) .

In order to investigate the effects of general working memory resources on age differences during task switching, study 6 will manipulate the frequency with which a switch occurs in the alternating task blocks. The rationale being that a less frequent switch will require more executively controlled general working memory resources, as the participant will need to simultaneously perform the task and keep track of where in the sequence they are in order to know when to switch to the alternative task. Study 7 will investigate the effects of voluntary control on age differences in task switching performance, by using an external cue to indicate when to switch between tasks on an alternating task block. The potency of the cue will be manipulated to vary the degree of voluntary control required. The rationale being that a more strongly potent cue will provide more external control and require less internal control than a

weak potency cue. In both studies the ability to co-ordinate two tasks within the task switching paradigm will also be examined, along with the specific switching costs by utilising differing measures associated with task switching.

Chapter 7

Studies 6 & 7 - Task Switching and Aging

7.1: General Rationale for Studies 6 & 7

Results from the previous studies investigating the effects of age, independently of speed of processing, on verbal fluency and random generation, suggest that within a working memory framework (e.g. Baddeley, 1986; 1996; 2000; Baddeley & Hitch, 1974) older adults show a decline in performance on some tasks, which are likely to make demands on the central executive component. More specifically, both the verbal fluency and random generation study results suggest that it may be the executively controlled ability to switch between strategies that can account for age differences in these tasks. Within the random generation studies (chapter 6), age-related deficits were found on the TPI measure, which indicates the number times a change is made between ascending and descending sequences. The TPI measure is presumed to reflect the executively controlled ability to switch strategies. This age difference can be compared to age equivalence in performance on other measures of randomness that are presumed to reflect inhibitory processes and non-executive working memory storage processes. However, both the verbal fluency and random generation tasks are complex tasks which are likely to make demands on a range of both central executive and non-executive processes (see Phillips, 1997), therefore making it difficult to draw firm conclusions on the nature of the pattern of age-related deficits and equivalence observed. It has been suggested that the task switching paradigm may be a useful method for investigating executively controlled switching processes, as it is possible to isolate the executive processes responsible for the switch fron the basic task processes (Meiran, 1996).

An investigation of the age-related changes, using the task switching paradigm, may therefore be able to provide more valid evidence to support the conclusions from the verbal fluency and random generation studies and extend understanding of the effects of aging on central executive processing, in particular the executive process of task switching. Studies 6 & 7 will therefore focus on the executive process of switching, using a task switching paradigm to investigate the effects of age on executively controlled task switching.

The results from the random generation studies, in particular study 5, also suggested that a general working memory resource, in the form of either active memory processing, or the co-ordination of storage and processing may also decline with age. In study 5, age-related deficits were evident on a number of measures under memory load conditions. The effect of a memory load on age-related task switching performance will be investigated further in study 6, by requiring participants to keep track of when a switch between tasks is necessary. By manipulating the task demands of keeping track of when a switch is necessary in terms of the length of the sequence before a switch is needed, it is expected to vary demands on an executively controlled co-ordination process or general working memory resource.

The potential role of voluntary control processes in determining age differences during switching was also suggested by the results of study 4. An effect of age on strategy switching was only evident in set size 10, not set size 5 results, and one potential explanation for this was that the amount of voluntary control for switching strategies would be much greater in a larger set size. The final study, study 7, will directly manipulate the amount of voluntary control required during task switching, by making use of a cued task switching paradigm and varying the potency of the external task cue. A more potent task switching cue is expected to require less executively controlled voluntary switching processes, as the switch is cued externally, whereas with a weak potency task cue, the external cueing will be weaker and voluntarily controlled switching processes should be required. Sections 7.2 – 7.5 will discuss study 6 and section 7.6 – 7.9 will discuss study 7. Section 7.10 will provide a general discussion of both studies 6 & 7.

7.2: Study 6: Introduction

The reconfiguration or preparatory component of task switching (see section 2.4.3 for discussion of the processes underlying task switching performance) is presumed to rely on voluntary executive control processes and as such will be the focus of studies 6 & 7. If switch costs, or some of the components of switch costs, reflect executive processing, then an age-related decline in the executively controlled components of task switching performance would be expected. However, the evidence relating to

age effects on switch costs is mixed, with most studies finding increases in switch costs among the elderly under some experimental conditions but not others (Botwinick, Brinley & Robbin, 1958; Kray & Lindenberger, 2000; Kramer, Hahn & Gopher, 1999; Mayr, 2001; Meiran, Gotler & Perlman, 2000). This review will concentrate mainly on age-related differences in the preparatory component of switch costs given the focus of studies 6 & 7 on executive control processes responsible for task switching; although conclusions relating purely to the preparatory component are limited as a number of studies do not differentiate between executively controlled preparation and non-executive passive dissipation.

Literature relating to aging and task switching has also tended to concentrate on the different effects of age on global switch costs, which are the costs that occur when comparing switch trials in mixed blocks to pure trial blocks (also known as alternation costs) and local switch costs that occur when comparing switch trials to non-switch trials within a mixed block of trials (specific switch costs). The costs that occur when comparing non-switch trials in mixed blocks to pure blocks (mixing cost) will also be discussed. Specific switch costs are calculated by obtaining the difference between repeat trials in the mixed trial block and switch trials in the mixed trial block and as such indicate the time cost at the specific switch point in a mixed block. These costs are presumed to reflect the executive process of task switching (Meiran et al, 2001). Mixing costs are the difference between RT on repeat trials in a pure task block and the RT on repeat trials in a mixed task block and are presumed to reflect the ability to maintain and co-ordinate two tasks sets within working memory (Meiran et al, 2001). Alternation costs are measured as the difference in reaction time (RT) between repeat trials in a pure task block and switch trials in a mixed task block and are global measures which include both the specific switch costs and the mixing costs. Whilst theoretical accounts of task switching criticise the measurement of global or alternation costs for confounding task switching processes with memory processes, the comparison of age differences on both alternation and specific switch costs can be a useful indicator of the effects of executively controlled memory processes on age-related differences in task switching.

Age differences in the preparatory component of switch costs have been examined by a number of studies, the majority of which show that both young and old adults

benefit from increased preparation time (Cepeda, Kramer & Gonzalez de Sather, 2001; Kramer, Hahn & Gopher, 1999; Meiran, Gotler & Perlman, 2001), however the findings related to age differences in advance preparation are mixed. Kramer, Hahn & Gopher (1999, exp 2) investigated the effects of age on the preparatory component of switch costs, by manipulating the RSI and cuing the switch between two tasks (digit value and element number tasks) with the presentation of a coloured box around the stimuli. Results indicated that switch costs were longer for old adults than for young adults when the preparatory interval was short, suggesting that older adults may require a longer preparation time for the reconfiguration process to take place. However, over two sessions of practice this difference between the old and young adults was dramatically reduced and a significant difference remained only in the shortest preparatory interval of 200 msec. Kramer et al (1999) argued that over time older adults are capable of learning to switch between tasks as effectively as young adults. However, they suggested that this learning may only have been able to take place because there were limited demands on working memory. Participants were provided with a cue informing them when a switch would take place and therefore did not have to keep track of the trial sequence in order to switch tasks. Kramer et al (1999, exp 3) tested this by removing the instructional cue and requiring participants to keep track of when a switch was required (every 5th trial), thus increasing the demands made on working memory. Results from their experiment 3 indicated that this increased working memory load did indeed prevent older adults from being able to capitalise on practice and large age differences were found across all RSIs when participants had to keep track of the trial sequence.

The study by Kramer et al (1999) provides limited evidence for an age deficit in the processes reflected in the preparatory component of switch costs. However, if an executively demanding working memory load is increased by not providing a cue for task switches, then age differences in the preparatory switch cost do occur. Further support for an age-related deficit in the preparatory component of switch costs comes from Cepeda, Kramer & Gonzalez de Sather (2001).

The results of the Kramer et al (1999) study would be consistent with the conclusions drawn from the previous random generation studies discussed in chapters 6 and 7, which suggest that whilst passive working memory storage may not be affected by

age, tasks which require active processing within working memory, or the co-ordination of storage and processing may decline with age. The requirement to keep track of when a switch is required, as in the Kramer et al (1999) study, is likely to rely on active working memory processing. Although Kramer et al (1999) explained their results in terms of an increased working memory load being the cause of the age differences in task switching performance when participants had to keep track of when to switch, an alternative explanation could also be that by removing the task cue, there would be a greater demand on internal voluntary task switching processes, rather than externally driven task switching. A comparison between cued and non-cued switching tasks cannot differentiate between these two explanations.

Findings from a similar task switching study that do not fit neatly into either the working memory load explanation by Kramer et al (1999), or a voluntary control explanation, are those by Kray & Lindenberger (2000). Kray & Lindenberger (2000) required participants to switch every 2nd trial without the use of an instructional cue, thus requiring them to keep track of the trial sequence. However, results indicate that whilst both young and old adults show increased switch costs with short RSIs, there are no differences in the rate by which preparation time reduces the switch cost. One possible explanation for the inconsistencies between Kramer et al's (1999) results and Kray & Lindenberger's (2000) findings, is the degree of demand placed on working memory. Kray & Lindenberger (2000) used switches on every 2nd trial, whilst Kramer et al (1999) used switches on every 5th trial, therefore the working memory demands required to keep track of the sequence would be much greater during Kramer et al's study.

Results from Kray & Lindenberger (2000) suggest that young and old adults do not differ in terms of their ability to prepare for a task switch. Further support for this age-equivalence in the preparatory switch cost comes from Mayr & Liebscher (2001), and Meiran, Gotler & Perlman (2001). However, in both of these studies instructional cues were used, therefore participants did not need to remember when to switch trials and the requirement to switch tasks was externally driven by the task cue rather than internally driven by voluntary control processes. Although the majority of evidence seems to indicate that old adults are capable of making use of preparation time to reduce switch costs as effectively as young adults, it remains unclear whether this

capacity to use preparation time efficiently is reduced in older adults when they need to remember when a switch has to be made. Further research examining the effects of varying working memory demands and voluntary control demands on the preparatory component is required to clarify any age-related changes in switch cost.

An alternative method of examining the effect of working memory demands on age-related changes in switch costs is to utilise different measures of switch costs. A number of studies (Kray & Lindenberger, 2000; Mayr, 2001; Mayr & Liebscher, 2001; Meiran et al, 2001) have found that age-related increases in switch cost occur when response time on switch trials is compared to response time on non-switch trials in single task blocks (global set selection, alternation or general costs), whereas there are small or no age-related differences in switch costs when response time on switch trials is compared to non-switch trials within an alternating block of trial (local set selection or specific switch costs). The main difference in terms of processing demands between switch costs and alternation costs is the increased demands of maintaining and co-ordinating two tasks within working memory for alternation, and Kray & Lindenberger (2000) argued that it is an impairment in this ability among older adults that is responsible for the increase in general switch costs with age (see also Meiran et al, 2001).

Meiran et al (2001) has argued that alternation (or global or general switch costs) can be separated into two separate types of switch cost: mixing cost, which is no switch RT in a mixed block minus single task RT; and switching cost which is switch RT in a mixed block minus no switch RT in mixed block. Specific switching costs are further separated into the dissipating component, the preparatory component and the residual component as discussed in section 2.4.2. Whilst the preparatory component of specific switching costs is likely to represent executively controlled task switching, the mixing cost is likely to represent executive control processes of task co-ordination within working memory. Meiran et al (2001) found that older adults showed an increased RT cost for both the mixing and switching components of alternation cost. However, the increased switching cost was explained by an increase in residual component rather than an increase in the preparatory component of the switch cost. However, instructional cues were provided which may account for the lack of age differences found in the preparatory component. Meiren et al (2001) suggest two

possible explanations for the effects of age on mixing cost. Firstly, that older adults may be able to adjust to the response set more fully in single task conditions, giving them an advantage in the single task condition; secondly, they also suggest that an alternative explanation of impaired working memory performance cannot be ruled out in explaining the increased mixing cost among older adults.

An alternative explanation for age-related increases in switch costs to those considered so far is that they may be accounted for by a speed of processing deficit in the elderly. Indeed, early research on age differences in switch costs supported this view (Botwinick, Brinley & Robbin, 1958; Brinley, 1965; Hartley et al, 1990). Both Botwinick et al (1958) and Hartley, Kieley & Slabach, (1990) found that whilst the absolute difference between switch and non-switch trials was greater for old adults than for young, the proportional difference showed no significant differences between the two age groups, suggesting that age-related slowing in the elderly age groups can account for age differences in task switching.

More recently however, a number of studies have demonstrated that even when proportional differences are used, age-related increases in task switching can still occur under certain circumstances and that these changes cannot be accounted for by a general slowing hypothesis (Cepeda et al, 2001; Kray & Lindenberger, 2000; Salthouse, Fristoe, McGuthry & Hambrick, 1998). Whilst there is some evidence to suggest that task switching performance cannot wholly be explained in terms of speed of processing differences, it may still account for some age-related differences in switch costs. It is therefore important to control for speed of processing when investigating age differences in task switching to ensure that any variation in switch costs with age cannot be accounted for by variations in processing speed.

Findings from the majority of studies investigating the effects of age and executive processes during task switching are limited in one of two ways. Firstly, studies such as those by Kramer et al (1999) and Kray & Lindenberger (2000) can be criticised for not taking into account theoretical accounts demonstrating the influence of passive dissipation on task switching performance. They are based on models of task switching such as Rogers & Monsell (1995) which assume that task switching relies on executive control processes that are responsible for advance preparation; and the

methods used are unable to separate out the advance preparation and passive dissipation components. Other studies (e.g. Cepeda et al, 2001; Mayr, 2001; Meiran et al, 2001), using the task-cuing paradigm to investigate the effects of age on task switching overcome this problem, but given recent developments suggesting that this paradigm does not make demands on endogenous control processes, are of little use for investigating the effects of age on executively demanding task switching processes.

The aim of study 6 is to investigate the effects of working memory load on age-related task switching performance. Given that results from the previous random generation studies 4 & 5 suggested that passive memory processes are age invariant, the working memory load manipulation will require some degree of active processing and the co-ordination of processing and storage to place greater demands on executive control. Based on the studies by Kramer et al (1999) and Kray & Lindenberger (2000) a task switching paradigm in which participants have to keep track of when to switch between the two tasks will be used and the memory load will be manipulated by varying the frequency of the switch, so that participants will switch either every 2nd or every 5th trial in mixed blocks. A less frequent switch on every 5th trial should place greater demands on working memory, as participants will be required to keep track of a longer sequence of trials, than if the switch is every 2nd trial. By manipulating the frequency of the switch, rather than comparing cued and non cued task switching paradigms to investigate the effects of working memory load, the confounding of voluntary control variations with memory load variations should be removed. This should provide a more valid method for investigating the effects of working memory load on age-related task switching performance.

Based on the model of task switching components by Meiran et al (2001), three measures of task switching cost will be taken, alternation cost, mixing cost and specific switching cost. Separating out mixing cost from specific switching costs will allow a more detailed consideration of the effects of age and memory load on both the specific executive function of task switching and the more general executive function of co-ordinating two tasks within working memory, within a framework of a fractionated working memory model. Similarly to studies 2 – 4, speed of processing, IQ and dementia will be controlled for. The effects of speed of processing and IQ on

task switching performance will be controlled for by including speed of processing as a covariate in the ANCOVA analysis of the results.

It is predicted that: older adults will show increased alternation, mixing and switching costs compared to young adults; alternation costs will be higher when switching every 5th trial compared to when switching every 2nd trial; there will be an interaction between age and memory load, such that older adults will show much higher alternation costs than young adults, particularly when switching every 5th trial compared to when the switch is every 2nd trial.

7.3: Study 6: Method

7.3.1: Design

A quasi-experimental mixed factorial design was used to investigate the effects of age, frequency of task switch and type of task on task switching performance. Age was the between subjects factor, with two levels (young adults aged 18 – 30 years and older adults aged 65 plus years). The within subjects factors were frequency of task switch, which has two levels (switch every 2nd trial and switch every 5th trial), and type of task, with two levels (number tasks and visual tasks). The dependent variable of task switching was measured using three measures of task switching similar to those used by Meiran et al (2001). Firstly, alternation cost, which is the RT for switch trials in a mixed task block – RT for repeat trials in a pure single task block. Secondly, mixing cost, which is the RT of repeat trials in a mixed task block – RT of repeat trials in a pure task block. The third task switching measure is specific switching cost, which is the RT of switch trials in a mixed task block – RT for repeat trials in a mixed task block. This will give absolute alternation, switching and mixing costs. Control measures of verbal intelligence (using NART), speed of processing (using speech articulation rate) and dementia (using MMSE) were also taken.

7.3.2: Participants

A convenience sample of 20 young adults (13 females and 7 males) aged between 18 – 30 years (mean age 22.8 years, standard deviation 4.2) and 20 older adults (17 females and 3 males) aged 65 years plus (age range 65 – 91, mean age 72.5 years, standard deviation 6.9) was used. The younger adult sample was obtained from

University students and administration staff, the older adult sample was obtained from community and day centres for older adults and relatives of the University staff. Inclusion and exclusion criteria were the same as for studies 2, 3, 4 & 5 (see section 5.3.2). No significant differences in MMSE score or NART score ($p>0.05$) were evident between the age groups. A significant difference between young and old adults was evident in speed of processing ($t(23.09) = -2.340$, $p = 0.028$), with older adults having a slower speed of processing than young adults (0.26 seconds per word and 0.20 seconds per word respectively).

7.3.3: Tasks

Two number tasks (digit number task and element number task) and two visual tasks (shape task and colour task) were used. Mixed blocks alternated either between the two number tasks or the two visual tasks. The four experimental tasks were designed using Superlab and were derived from experimental tasks used within the previous task switching literature, such as the digit / element task used by Cepeda et al (2001) and the shape / colour task used by Kray & Lindenberger (2000). Experimental tasks were presented to participants on a laptop computer screen sized 24.8cm by 18.7cm. Reaction time responses were measured and recorded through the use of a 2 key response box to the nearest millisecond.

Example 1	Example 2	Example 3	Example 4
333	33333	555	55555

Figure 7.1: Stimuli for Number Tasks

The potential stimuli used for the two number tasks were either three or five number 3s or three or five number 5s (see figure 7.1). Numbers in the element and digit tasks were presented centrally in the screen in Arial size 36 font. The largest array size being 0.7cm high by 8.3cm across. In the element number task participants were required to indicate how many elements were presented on the screen. If three elements were present (as in examples 1 & 3) then participants were required to press the left-hand key on the response box. If five elements were present then the response would be the right-hand key on the response box. In the digit number task

participants were required to identify what the digit number was. If the digit number was a three (see examples 1 & 2) then participants had to respond by pressing the left-hand key on the response box. If the digit number was a five (as in examples 3 & 4), then the response would be to press the right-hand key on the response box.

Potential stimuli for the two visual tasks were coloured shapes (see figure 7.2), either a square sized 2.7cm by 2.7cm or a triangle size 2.7cm base and 2.7cm high. In the shape task participants had to indicate whether the shape was a square or a triangle. If the shape was a square then the response was to press the left-hand key on the response box. If the shape was a triangle then the response was to press the right-hand key. In the colour task participants had to indicate whether the colour was red or blue. The response to a red shape was to press the left-hand key and for a blue shape to press the right-hand key on the response box.

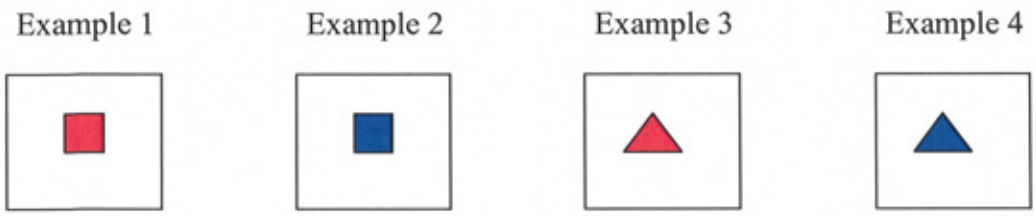


Figure 7.2: Stimuli for Visual Tasks

All tasks were presented in blocks of 20 trials, either pure blocks with 20 trials of a single task repeated, or mixed blocks where two tasks were alternated either every 2nd trial or every 5th trial. Blocks of trials consisted of all potential relevant stimuli randomly ordered. For all tasks blocks the first screen displayed the task instructions (see appendix 17). A blank screen was then presented for 500 msec followed by the first trial stimuli. Stimuli were presented in the middle of a blank white screen. The stimuli remained on the screen until a response was made then a response stimulus interval (RSI) of 200 msec followed before the presentation of the next stimuli. An RSI of 200 msec was selected, as this would allow insufficient time for advance preparation. A pilot study using a shorter RSI of 100 msec suggested that older adults were unable to perceive when one stimulus had gone and the next had appeared when the RSI was only 100msec.

Dementia, verbal intelligence and speed of processing were measured using the same tasks as in studies 2 and 3 (see sections 4.2.3 and 5.3.3 for descriptions of these tasks and scoring procedure).

7.3.4: Procedure

All participants first completed the MMSE, then the speech articulation task and then the NART before being introduced to the experimental procedures (see sections 4.2.3 and 5.3.3 for tasks and scoring procedures for these tasks).

Participants were introduced to the experimental task procedures during a practice session. It has been demonstrated that older adults in particular show large effects of practice for switch trials (Kramer et al, 1999), therefore a practice session was provided before the start of data collection to reduce the effects of practice during the data collection phase. Data collected was also tested, to determine whether any practice effects occurred during the experimental procedures.

Each task was first explained and demonstrated to participants, then the practice session was given. Practice sessions consisted of 2 practice trial blocks of each pure task block, followed by 4 practice trial blocks of the mixed trial blocks for each task pair (digit / element mixed task blocks and shape / colour mixed task blocks). For half of these mixed trial blocks participants practiced switching every 2nd trial and for the other half they practiced switching every 5th trial. If participants remained unsure of the task procedures the whole practice session was repeated.

Following the practice participants then undertook 4 pure blocks of 20 trials for each of the four individual tasks; and 32 mixed blocks of 20 trials (8 mixed digit / element blocks switching every 2nd trial, 8 mixed digit / element blocks switching every 5th trial, 8 mixed shape / colour blocks switching every 2nd trial and 8 mixed shape / colour blocks switching every 5th trial). The order of completion for the visual and number task blocks was counterbalanced so that half of the young and half of the older adults completed all the visual task blocks and half the number task blocks first. Within the visual task blocks participants undertook 4 pure block trials first (2 shape and 2 colour, the order of which was counterbalanced). This was followed by all of the mixed shape / colour blocks (with half of the participants undertaking mixed

blocks switching every 2nd trial first and half undertaking mixed blocks switching every 5th trial first). The remaining 4 pure blocks were then completed last. The same counterbalancing procedure was followed for the number task blocks, counterbalancing the order of tasks for pure blocks and the order of switch frequency for the mixed blocks.

Reaction time and error scores were recorded for each individual trial. Mean RT and error scores for the pure block trials, repeat trials in mixed blocks and switch trials in mixed blocks were then calculated separately for the number and visual task conditions and for frequency of switch conditions in mixed blocks. Mean RT score calculation was based on correct RT only and outlying scores falling outside of two standard deviations from the mean score for that condition were removed from the analysis. RT scores were then used to calculate absolute alternation, mixing and specific switching costs (see appendix 9 for formulae).

7.4: Study 6: Results

7.4.1: Data Analysis

Mean and standard deviation scores for all dependent variables and for MMSE, NART and speech articulation rate measures were calculated for young and old adults separately. To determine the effects of age, memory load (frequency of task switch) and task type on each of the task switching measures a series of three factor mixed ANOVAs were conducted. Three factor mixed ANCOVAs were also carried out using IQ and speed of processing as covariates separately and both together. Bonferroni corrected one way ANCOVAs were used for post hoc analysis of significant results. The Bonferroni correction was calculated as the accepted significance level (0.05) divided by the total number of comparisons to be made to obtain the value of the adjusted acceptable level of significance (Roberts & Russo, 1999). This will adjust the significance level to reduce the possibility of a type 1 error occurring when multiple pairwise comparisons are to be made. All ANOVAs and ANCOVAs were carried out for absolute alternation costs, absolute mixing costs and absolute switching costs.

Error rates were also investigated using a 4 factor ANOVA to determine any differences in error rates between the two age groups under different modality, trial type and frequency of switch conditions. Analysis was also conducted to determine whether any effects of practice were present during the data collection for young and old adults, in either pure block or mixed block repeat and switch trials for each task. These order effects were examined using two way mixed ANOVAs with age and order being the two factors.

The results section reports the ANOVA and ANCOVA analysis with both speed of processing and IQ as covariates for the absolute alternation, mixing and switching costs. ANCOVA analyses with IQ or speed of processing alone as a covariate are reported in appendix 10. Analysis of error rates and practice effects are reported in appendix 11 and will be considered in the discussion (section 7.5).

7.4.2: *Absolute Alternation Costs*

ANOVA analysis showed a significant main effect of age ($F(1,36) = 11.923$, $p = 0.001$) with older adults showing higher alternation costs than young adults (see table 7.1), thus supporting the prediction that older adults have greater task switching costs than young adults. A significant main effect of memory load was also evident ($F(1,36) = 9.805$, $p = 0.003$) with higher alternation costs when switching every 5th trial compared to when switching every 2nd trial (see table 7.1), supporting the prediction that a greater memory load will increase task switching costs. No significant main effect of task type and no significant 2-way or 3-way interactions were found ($p>0.05$).

	Digit Element Switch 2nd Alternation cost (msec)	Digit Element Switch 5th Alternation cost (msec)	Shape Colour switch 2nd Alternation cost (msec)	Shape Colour switch 5th Alternation cost (msec)
Young Adults	642 (289)	791 (549)	748 (358)	896 (503)
Old Adults	1149 (825)	1655 (1157)	1202 (559)	1624 (976)

Table 7.1: Mean (standard deviation) Alternation Costs for Young and Old Adults

The main effect of age remained significant in the ANCOVA analysis when controlling for both speed of processing and IQ ($F(1,33) = 10.178$, $p = 0.003$), suggesting that the effect of age on alternation cost can not be explained by age differences in speed of processing or IQ. The ANCOVA analysis showed no significant main effects of either memory load or task type ($p>0.05$). However, the interaction between age and memory load was significant ($F(1,33) = 7.774$, $p = 0.009$). Post hoc analysis showed a significant simple effect of age when switching every 5th trial ($F(1,33) = 11.541$, $p = 0.002$), with older adults showing greater alternation costs than young adults when switching every 5th trial (see figure 7.3). No other simple effects were significant at the corrected p value ($p>0.0125$). This supports the prediction that switching every 5th trial will show greater effects of age on switch costs than switching every 2nd trial. No other significant 2-way or 3-way interactions were found with the ANCOVA analysis ($p>0.05$).

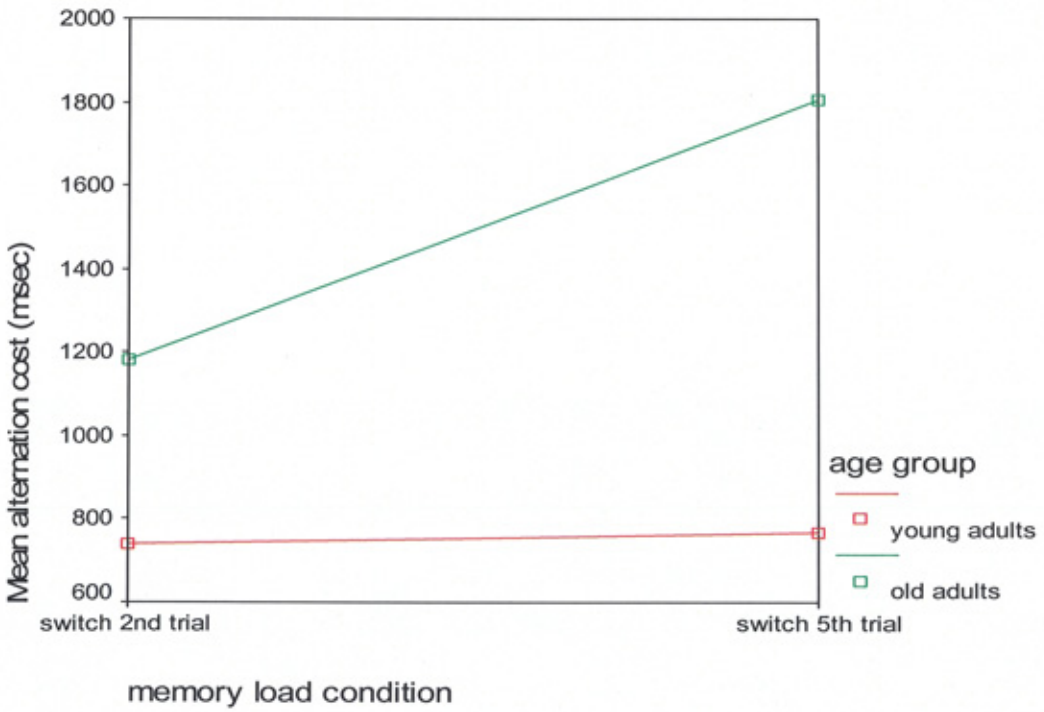


Figure 7.3: Age x Memory Load Interaction (controlling for speed of processing and IQ) for Alternation Cost

7.4.3: Absolute Mixing Cost

	Digit Element Switch 2nd Mixing cost (msec)	Digit Element Switch 5th Mixing cost (msec)	Shape Colour Switch 2nd Mixing cost (msec)	Shape Colour Switch 5th Mixing cost (msec)
Young Adults	311 (260)	295 (219)	280 (190)	332 (245)
Old Adults	671 (627)	441 (256)	691 (395)	447 (388)

Table 7.2: Mean (standard deviation) Mixing Costs for Young and Old Adults

Significant main effects of age ($F(1,36) = 6.528$, $p = 0.015$) and memory load ($F(1,36) = 17.576$, $p = 0.0001$) were found with the ANOVA analysis. Mean figures (see table 7.2) show that older adults have greater mixing costs than young adults, and along with the significant main effect of age support the prediction that older adults will have greater task switching costs than young adults. In relation to the main effect of memory load, mixing costs are generally greater when switching every 2nd trial compared to when switching every 5th trial, (see table 7.2), apart from young adults in the shape colour task. This significant difference in mixing cost between the memory load conditions is opposite to that predicted, as mixing cost increases with a more frequent switch which will have a lower memory load. No significant main effect of task type was found ($p>0.05$) and the only significant interaction was between age and memory load ($F(1,36) = 23.30$, $p = 0.0001$).

Post hoc analysis of the age by memory load interaction showed a significant simple effect of memory load among older adults ($F(1,17) = 22.572$, $p = 0.0001$), with older adults showing greater mixing costs when switching every 2nd trial compared to when switching every 5th trial (see figure 7.4). A significant simple effect of age was also present when the frequency of switch was every 2nd trial ($F(1,38) = 10.815$, $p = 0.002$), with older adults showing greater mixing costs than young adults when switching every 2nd trial (see figure 7.4). No other simple effects were significant using the Bonferroni corrected p value ($p>0.0125$). This indicates that whilst young adults show no difference in mixing cost with different frequency of switches, older adults show increased mixing cost when a more frequent switch is required. This is in

contradiction to the prediction that older adults would show increased mixing costs with a less frequent switch, which has a lower working memory load.

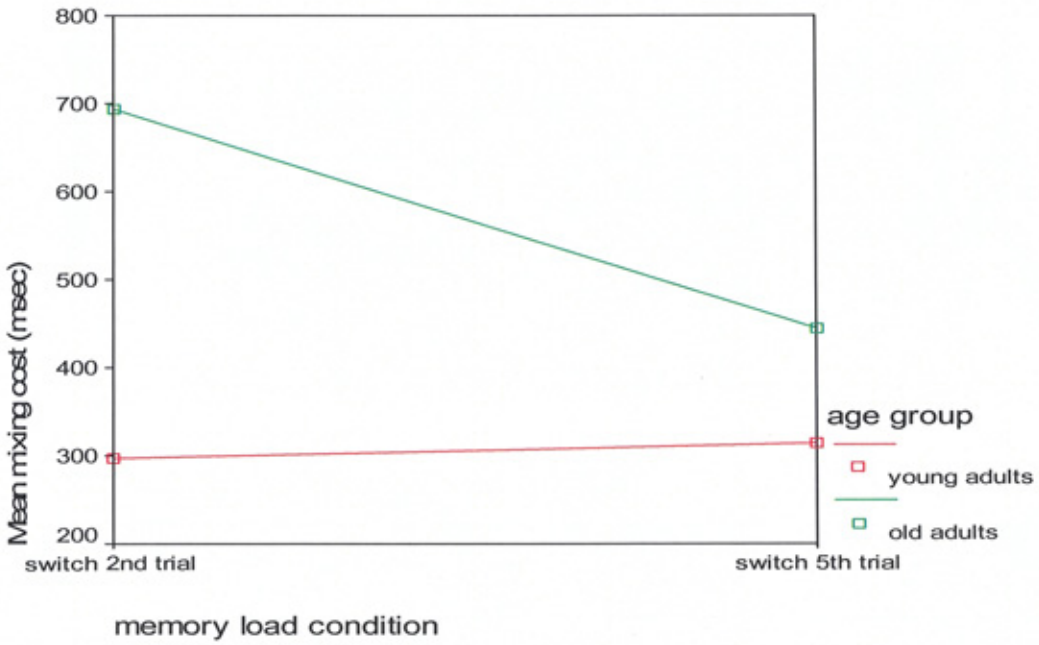


Figure 7.4: Age x Memory Load Interaction (no controls) for Mixing Cost

ANCOVA analysis controlling for both speed of processing and IQ removed both the main effects of age and memory load ($p>0.05$); however, the significant interaction between age and memory remained evident ($F(1,33) = 15.118$, $p = 0.0001$). Post hoc analysis showed no significant simple effects using the Bonferroni corrected p value ($p>0.0125$), although the effect of age when switching every 2nd trial was approaching significance ($F(1,35) = 6.736$, $p = 0.014$), with a trend for older adults to show higher mixing costs than young adults when switching every 2nd trial (see figure 7.5).

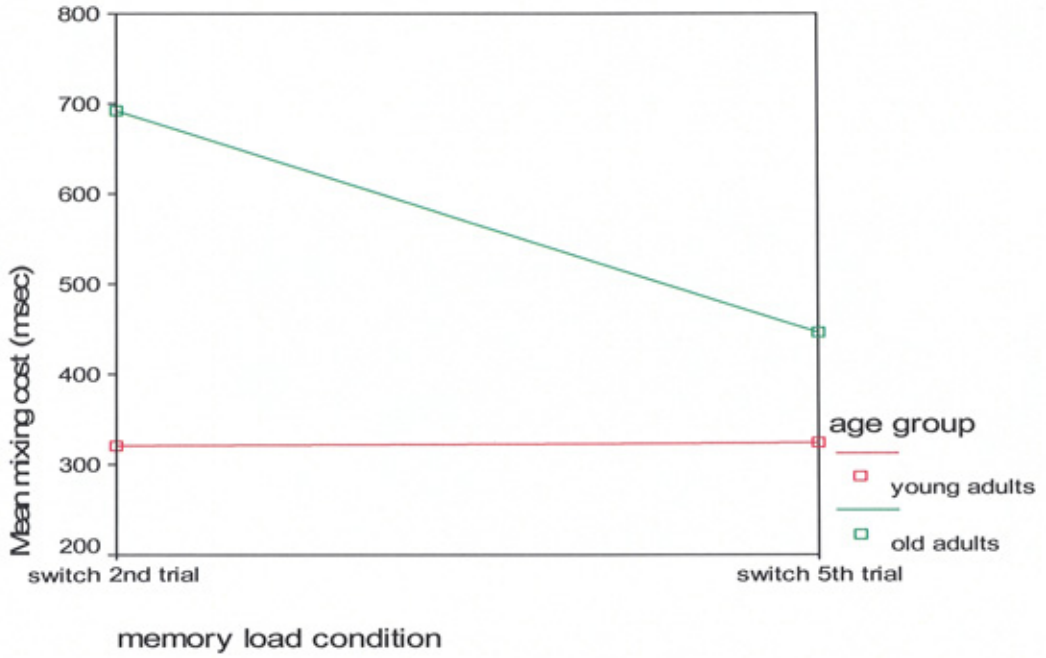


Figure 7.5: Age x Memory Load Interaction (controlling for speed of processing and IQ) for Mixing Costs

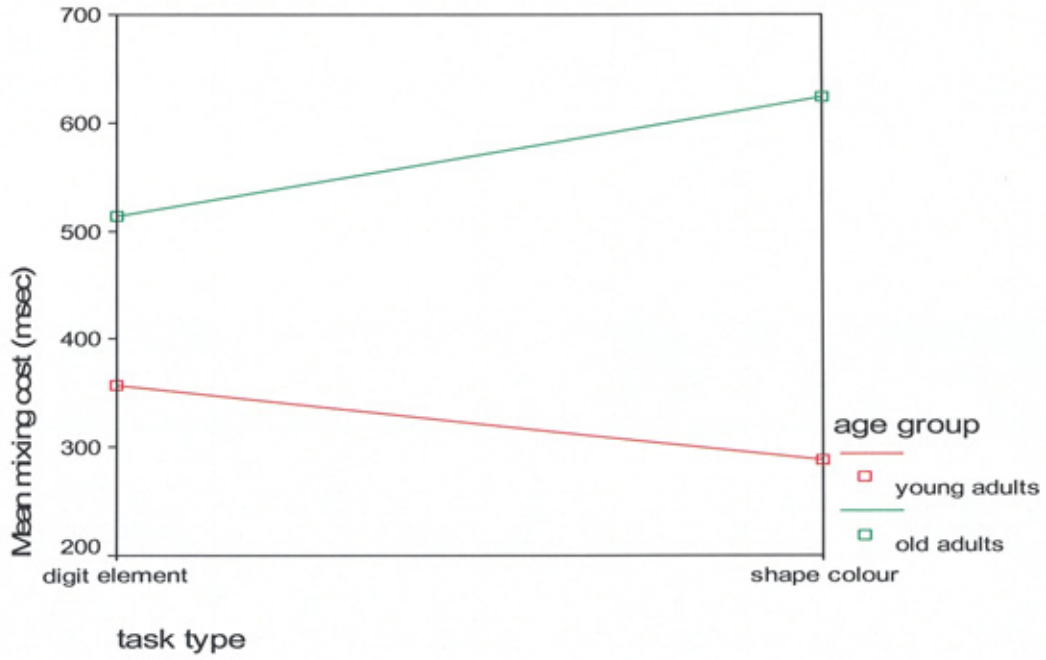


Figure 7.6: Age x Task Type Interaction (controlling for speed of processing and IQ) for Mixing Costs

A significant main effect of task type was also evident ($F(1,33) = 11.933$, $p = 0.002$) and a significant interaction between task type and age ($F(1,33) = 4.204$, $p = 0.048$). Post hoc analysis showed a significant simple effect of task type among older adults

($F(1,14) = 18.459$, $p = 0.001$) with older adults showing greater mixing costs in the shape colour task compared to the digit element task (see figure 7.6). No other simple effects were significant using the Bonferroni corrected p value ($p>0.0125$).

7.4.4: Absolute Specific Switching Costs

ANOVA results indicate a significant main effect of age ($F(1,36) = 10.238$, $p = 0.003$) with older adults showing greater specific switching costs than young adults (see table 7.3), supporting the prediction that older adults will show greater task switching costs than young adults. A significant main effect of memory load was also evident ($F(1,36) = 16.943$, $p = 0.0001$), with higher specific switching costs evident when switching every 5th trial compared to every 2nd trial (see table 7.3), supporting the prediction that switching costs will be higher with a greater memory load.

	Digit Element Switch 2nd Switching cost (msec)	Digit Element Switch 5th Switching cost (msec)	Shape Colour Switch 2nd Switching cost (msec)	Shape Colour Switch 5th Switching cost (msec)
Young Adults	330 (185)	496 (504)	467 (247)	563 (426)
Old Adults	478 (410)	1214 (1007)	510 (433)	1177 (737)

Table 7.3: Mean (standard deviation) Switching Costs for Young and Old Adults

The interaction between memory load and age was also significant ($F(1,36) = 8.050$, $p = 0.007$). No significant main effect of task type and no other significant interactions were evident in the ANOVA analysis ($p>0.05$).

When controlling for both speed of processing and IQ in the ANCOVA analysis the effect of memory load was not significant ($p>0.05$). However, the main effect of age ($F(1,33) = 11.439$, $p = 0.002$) and the interaction between memory load and age ($F(1,33) = 13.686$, $p = 0.001$) remained significant, suggesting that age differences in speed of processing and IQ cannot account for the age differences evident in the specific switching measure. Post hoc analysis indicated a significant simple effect of age when switching every 5th trial ($F(1,33) = 14.600$, $p = 0.001$), with older adults showing higher specific switch costs than young adults (see figure 7.7). No other simple effects were significant using the Bonferroni corrected p value ($p>0.0125$).

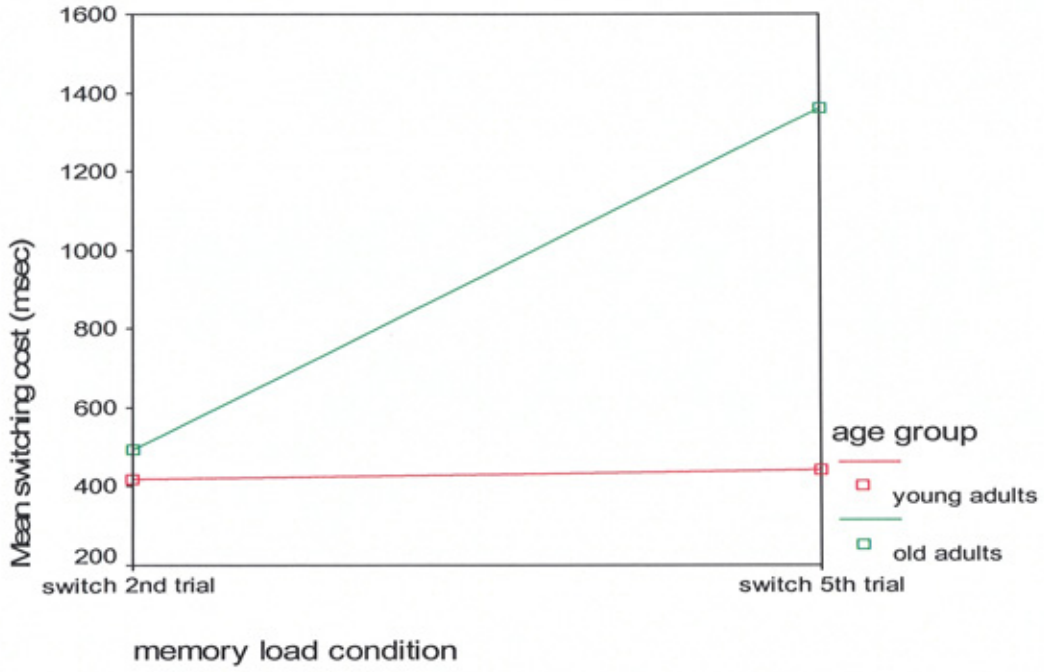


Figure 7.7: Age x Memory Load Interaction (controlling for speed of processing and IQ) for Specific Switching Costs

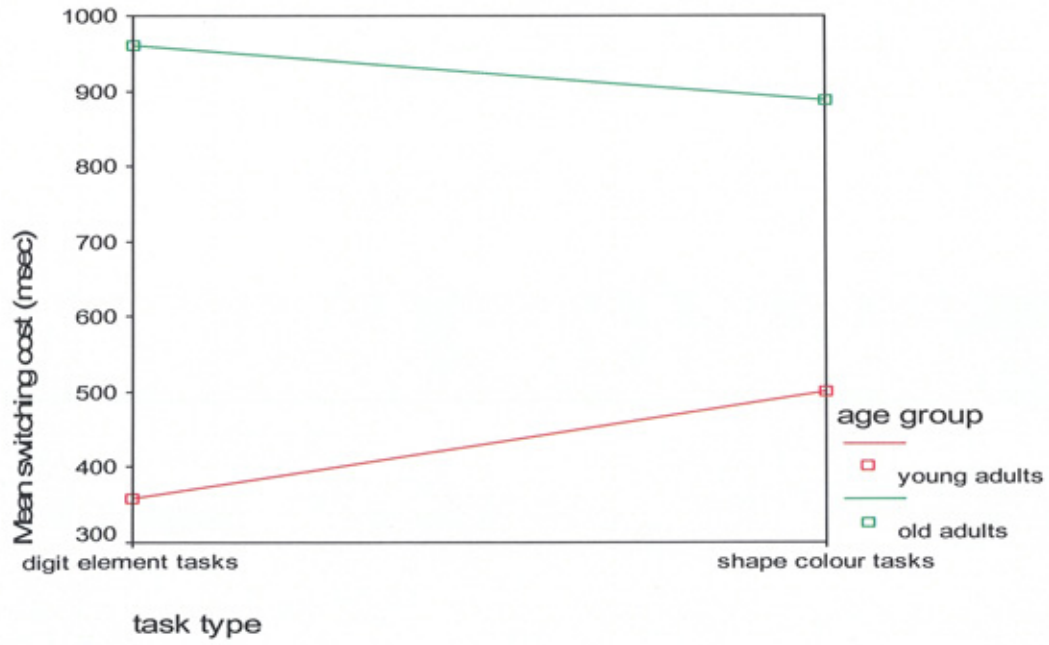


Figure 7.8: Age x Task type Interaction (controlling for speed of processing and IQ) for Specific Switching Costs

ANCOVA analysis showed that the interaction between task type and age was also significant ($F(1,33) = 5.390$, $p = 0.027$). Post hoc analysis found significant simple effects of age in both the digit element task ($F(1,34) = 9.652$, $p = 0.004$) and the

shape colour task ($F(1,34) = 7.832$, $p = 0.008$). From figure 7.8 it can be seen that for both the digit element task and shape colour task older adults have greater switching costs than young adults. No other simple effects were significant using the Bonferroni corrected p value ($p>0.0125$).

7.5: Study 6: Discussion

The main purpose of study 6 was to examine the effects of age and memory load on task switching. Three measures of task switching were examined; alternation cost, mixing cost and switching cost. Results from the alternation cost measures indicate that both age and memory load have an effect on task switching performance. Results suggest that older adults show higher alternation costs than young adults supporting the hypothesis that older adults will be impaired on measures of task switching. These results are consistent with those of Kramer et al (1999) and add to their findings by demonstrating that these age differences remain when both speed of processing and IQ are controlled for. This supports the conclusions from a number of previous studies that speed of processing cannot wholly account for age differences in task switching (e.g. Cepeda et al, 2001; Kray & Lindenberger, 2000; Salthouse et al, 1998).

One explanation for age differences in task switching, which has been suggested by a number of studies, is that age differences during task switching tasks may be evident when participants have to remember when to switch tasks, i.e. when no instructional cues are given (Kramer et al, 1999). However, other studies (for example, Kray & Lindenberger, 2000) found no age differences even when no instructional cues were given. The results from the current study add to this debate and may be able to provide an explanation for the differential findings from the previous studies. The effect of memory load found in study 6 suggests that when no instructional cues are given, greater switch costs are found when the switch occurs every 5th trial, compared to every 2nd trial. This suggests that increasing the memory load by requiring participants to remember longer sequences before switching will increase the time costs of switching between tasks supporting the hypothesis that increasing memory load will increase switching costs.

More importantly from an aging perspective, the effect of memory load interacts with the effect of age when speed of processing and IQ are controlled for, with significant effects of age evident only when switching every 5th trial, not when switching every 2nd trial. This suggests that older adults have particular difficulty switching between tasks when the task requirements have a greater memory load component. This explanation can account for the differences found in the results from previous studies mentioned earlier. Kray & Lindenberger (2000) required participants to switch every 2nd trial, whereas Kramer et al (1999) required a switch every 5th trial and as suggested by the results of the current study, it may be this difference in the memory load requirements that can account for the different effects of age found in these previous studies.

The interaction between memory load and age found in study 6 provides strong support for the conclusion of Kramer et al (1999), that increasing the working memory load during task switching can account for the increased switch costs among older adults; and the results overcome the criticism of Kramer et al's (1999) conclusions, that an alternative explanation of differences in the requirement for internal voluntary control during task switching could account for the age effects. Kramer et al (1999) based their conclusions on a comparison of age effects in task switching conditions that had an instructional cue and task switching without an instructional cue that depended on memory for the sequence. As well as differing in terms of memory load demands, these task switches also differ in terms of the requirement for intentional control making it difficult to draw firm conclusions. The current study however overcomes this by comparing task switching conditions that vary the memory load, but that do not differ in terms of the degree of internal, voluntary control required for the switch, thus providing much stronger evidence for the effect of memory load on age-related differences in task switching.

So far, results from the alternation cost measure have been discussed; however, the alternation cost is a global measure of task switching performance and from this measure it is not possible to determine whether the effects of age and memory load occur specifically when a task switch is required, or whether they are a consequence of the requirement to co-ordinate two tasks. By breaking down the alternation cost

into its component parts (specific switching and mixing costs), it is possible to gain a clearer picture of the effects of age and memory load on task switching performance.

The specific switching cost utilised in the current study showed similar effects of age, memory load and interaction between memory load and age to those found with the alternation cost, suggesting that these effects do occur specifically when task switching is required and that they are not merely a consequence of having to co-ordinate two tasks, thus supporting the hypotheses that both age and memory load will have an effect on switch costs. This is in contrast to the conclusions of Kray & Lindenberger (2000) who found age effects in general switch costs but not specific switch costs. They suggested that this indicated that age related switch costs were a consequence of having to co-ordinate two tasks within working memory, rather than a specific task switching deficit. One explanation for this difference in results between the two studies may be the increased memory load used in the current study. In the Kray & Lindenberger (2000) study participants switched every 2nd trial, whereas in the current study, the interaction indicated that the effects of age on specific switch costs were only apparent when switching every 5th trial rather than every 2nd trial, demonstrating that older adults do show a deficit specifically in task switching when working memory demands are increased sufficiently.

As the specific switching cost measure compares performance on switch and no switch trials within a heterogeneous task block, an age related deficit in maintaining and co-ordinating performance on two tasks within working memory cannot account for the increased specific switch costs among the older adults when switching every 5th trial. The increased age-related specific switch costs are therefore likely to be a consequence of the increased demands on processing and retaining sequential information rather than co-ordination differences. Both the effect of age and the interaction between age and memory load for specific switch costs remained when both speed of processing and IQ were controlled for, suggesting that these effects of age on task switching cannot be accounted for by age differences in either speed of processing or IQ.

The effect of co-ordinating two tasks within working memory during task switching can be investigated by looking at the mixing cost, as mixing cost looks at the RT cost

associated with repeat trials in a heterogeneous block compared to repeat trials in a pure task block. Similarly, to both the alternation cost and specific switching cost, the mixing cost measure showed significant effects of both age and memory load and an interaction between age and memory load. Controlling for speed of processing and IQ removed both the main effects of age and memory load, but did not remove the interaction between age and memory load. The interaction between age and memory load indicated that older adults showed greater mixing costs when switching every 2nd trial compared to when the switch was every 5th trial and that older adults showed greater mixing costs than young adults only in the switch every 2nd trial conditions. This is the opposite pattern to that expected, as older adults are showing greater mixing costs when memory load is lower in terms of the length of sequence to be remembered. Young adults however show no effect of memory load on mixing cost.

Mixing cost is presumed to reflect the ability to co-ordinate the two tasks within working memory during task switching conditions, therefore results showing age differences in mixing cost suggest that older adults have an impaired ability to co-ordinate tasks within working memory compared to young adults. This is consistent with the findings of Meiran et al (2001) who demonstrated that older adults showed impaired mixing cost using a cued task switching paradigm. However, in the current study this increased mixing cost is only evident when switching every 2nd trial, not when switching every 5th trial. The effect of switch frequency on mixing costs among the older adults, suggests that older adults are impaired in terms of co-ordinating two tasks within working memory when the switch is more frequent, as in the switch every 2nd trial condition, rather than when a longer sequence has to be remembered as in the switch every 5th trial condition.

The age-related pattern of performance on mixing cost cannot be explained in terms of a deficit in retaining sequential information within working memory, given the increased age-related decline when switching after shorter sequences. One alternative explanation that may be able to account for the age-related pattern of effects, is that there are age differences in terms of set selection processes. Differences in set selection processes have been used in previous studies to explain age-related differences in global switch costs (Mayr, 2001; Mayr & Liebscher, 2001). Using a 'fade out' paradigm Mayr & Liebscher (2001) demonstrated that older adults

continue to use a set-selection mode of processing after the point when it is necessary (i.e. for repeat trials as well as switch trials during mixed task blocks), rather than switching to a more efficient within-set-selection mode of processing. This means that time costs will occur on repeat trials as well as switch trials in mixed blocks, thus increasing global switch costs, which they measured as switch RT on pure block trials minus RT on mixed block trials. Mayr & Liebscher (2001) found that whilst young adults were able to rapidly return to a similar level of performance on repeat trials in mixed trial blocks to that of pure task blocks after only 2 repeat trials, older adults time costs for repeat trial on mixed blocks was much greater than young adults and RTs took much longer to return to similar levels to those on pure blocks.

In relation to the mixing cost results for the current study it may be that when switching every 2nd trial young adults are able to quickly return to a within-set-selection mode of processing and therefore have much quicker RT for repeat trials, whereas older adults remain in a more time costly set-selection mode of processing, even for repeat trials, and therefore show much greater RTs for the repeat trials thus increasing mixing cost; whereas, when switching every 5th trial older adults may be able to return to within-set-selection processing towards the end of the repeat trial sequence and therefore the average repeat trial times and mixing costs will not be so high.

The effects of task type were mixed, with no evidence of any effects of task type for the alternation cost, suggesting that there is little difference in task switching performance depending on the task type (visual or numeric). However, interactions between task type and age were evident when speed of processing and IQ were controlled for in both the mixing and the specific switching cost. The mixing cost interaction indicated that older adults showed greater mixing costs in the shape colour compared to the digit element tasks, whereas young adults showed no effect of task type. This suggests that when co-ordinating two tasks within working memory, older adults have greater difficulty co-ordinating visual tasks compared to numeric costs. The interaction for the specific switching cost showed simple effects of age for both the shape colour and the digit element tasks, but no simple effects of task type, therefore providing little evidence for any differences in specific switch costs between the two task types. Apart from the mixing cost interaction the results show little

evidence for differences in task switching performance between the different task types, which is consistent with the conclusion that task switching relies on executive resources which are considered to be domain or modality free (Engle, 1999b).

It has been suggested by Kramer et al (1999) that under certain conditions older adults are able to capitalise on practice in order to reduce switch costs to a similar level to those of young adults. It could therefore be argued that the age-related alternation, mixing and switching costs observed in the current study would be removed if sufficient practice were given beforehand. To ensure that any age–related switch costs were robust effects and not a consequence of lack of practice, practice sessions were given before the data collection began for all experimental task conditions. The data collected was also analysed for any effects of practice (see appendix 11). Results from this analysis showed that on the whole no effects of practice were evident for either young or old adults and that where differences in RT's did occur they tended to show slower RTs in later trials compared to earlier trials, which is more consistent with effects of fatigue rather than practice. The one exception to this being the RTs for older adults in the shape colour switch every 2nd trial switch trials, where quicker RTs were apparent for later trials compared to earlier trials, suggesting that for this condition older adults did indeed show some effect of practice.

It is puzzling why an effect of practice should be apparent in only the shape colour switch every 2nd trial condition, given that the order of conditions was counterbalanced and that all tasks were given the same amount of practice beforehand. However, it is important to consider the effect that this might have on the results of the study. The practice effect on switch trials in the shape colour switch every 2nd trial condition may influence the alternation and switching cost results, as these costs include the RTs for switch trials. The lack of any 3-way interactions between age, memory load and task type suggests that there were little differences in the effects of age and memory load between the digit element and shape colour tasks and therefore the effect of practice in the shape colour switch every 2nd trial is unlikely to have had any impact on the overall findings. It does demonstrate however the importance of taking the effects of practice into account when investigating the effects of age on task switching.

An alternative explanation that could be used to account for age differences in task switching, is that young and old adults place different emphasis on speed and accuracy, with younger adults emphasizing speed at the cost of accuracy and older adults emphasizing accuracy at the expense of speed, i.e. a speed accuracy trade off. In the current study analysis of error rates found that older adults showed higher error proportions as well as higher RTs (see appendix 11), showing no evidence of a speed accuracy trade off. Indeed the results suggest that not only do older adults show slower RTs but that they also have higher error rates than young adults. Higher error rates were also found for switch trials, than for repeat trials, however no significant interaction between age and trial type was found and generally error rates were low for all participants in all conditions (see table A11.1, appendix 11).

One criticism that could be levelled at the task switching paradigm used in this study is that the effects of age could be accounted for in terms of a TSI explanation, as the time required for advance preparation is confounded with the time required for passive dissipation of the previous task set. However, the TSI explanation (Allport et al, 1994) cannot account for the interactions between age and memory load, as the time available for passive dissipation is the same in both the switch every 2nd trial and switch every 5th trial conditions and therefore according to the TSI hypothesis no differences should be evident between these task conditions.

The results of study 6 suggest that older adults show both increased switching costs at the specific point of task switching and increased mixing costs for repeat trials when undertaking mixed trial blocks, which cannot be accounted for by age-related differences in speed of processing or IQ. These age-related task switching costs appear to be a consequence of different processes. An age-related increase in specific switching cost is evident when memory load is increased, by requiring a longer sequence to be remembered before switching (switch every 5th trial). This suggests that older adults may have a deficit in the central executive process responsible for retaining and updating sequential information. The age-related increase in mixing cost is evident when a more frequent task switch is required (switch every 2nd trial), which cannot be explained in terms of a decline in the ability to retain and update sequential information. The most likely explanation for the age-related increase in mixing cost, is that older adults take longer to switch from a costly set-selection

processing mode to a more efficient within-set-selection mode of processing when co-ordinating performance on two tasks.

Study 6 has examined the effects of age and memory load on task switching processes using a non-cued task switching paradigm. This paradigm makes demands on the internal voluntary controlled executive process of task switching, however conclusions regarding the voluntary control of the task switch are not possible, because the task also makes demands on the memory processes required to keep track of the sequence. Study 7 intends to extend these findings by using a cued task swirching paradigm and directly manipulating the requirement for voluntary control.

7.6: Study 7: Introduction

The aim of study 7 is to investigate the effects of voluntary control on age-related task switching performance. Voluntary control of task performance is considered to be one of the functions of the central executive component and it is assumed that when the demands for voluntary control are high, for example, when there is no external cue for switching between tasks, there will be greater reliance on executive control processes (Duncan, 1995). Results from study 4 suggested that the age differences in the switching measure of random generation were only evident with a set size of 10, when the degree of voluntary control over switching was great. When switching was controlled to a greater extent by external factors such as a small set size, as in the set size 5 condition, no age differences were present. Study 7 aims to directly manipulate the amount of voluntary control in a task switching paradigm to investigate this further.

There are no previous studies which specifically examine the effects of voluntary control on age-related task switching performance, although variation in voluntary control demands may be able to account for the age-related differences in task switching found in the study by Kramer et al (1999) (see section 7.2 discussion). However, the comparison between cued and non cued task performance made in this study differs both in terms of its demands on voluntary control and its demands on working memory load, therefore it is difficult to make firm conclusions regarding the effects of voluntary control on task switching.

In order to investigate the effects of voluntary control during age-related task switching performance without varying the demands made on working memory, study 7 will use a cued task switching paradigm and vary the potency of the cue. Recently it has been suggested that the cued-task switching paradigm may not rely on central executive processes (Logan & Bundesen, 2003), however the cues used by Logan & Bundesen (2003) were explicit, as they directly informed the participant which task to do. It has been suggested that responses to advance preparation (and therefore demands on the central executive) may be different depending on the potency or explicitness of the task cue (Meiran, 1996). According to Meiran (1996), a more potent or explicit task cue is less likely to be disrupted by randomly varying the advance preparation period, compared to a less potent task cue (such as relative position within a grid). This is likely to be because a more explicit task cue makes less demand on the voluntary executive control required for advance preparation. If older adults show poorer performance on tasks that require a high degree of voluntary control in order to switch, it is likely that they will show greater switch costs when a less potent task cue is used, compared to when a more potent or explicit task cue is used. Similarly to study 6, study 7 will measure absolute switch costs for the alternation, mixing and specific switching components of task switching. Speed of processing and IQ will be controlled for as covariates during the ANCOVA analysis.

It is predicted that: older adults will show greater alternation, mixing and switching costs compared to young adults; greater alternation, mixing and switching costs will be evident when a weak potency cue is used, compared to when a strong potency cue is used; and that there will be an interaction between age and cue potency, such that the age difference will be greater when task switching is cued with a less potent (weak potency) cue, than when the switch is cued with a more potent (strong potency), or explicit cue.

7.7: Study 7: Method

7.7.1: Design

A quasi-experimental mixed factorial design was used to investigate the effects of age, potency of task cue and type of task on task switching performance. The

between subjects factor being age and having two levels (young adults aged 18 – 30 years and older adults aged 65 plus). The within subjects factors being: potency of task cue, with two levels (weak potency and strong potency); and task type, which has two levels (number tasks and visual tasks). The dependent variable of task switching was measured using the same three measure of task switching: alternation, mixing and specific switching costs (see section 7.3.3). Absolute costs were calculated for the three measures. Control measures of verbal intelligence (using NART), speed of processing (using speech articulation rate) and dementia (using MMSE) were also taken.

7.7.2: Participants

The same convenience sample of young and older adults as in study 6 was used (see section 7.3.2 for sampling details).

7.7.3: Tasks

Similar number stimuli (digit and element tasks) and visual stimuli (shape and colour tasks) to those described in study 6 were used. However, for this study each trial presentation within both pure and mixed blocks was preceded by a task cue. The task cue being; either a strong potency cue, or a weak potency cue. All tasks were presented in blocks of 20 trials, either pure blocks, with a single task repeated, or mixed blocks, where either the digit and element tasks were randomly ordered or the shape and colour tasks were randomly ordered.

The first screen in each block of trials displayed the task instructions (see appendix 17), which remained on screen until participants pressed either of the response keys. This was then followed by a blank screen for 500msec, before the task cue for the first trial was presented. A cue task interval (CTI) of 400msec was used, during which time the cue remained on the screen. This was immediately followed by the presentation of the stimulus, which remained on the screen until a response was made. Following response a blank screen was presented for 1000 msec, this represented the response cue interval (RCI) before the presentation of the cue for the next trial.

For the strong potency cue in the digit task the word "Digit?" was presented and for the element task "Elements?" These were presented in system font size 42 bold and

placed centrally for the strong potency cue. The weak potency cue utilised position within the screen to cue the digit and element number tasks and presented the word 'Ready?" in either the top half (3cm above centre) or the bottom half (3cm below centre) of the screen. Cue and stimuli presented in the top half of the screen cued the digit number task and stimuli presented in the bottom half of the screen cued the element number task. The strong potency cues in the visual tasks were "Shape?" for the shape task and "Colour?" for the colour task. Weak potency cues again utilised position within the screen with cue and stimuli presented in the top half of the screen cueing the shape task and stimuli presented in the bottom half of the screen cueing the colour task. In mixed task blocks the timing of the task switch, as indicated by the cues, was unpredictable and could occur anywhere between every first and every fifth trial randomly.

7.7.4: Procedure

Dementia, verbal intelligence and speed of processing measurements for each participant were carried forward from the results of study 6. As in study 6, participants were given a practice session where each task was explained and demonstrated, followed by a period of practice on both pure and mixed task blocks. Practice sessions consisted of 2 practice trial blocks for each pure task block and 4 practice trial blocks of mixed trial blocks for each pair of tasks. The practice session was repeated for any participant who remained unsure of the task procedures.

Following the practice, participants then undertook 4 pure trial blocks of 20 trials for each of the four individual tasks and 32 mixed blocks of 20 trials (8 mixed digit / element blocks with a strong potency cue, 8 mixed digit / element blocks with a weak potency cue, 8 mixed shape / colour blocks with a strong potency cue, and 8 mixed shape / colour blocks with a weak potency cue). The order of completion for the visual and number task blocks was counterbalanced so that half of the young and half of the older adults completed the visual task blocks first and half the number blocks first. Within the visual task blocks participants undertook 4 pure trial blocks first (2 shape and 2 colour, the order of which was counterbalanced within each age group). This was followed by all the mixed shape / colour blocks (with half of the participants undertaking blocks with strong potency cues first, and half undertaking blocks with weak potency cues first). The remaining 4 pure blocks were then completed last. The

same counterbalancing procedure was followed for the number task blocks, counterbalancing the order of tasks for pure blocks and the order of cue potency for the mixed blocks.

Reaction times and error scores were recorded for each individual and mean RT and error scores for the pure block trials, repeat trials in mixed blocks and switch trials in mixed blocks were then calculated separately for the number and visual task conditions and for the cue potency conditions in mixed blocks. Mean RT scores and alternating, mixing and specific switching costs were calculated in the same way as for study 6 (see appendix 9).

7.8: Study 7: Results

7.8.1: Data Analysis

Mean and standard deviation scores for all dependent variables were calculated for young and old adults separately. To investigate the effects of age, voluntary control as measured by cue potency and task type on each of the task switching measures a series of 3 factor mixed ANOVAs were carried out. Three way mixed ANCOVAs controlling for speed of processing and IQ as covariates were also undertaken. All ANOVAs and ANCOVAs were carried out for absolute alternation, mixing and switching costs. Post hoc analysis of significant results used Bonferroni corrected ANCOVAs. Analysis of error rates was also undertaken with a four way mixed ANOVA to determine any differences in error rates between the two age groups and under different task modality, trial type and cue potency conditions. Any effects of practice were investigated by using 2 factor mixed ANOVAs with age and order being the two factors.

ANOVA and ANCOVA analyses, controlling for both speed of processing and IQ for absolute alternation, mixing and switching costs are reported in the results section. Absolute alternation, mixing and switching cost ANCOVAs controlling for speed of processing alone and IQ alone are reported in appendix 12. Error analysis and practice effects are reported in appendix 13.

7.8.2: Absolute Alternation Costs

ANOVA analysis showed a significant main effect of age ($F(1,37) = 11.943$, $p = 0.001$), with older adults showing greater alternation costs than young adults (see table 7.4). This supports the prediction that older adults will show greater task switching costs than young adults. A significant main effect of cue potency was also evident ($F(1,37) = 6.962$, $p = 0.012$), with higher alternation costs under weak cue potency conditions. The interaction between task type and cue potency was also significant ($F(1,37) = 15.720$, $p = 0.0001$). The ANOVA analysis found no other significant main effects or interactions ($p>0.05$).

	Digit Element Weak Potency Cue Alternation Cost (msec)	Digit Element Strong Potency Cue Alternation cost (msec)	Shape Colour Weak Potency Cue Alternation cost (msec)	Shape Colour Strong Potency Cue Alternation cost (msec)
Young Adults	309 (284)	258 (170)	482 (285)	283 (148)
Old Adults	773 (551)	834 (702)	968 (820)	703 (754)

Table 7.4: Mean (standard deviation) Alternation Costs for Young and Old Adults

ANCOVA results controlling for speed of processing and IQ showed a significant main effect of age ($F(1,34) = 10.059$, $p = 0.003$), with older adults showing higher alternation costs than young adults. No other main effects or interactions were significant ($p>0.05$). This suggests that whilst age differences in task switching cannot be accounted for by speed of processing, the effects of cue potency on task switching are removed by either speed of processing or IQ, or both. ANCOVA analysis controlling for IQ alone and speed of processing alone (see appendix 12) suggest that both remove the effect of potency, with no significant main effects of potency or interactions with potency evident when either IQ or speed of processing alone are controlled for ($p>0.05$).

7.8.3: Absolute Mixing Costs

ANOVA results showed a significant main effect of age ($F(1,37) = 12.044$, $p = 0.001$), with older adults showing much greater mixing costs than young adults (see table 7.5). A significant interaction between task type and cue potency was also

evident ($F(1,37) = 15.513$, $p = 0.0001$). No other main effects or interactions were significant ($p>0.05$).

	Digit Element Weak Potency Cue Mixing cost (msec)	Digit Element Strong Potency Cue Mixing cost (msec)	Shape Colour Weak Potency Cue Mixing cost (msec)	Shape Colour Strong Potency Cue Mixing cost (msec)
Young Adults	179 (141)	206 (146)	275 (196)	186 (131)
Old Adults	567 (474)	601 (509)	756 (515)	552 (675)

Table 7.5: Mean (standard deviation) Mixing Costs for Young and Old Adults

ANCOVA results controlling for speed of processing and IQ demonstrated a significant main effect of age ($F(1,34) = 10.743$, $p = 0.002$), which suggests that age differences in mixing costs cannot be accounted for by either speed of processing or IQ. No other significant main effects or interactions were evident in the ANCOVA analysis ($p>0.05$).

7.8.4: Absolute Specific Switching Costs

	Digit Element Weak Potency Cue Switching cost (msec)	Digit Element Strong Potency Cue Switching cost (msec)	Shape Colour Weak Potency Cue Switching cost (msec)	Shape Colour Strong Potency Cue Switching cost (msec)
Young Adults	129 (159)	51 (72)	207 (135)	96 (78)
Old Adults	206 (140)	233 (244)	212 (332)	151 (151)

Table 7.6: Mean (standard deviation) Switching Costs for Young and Old Adults

ANOVA results for specific switching costs showed a significant main effect of cue potency ($F(1,37) = 4.929$, $p = 0.033$), with greater specific switching costs in weak cue potency conditions compared to strong cue potency conditions (see table 7.6). This supports the prediction that specific switching costs will be greater with weak potency cues than with strong potency cues. No other significant main effects of task type, or age and no significant interactions ($p>0.05$) were found, although the effect of

age was approaching significant (F(1,37) = 4.070, p = 0.051), with older adults showing higher specific switching costs than young adults (see table 7.6).

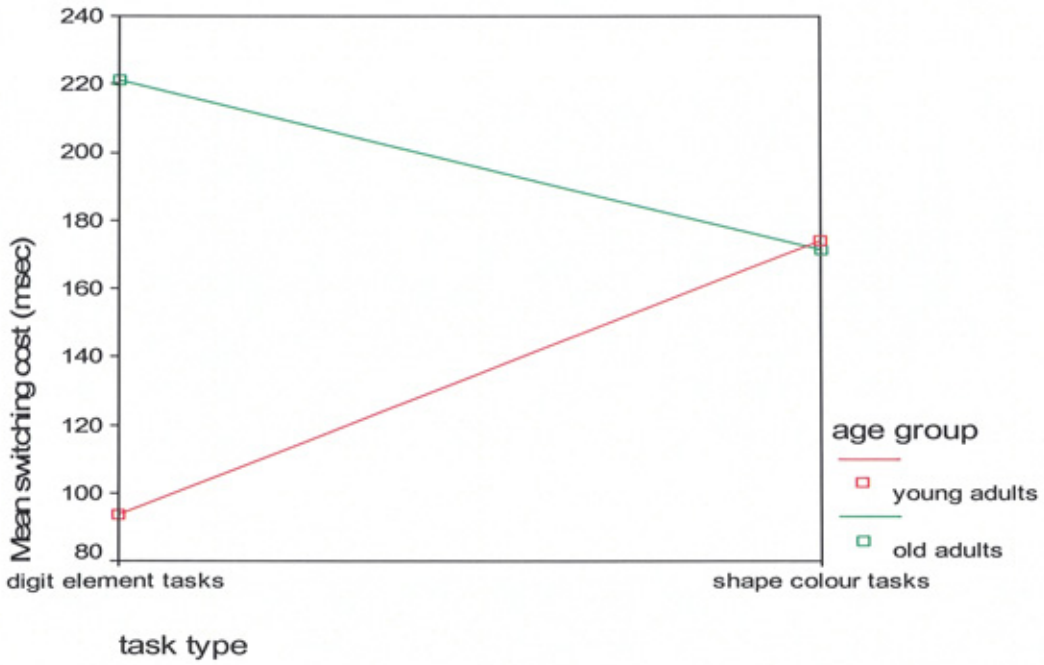


Figure 7.9: Age by Task Type Interaction (controlling for speed of processing and IQ) for Specific Switching Cost

ANCOVA results controlling for speed of processing and IQ found no significant main effects of age, task type or cue potency (p>0.05). The interaction between age and task type was significant (F(1,34) = 4.142, p = 0.050), however no other significant interactions were evident (p>0.05). Post hoc analysis of the age by task type interaction indicated a significant simple effect of age for the digit element task, with older adults showing higher specific switching costs than young adults in the digit element task (F1,34) = 7.860, p = 0.008) (see figure 7.9). No other significant simple effects were found using the Bonferroni corrected p value (p>0.0125).

7.9: Study 7: Discussion

The main purpose of study 7 was to investigate the effects of age and voluntary control on task switching performance. Three measures of task switching were used: alternation cost, which is presumed to be a general or global measure of the processes required for switching between tasks; specific switching cost, which is a more specific measure of the processes required at the specific switch point; and mixing cost, which

is presumed to measure the processes required for co-ordinating the two tasks during task switching.

Results from the specific switch cost measure show an effect of cue potency, with greater specific switch costs evident with a weak potency cue, compared to when a strong potency cue is used. However, this effect of cue potency is removed when speed of processing and IQ are both controlled for. ANCOVA analysis controlling for speed of processing alone and IQ alone (see appendix 12) indicates that controlling for either speed of processing or IQ removes the effect of cue potency. This suggests that varying the cue potency during task switching so that the cue is less potent makes greater demands on general processes, such as speed of processing and IQ. These results provide little support for the prediction that increasing the demands on executive voluntary control processes during task switching, by using a weak potency cue, will increase specific switch costs. Whilst this effect did occur, it can be accounted for by either speed of processing or IQ differences, rather than differences in the demands on executive voluntary control. This is consistent with research by Logan & Bundesen (2003) which suggested that task switching using the cued paradigm may not rely on executive processes.

No effects of age and no interactions between age and cue potency were evident, which goes against the predictions that older adults would show greater specific switch costs than young adults, particularly in the weak potency cue condition. The lack of age effects could be explained in a number of ways. Firstly, it may be that executive voluntary control processes do not decline with age; secondly, it may be that the cued task switching paradigm used does not make demands on executive voluntary control processes; and thirdly, it could be that with practice older adults are able to switch tasks as well as younger adults. A number of studies have suggested that executive voluntary control processes do decline with age (Duncan, 1995) and this, taken with the previous discussion that the effects of cue potency could best be explained by differing demands on general processes, such as speed of processing and IQ, suggests that the lack of age effects can best be explained in terms of the tasks not making demands on executive voluntary control processes, rather than these executive processes not varying with age. This argument is consistent with recent evidence

which suggests that the cued task switching paradigm may not make demands on the executive control processes (Logan & Bundesen, 2003).

Previous research (Kramer et al, 1999) suggested that older adults were able to perform as well as young adults on task switching if given sufficient practice. Within the current study participants were given practice blocks prior to the data collection blocks to ensure that practice could not account for any age differences in task switching performance. The data collected was also analysed for any effects of practice (see appendix 13). Analysis of practice effects in the mixed blocks showed a 3-way interaction between order, trial type and age, with young adults showing no effect of order and older adults showing an effect of order on switch trials but not repeat trials. This suggests that switch task performance in older adults does improve with practice, whilst repeat task performance is not affected by practice. The effect of practice for older adults on switch trial performance may therefore be able to account for the lack of age differences found in the specific switch cost measure.

Whilst the results from the specific switch cost measure suggests that task switching performance when a cue is present does not decline with age, regardless of the potency of the cue, the results from the alternation cost measure do show an effect of age, with older adults showing greater alternation costs than young adults, even when both speed of processing and IQ are controlled for. Whilst both alternation and specific switch costs are assumed to make demands on executive voluntary control of advance preparation, alternation costs are different from specific costs in terms of the demands made on central executive processes required to co-ordinate and maintain two tasks within working memory (Kray & Lindenberger, 2000). Given that there are no evidence of age difference in the specific switch costs, one explanation that may be able to account for the effects of age on alternation cost, is that older adults may have an impaired ability to co-ordinate and maintain two task sets within working memory. The alternation cost results from this study are consistent with the findings of Mayr (2001) and Mayr & Liebscher (2001), who demonstrated that older adults tend to maintain a costly set selection mode of processing during mixed task blocks, even when a switch is not necessary.

The mixing cost results from study 7 also support the conclusions of Mayr (2001) and Mayr & Liebscher (2001) with older adults showing greater mixing costs than young adults, which remain when speed of processing and IQ are controlled for. The mixing cost measure looks at the difference in RT cost between pure task blocks and repeat trial performance during mixed task blocks, and as such indicates the cost of co-ordinating and maintaining two task sets within working memory when a switch is not required. The age-related increase in mixing cost is therefore likely to be a consequence of an impaired central executive ability to maintain and co-ordinate two task sets within working memory, rather than an impaired ability to switch between the tasks at the specific switch point.

An alternative explanation for age differences in task switching is that switch cost performance may reflect a speed accuracy trade off, and that older adults place greater emphasis on accuracy at the cost of speed. Analysis of the error rates (see appendix 13) indicated that older adults produced significantly more errors than young adults, particularly on switch trials, which taken with their increased time costs indicates that older adults perform worse than young adults both in terms of speed and accuracy. A speed accuracy trade off therefore cannot account for the age differences found in the alternation and mixing cost measures.

Results from all three measures (specific switching, alternation and mixing cost) showed no effects of cue potency, and no interactions between cue potency and age, after speed of processing and IQ were controlled for, suggesting that these measures within a cued task switching paradigm do not rely on central executive voluntary control processes, regardless of the potency of the task cue. This is consistent with the conclusions of Logan & Bundesen (2003) who suggest that the explicit cued task switching paradigm does not make demands on central executive processes. The results also extend the conclusion of Logan & Bundesen (2003), firstly by indicating that even with a weak potency or less explicit cue these voluntary control processes do not seem to be utilised. Secondly, the age differences in the alternation and mixing cost measures suggest that although the cued task switching paradigm does not make demands on voluntary controlled executive processes, it does still make demands on other central executive processes, in particular those required to maintain and co-ordinate two task sets within working memory.

An alternative explanation of why few effects of cue potency were found may be that cues used did not act as expected in terms of their potency. During the task procedures it was noted that a number of participants experienced difficulties with the strong potency cues for the digit element task. The strong potency cues used were the words 'digit' and 'elements' to indicate which task was to be undertaken during the mixed blocks. A number of participants commented that they found it difficult to remember what 'elements' meant. Rather than it being an explicit cue that immediately cued the appropriate task set, participants had to convert the meaning of the word 'elements' into a more meaningful 'how many' context in order to be able to do the task. This would slow down the RT within the explicit cued element condition and thus reduce any advantageous effects of explicit strong cue potency. To determine whether this methodological problem with the strong potency element task cue could account for the lack of age effects on cue potency, the results were analysed again, only for the shape colour tasks (see appendix 14). Results from the shape colour task alone were similar to the original analysis with effects of cue potency eliminated when speed of processing and IQ are controlled for. This supports the conclusion that lack of cue potency effects are not a consequence of methodological problems with the digit element task, but may be because task switching under cued conditions does not require executive voluntary control.

7.10: General Conclusion Conclusion for Studies 6 & 7

Results from studies 6 & 7 highlight a number of important issues. Firstly, they demonstrate that some age-related differences in task switching performance cannot be accounted for by age-related changes in either speed of processing or IQ. This suggests that task switching makes demands on processes that are independent of general factors such as speed of processing and IQ and is inconsistent with a general speed of processing explanation of age differences in cognitive task performance, such as that proposed by Salthouse (1996).

The pattern of age-equivalence and age-related decline across the different measures of task switching performance and with the different task switching paradigms, suggests that task switching relies on a number of processes which are differentially

affected by age. Results from the specific switching measure, (i.e. the switch costs at the specific switch point) show an age-related decline only when the memory load is high in terms of the requirement to maintain and update sequential information. No age differences were found for the specific switch cost in study 7 using the cued task switching paradigm, which has no requirement to retain sequential information as the task switch is cued rather than depending on remembering where you are in the sequence. Specific switch costs in study 6, showed age differences only with longer sequences of five trials between the switch points, not with shorter sequences of two trials. This suggests that older adults have an impaired ability to retain and update sequential information and that this age difference can account for age differences in task switching performance at the specific task switch point.

Results from the mixing cost measure showed increased mixing costs for both the cued (study 7) and non-cued (study 6) task switching paradigms. The mixing cost measure is presumed to reflect executive processes required to maintain and co-ordinate two tasks within working memory. An age-related increase in mixing cost therefore suggests that older adults have an impaired ability to maintain and coordinate two tasks within working memory and that this impaired co-ordination ability can account for age differences in task switching.

The lack of age effects on specific switch costs in the cued task switching paradigm and the lack of cue potency effects after controlling for speed of processing and IQ in study 7, suggest that the cued task switching paradigm does not make demands on executive processes requiring voluntary control regardless of the potency of the cue. However, given the age-related increase in both the alternation cost and mixing cost measures, the results from study 7 suggest that whilst cued task switching may not make demands on executive voluntary control processes, it does still utilise executive processes necessary for the co-ordination and maintenance of two tasks, but that these processes are utilised during both switch and repeat trials. This means that increased time costs are evident on mixed block trials compared to pure block trials but that increased costs at the specific switch point are not evident when compared to repeat block trials.

The final conclusions (chapter 8) will consider the implications of the results from the task switching studies 6 & 7 and the results from studies 1 – 5 in relation to models of working memory and in relation to theoretical accounts of cognitive aging. In particular, the role of a decline in central executive processes as an account of adult age-related changes in cognitive task performance will be discussed.

Chapter 8
Conclusions

8.1: Introduction

This final discussion chapter will consider the implications of the results from the previous seven studies in relation to the main aims of the thesis and in relation to current research and understanding of working memory and cognitive aging. Firstly, a chronological overview of the thesis will be provided in section 8.2, which will discuss the main findings of each of the studies and the progressive development of ideas throughout the thesis. Sections 8.3 – 8.7 will discuss the conclusions from the results in relation to the theoretical accounts of cognitive aging considered in chapter 3 (speed of processing, inhibitory processing, resource capacity and executive processing accounts of cognitive aging) and theoretical accounts of working memory (discussed in chapter 2). Specifically in section 8.7 the pattern of age-related equivalence and decline found throughout the studies will then be considered in relation to the specific executive processes of switching, co-ordination of tasks and retention of sequential information and the implications the results have for models of working memory will be discussed. Section 8.8 will discuss the issues related to the use of the central executive tasks and section 8.9 will consider the limitations in the methodology used throughout the studies. Section 8.10 will consider the direction for future research and section 8.11 will finish with the final conclusions.

8.2: Development of the Thesis

Within the context of a fractionated working memory model (Baddeley & Hitch, 1974; Logie 1995) study 1 aimed to investigate the effects of age on visuo-spatial working memory tasks, using four tasks and four different age groups (20 – 30 years, 40 – 50 year, 60 – 69 years and 70 plus years). The size JND and the trajectory JND tasks which were presumed to make demands on the visual cache and inner scribe components respectively; and the pattern span and sequence span tasks which were both presumed to make demands on the central executive, as well as the visual cache and inner scribe components. The main findings of the study suggested that performance declined with age on the pattern span and sequence span tasks, which

made demands on executive as well as VSSP components of working memory; whereas no effects of age were found on the size and trajectory JND tasks which only made demands on the VSSP slave system components. From these results it was concluded that the age-related differences could be best accounted for in terms of a decline in central executive processes, and that VSSP slave system processes did not decline with age. Specifically, the age differences found in the sequence span task were tentatively explained in terms of a decline in the executive processes responsible for the retention of sequential information and the age difference in the pattern span were explained in terms of a decline in the executive processes responsible for voluntary controlled strategic retrieval. However, these conclusions were limited as the tasks used were likely to make demands on a number of different processes and it was not possible to rule out speed of processing as an explanation for the results.

Studies 2 & 3 were designed to build on the conclusions from study 1 and aimed to investigate the effects of age on executive processing further: in particular the effects of age on voluntary controlled strategic retrieval were investigated using four fluency tasks. Initial letter, excluded letter, shape and excluded shape fluency tasks were used. In addition to this controls of IQ and speed of processing were taken. In study 2 age differences were found in the number of words generated during excluded letter fluency, but not initial letter fluency even after controlling for speed of processing and IQ. These age differences in excluded but not initial letter fluency could be explained in a number of ways. One explanation may be that older adults continue to use a less effective, automatic task-consistent strategy, whereas young adults are able to switch to a more effective, executively demanding, task-discrepant strategy, which is under the voluntary control of executive resources (Abwender et al, 2001). During both letter and excluded letter fluency older adults made greater use of a phonemic strategy, which for these tasks is considered by Abwender et al (2001) to be a task consistent strategy. Whilst this may be effective for generating words during initial letter fluency it is likely to be less effective for excluded letter fluency given the need to exclude a particular letter. Young adults on the otherhand tended to utilise a task-discrepant semantic strategy, particularly in the excluded letter fluency.

The results from the different strategy measures taken suggest that the use of this task-discrepant strategy is likely to make demands on a number of executive processes

such as the voluntary control of strategy use, the ability to switch between strategies and the ability to inhibit automatic strategy use. It is difficult to draw firm conclusions regarding the nature of the age-related decline in excluded letter fluency performance because it is likely to make demands on a number of both executive and non-executive resources; however, it is likely that the age differences found are a consequence of an age-related decline in executive processes. Given the potential fractionation of the central executive (Baddeley, 1996) it remains to be identified precisely which executive processes decline with age.

Results from study 3 found no age differences in the shape and excluded shape tasks after controlling for speed of processing and IQ, suggesting that the shape and excluded shape fluency tasks rely on different resources to the excluded letter fluency task used in study 2, however problems in differentiating between the different possible strategies makes any conclusions from study 3 limited. The difference in findings between studies 2 and 3 may suggest that there are modality specific executive resources. However, given the limitations in the validity of the tasks as measures of executive retrieval, this conclusion cannot be substantiated.

Studies 4 and 5 were developed to address the issues raised by the results of study 2, by using a task which allowed for the investigation of the different executive processes separately. The general aims of studies 4 and 5 were to investigate the effects of age on central executive processing further by using oral and keypress random generation tasks which, through the use of different measures of randomness and different task parameters, was expected to make demands on different executive and non-executive processes. The findings from study 4 highlighted a number of interesting issues regarding the different processes underlying random generation performance. Results showed different effects of response rate and set size on oral and keypress measures of random generation, which suggests that random generation across the two modalities does not rely on the same resources to the same extent. Results suggested that oral random generation makes greater demands on executive resources than keypress random generation. It was concluded that set size 10 was likely to make greater demands on executive processes compared to set size 5. This was explained in terms of the differing demands on voluntary control for the two task parameters. With a smaller set size of 5 the generation of items is externally

constrained by the small set size, whereas for a larger set size of 10 there is a greater amount of voluntary control in terms of how items can be generated. An example of this is evident with the TPI measure, which is a measure of switching between ascending and descending sequences. In set size 5 a switch from ascending to descending sequences is heavily constrained by the small set size, in comparison to the larger set size of 10.

Of the differing measures of randomness, general measures, monitoring / updating measures and inhibitory measures showed no effects of age after controlling for speed of processing, whereas the switching measures did show evidence of an effect of age in the set size 10 conditions. From this it was concluded that the monitoring measures were likely to rely on passive memory storage processes, rather than executively controlled memory processes, and that this passive storage ability does not decline with age. Alternatively, it may have been that that the memory demands were not sufficiently high to show any effects of age. The lack of age effects on the measure of inhibitory processing suggested that the ability to inhibit stereotypical responses does not decline with age. The decline in performance among older adults on the switching measure of randomness in set size 10, suggested that older adults showed an impaired ability to switch between strategies, and that this represented a deficit in the voluntary controlled executive process of switching.

The lack of age effects on the monitoring and inhibitory measures of randomness was investigated further in study 5, by adding a concurrent memory load and inhibitory load during random generation, to determine whether this increased load had an effect on age-related random generation performance. Results indicated effects of both memory and inhibitory load on both memory and inhibitory measures of randomness and for the inhibitory measure effects of age were evident in the load conditions. However, all of these effects could be accounted for by controlling for speed of processing, suggesting that any age differences in inhibitory processes or passive memory processes are a consequence of age-related speed of processing differences. The lack of age effects on the monitoring measures supports the conclusions of study 4, that this measure makes demands on passive storage rather than executive processes. One potential explanation put forward for the effect of both a memory load and an inhibitory load on the inhibitory measure of random generation was that

older adults may have an impaired general working memory capacity. Results from the monitoring measure suggested that this possible age-related deficit in general working memory capacity was not likely to be a consequence of a reduced storage capacity; however, it remains unclear whether it could be a consequence of reduced processing resources or a reduced ability to combine storage and processing.

In study 5, the switching measure continued to show an effect of age which was not removed when controlling for speed of processing and IQ and it was concluded that older adults have a deficit in the executive process of switching. Both memory and inhibitory loads led to a decline in randomness on the switching measure, but these effects of load were eliminated when speed of processing was controlled for. Analysis of error rates under both load conditions showed that older adults produced more errors, and that this increase in errors could not be accounted for by either speed of processing or IQ. This age-related increase in errors was explained in terms of an impaired central executive ability to co-ordinate the two tasks.

Based on the results of both the verbal fluency and random generation tasks, it is evident that older adults do show an age-related decline in performance on some executively demanding tasks, independently of any age-related speed of processing deficit. In particular, the results suggest that the specific executive processes of switching are likely to decline with age. Results also indicated that this age-related decline in performance may be related to the requirement for voluntary switching and the requirement for either active processing, or to co-ordinate both storage and processing components of a task. The final two studies were therefore designed to investigate executive switching processes further, to determine under what conditions age-related switching performance declines. Studies 6 and 7 utilised the task switching paradigm to investigate age-related switching performance, as this paradigm allows for the executive control processes during task switching to be isolated from the basic task processes (Meiran, 1996). The use of different measures of task switching also allowed for specific switching costs to be separated out from more general switch costs required for the co-ordination of two tasks within working memory.

Study 6 aimed to investigate the effects of age and an active memory processing load on task switching performance, by requiring participants to keep track of when to switch from one task to another. The active memory processing load was manipulated by varying the frequency of the switch. A longer sequence before switching was expected to place greater demands on executive, active memory processes rather than passive storage memory processes, and would allow further investigation of the conclusions drawn from study 5 regarding the effects of memory load. Results from study 6 indicated interactions between age and memory load on all measures of task switching, which could not be accounted for by age-related differences in speed of processing or IQ. Age effects on the specific switch cost and alternation cost measures were explained in terms of an age-related deficit in the executive process of task switching, which is only apparent when the demands for active memory processing are high, in this case high memory demands for sequential information when a longer sequence has to be remembered. Age effects on the mixing cost could not be explained in terms of high demands on sequential information, as age effects were greater for shorter sequences where the switch was more frequent. It was concluded that the mixing cost results may indicate that older adults have an impaired ability to co-ordinate the two task sets within working memory and that this is a consequence of older adults maintaining a more inefficient and costly set selection mode of processing when switching frequently, whereas young adults can more quickly return to a more efficient within set selection mode of processing, even when switching every 2nd trial.

The aims of study 7 were to investigate the effects of age and voluntary control on task switching performance,e by using a cued task switching paradigm and varying the potency of the cue. It was expected that a less potent cue would place greater demands on the executive voluntary control processes required for task switching. Results for the specific switching cost showed no effects of age, and the effects of cue potency were removed by controlling for speed of processing. From this it was concluded that cued task switching does not utilise voluntary control processes for switching between the tasks, but that the task switch is controlled by the external task cue. Age effects which could not be accounted for by either speed of processing or IQ were found however, for the alternation and mixing cost measures and these were

explained in terms of an age-related impairment in the ability to co-ordinate the two tasks within working memory, supporting the conclusions from the previous study.

Sections 8.3 to 8.7 will discuss the conclusions from these studies in relation to theories of cognitive aging and theoretical models of working memory and executive processing.

8.3: Speed of Processing and Cognitive Aging

It is well recognised that older adults have a slower speed of processing than young adults (Cerella, 1985; Fisk & Warr, 1996; Salthouse, 1982, 1991a, 1996) and the results from studies 2 – 7 support this, with older adults showing much slower speech articulation rates than the young adults. The current debate regarding speed of processing and cognitive aging does not dispute this, but is interested in determining the influence of speed of processing on age-related cognitive performance and the results of the current studies can add to this debate. Conclusions from studies 2 - 7 indicated that whilst some of the age differences found could be accounted for by speed of processing, a number of the age-related effects on fluency, random generation and task switching were not removed by statistically controlling for speed of processing. This suggests that a general slowing account of cognitive aging (Cerella, 1985; Salthouse, 1996) cannot fully explain the findings from these studies.

Some previous studies have suggested that age differences in speed of processing can account for age differences in verbal fluency (Phillips, 1999; Salthouse et al, 1996), random generation (Fisk & Warr, 1996) and task switching (Salthouse et al, 1998); however, the results from studies 2 – 7 are inconsistent with these findings. One explanation for this inconsistency may be that in studies 2 – 7 a number of different task measures for each task was taken for a variety of task parameters, whereas in the studies by Fisk & Warr (1996), Phillips (1999), Salthouse et al (1996) and Salthouse et al (1998) fewer task variations and measures, and different measures of speed of processing were used. Indeed the results from studies 2 – 7 indicate that it is only under certain task conditions that these age-related differences that are independent of speed of processing occur. The nature of these age differences will be discussed in later sections of this chapter; however, what is clear is that there are age-related

changes in some executively demanding tasks that are not a consequence of age-related speed of processing changes.

The results from studies 2 – 7 therefore provide further support for the view that whilst a reduction in speed of processing can explain some of the variation in age-related cognitive task performance, it is not the only process which is responsible for age-related changes. More recent accounts of cognitive aging have concluded that whilst speed is an important factor in age-related cognitive task performance, other independent factors are also important (Anderson & Craik, 2000; Salthouse & Ferer-Caja, 2003; Schretlan et al, 2000; Stankov, 1999). In particular, these studies all highlight the importance of executive or attentional control processes as being important factors influencing cognitive aging, and Salthouse & Ferrer-Caja (2003) also found that memory processes played an important role. The results from studies 2 – 7 are generally consistent with this view and conclusions regarding age related changes in executive and memory processes will be considered in detail in sections 8.6 and 8.7.

One limitation of the conclusions drawn regarding the contribution of speed of processing to the pattern of age-related performance found on the fluency, random generation and task switching measures, is that speed of processing was only measured using one measure, speech articulation rate. This measure was selected as it was considered to be a measure of basic speed of processing that is independent of perceptual and motor speed demands (Hughes & Bryan, 2002). However, it is possible that if other measures of speed of processing were used, the findings of age-related changes after controlling for speed of processing may have been different. This may also explain some of the differing contributions of speed of processing to the tasks found between the present studies and previous research. However, as controlling for speech articulation rate reduced some of the effects of age and removed others, it is likely that this measure is a valid measure of a basic, common speed of processing concept, even though differing speed of processing measures will also reflect different task processes (Hertzog, 1989; Salthouse, 1991a). Despite the limitations in the speed of processing concept and the measures of processing speed, it is clearly an important factor in cognitive aging and the results from the current studies indicate that future research on cognitive aging needs to take speed of

processing into account when investigating other factors associated with age-related cognitive performance.

8.4: Inhibitory processing and Cognitive Aging

A decline in inhibitory processing with age was one potential explanation for some of the results of study 2, which found an age-related decline in the excluded letter fluency task and the use of task discrepant strategies. However, the results from study 4 found no differences between the young and old adults on the adjacency and runs measures of random generation which were presumed to reflect inhibitory processes. From this it was concluded that inhibitory processing does not decline with age. This conclusion is inconsistent with research suggesting that older adults show a decline in inhibitory processing compared to young adults (Hasher & Zacks, 1988; Hasher, Zacks & May, 1999; McDowd & Shaw, 2000). There are two potential explanations for the differences between the results of study 2 and the previous research.

Firstly, it may be that there are separable inhibitory processes and that not all of them decline with age. Hasher et al (1999), Hasher et al (2001), Kane et al (1997) and McDowd & Filion (1995) have suggested that there are separable inhibitory processes (see section 3.2 for discussion of this) and it may be that the adjacency and runs measures make demands on a specific inhibitory process that do not decline with age. The adjacency and runs measures are presumed to rely on the processes responsible for the inhibition of prepotent responses, which is one of three separable inhibitory processes proposed by Hasher et al (1999) and Hasher et al (2001). The results therefore suggest that the ability to inhibit prepotent responses does not decline with age. However, research using other tasks such as the Stroop task, which also relies on the inhibition of prepotent responses, does show evidence of an age-related decline (Christ et al 2001; Daigneault et al, 1992; Houx, Jolles & Vreeling, 1993; West, 1996).

Secondly, it may be that the random generation task only makes minimal demands on the inhibitory processes measured by adjacency and runs and that these demands are not great enough to show any small age differences in the inhibitory processes utlised during the task. Increasing the inhibitory demands of the task may lead to evidence of

an age-related decline in performance. Inhibitory demands were increased in study 5 by including an inhibitory load condition and consequently age differences on the adjacency and runs measures were evident under inhibitory load conditions. However, age differences on these measures were also evident under memory load conditions as well, suggesting that the nature of the age related deficit is not specifically inhibitory, but a more general processing deficit. This general decline in performance under load conditions, among the older adults, was removed when controlling for speed of processing however, which suggests that the age differences in inhibitory measures of random generation can be accounted for by age-related speed of processing differences.

These results can be interpreted as indicating that age differences in some inhibitory measures, such as those requiring the inhibition of prepotent responses, may be mediated by age differences in speed of processing. This interpretation is consistent with a number of studies that have demonstrated a relationship between age-related inhibitory performance and speed of processing (Earles et al, 1997; Salthouse & Meinz, 1995; Shilling et al; 2002). Although the results from study 5 add to the evidence supporting the notion that age-related difference in the inhibition of prepotent responses are mainly a consequence of reduced speed of processing, it remains unclear whether this relationship between speed and inhibitory processing can be generalised across other types of inhibitory processes. Both the studies by Salthouse & Meinz (1995) and Shilling et al (2002) only used Stroop based tasks, therefore limiting the conclusions regarding inhibitory processing to the inhibition of prepotent responses. The study by Earles et al (1997) used Stroop measures and negative priming measures. Study 5 used different measures of inhibition of prepotent responses to the Stroop based tasks (adjacency and runs measures of randomness during random generation), this adds to the previous studies by demonstrating that the relationship between speed of processing and inhibition of prepotent responses is consistent across different tasks besides Stroop tasks, and across different speed of processing measures. However, further research investigating the relationship between other inhibitory processes and speed of processing is necessary to determine whether other inhibitory processes can influence age-related cognitive performance independently of speed of processing.

8.5: Resource Capacity and Cognitive Aging

An alternative explanation for cognitive aging effects is that older adults have a reduced processing resource capacity, which is generally seen as either reduced working memory resources (Cherry & Park, 1993; Dobbs & Rule, 1989; Foos, 1995) or reduced attentional resources (Craik. 1983; 1986; Craik & Byrd, 1982) (see section 3.4 for discussion of this). Although the current studies were not specifically designed to investigate a general resource account of cognitive aging, and cannot therefore support or refute this theory, the results can still provide some evidence relevant to resource theory explanations. One of the main debates within resource capacity explanations is whether age differences are a consequence of reduced storage capacity (Foos & Wright, 1992), reduced processing capacity (Dobbs & Rule, 1989) or a reduced ability to coordinate storage and processing (Brebion et al, 1997).

The results from studies 1 – 7 would be consistent with the view that older adults have either a reduced processing capacity or a reduced ability to co-ordinate processing and storage. Study 1 found that the tasks relying purely on VSWM storage showed age equivalent performance, whereas those requiring VSWM storage and central executive processing declined with age. Similarly, in study 4 the random generation measures that relied mainly on memory storage and monitoring did not decline with age, whereas age differences were found in one of the measures requiring central executive processing. Study 5 also found that when both storage and processing was required under memory and inhibitory load conditions, random generation performance for older adults was impaired. These findings are more consistent with either an age related processing capacity deficit or an age-related co-ordination deficit.

The age equivalence in the VSSP slave system measures in study 1 and in the measures of memory storage in study 4, are inconsistent with studies such as Foos & Wright (1992) and Stine & Wingfield (1990) suggesting that passive storage declines with age. These findings suggest older adults do not have a reduced storage capacity. Throughout the seven studies, measures that did show an age-related decline, tended to be those which made demands on executive processes (the pattern span and sequence span task in study 1, excluded letter fluency in study 2, strategy switching

measures of randomness in studies 4 & 5 and task switching measures, which made demands on active memory process or co-ordination processes). These measures all make demands on active processing and as such provide support for resource capacity theories, emphasizing the role of age-related declines in processing efficiency as an explanation for adult age differences in working memory tasks (e.g. Dobbs & Rule, 1989; Morris, Gick & Craik, 1988). However, it could also be argued that all of these tasks also require the co-ordination of both storage and processing, and that it is this ability to co-ordinate storage and processing rather than the actual processing resource itself that declines with age. Evidence from the random generation and task switching studies also suggest that a general reduced processing efficiency cannot fully account for the pattern age-related performance in studies 4 – 7, as some measures which make demands on processing resources do not decline with age. For example, random generation measures that placed demands on inhibitory processing showed no age-related decline in performance, nor did the specific task switching measures when the memory demands were low (i.e. when switching every 2nd trial and when an external cue was present). This suggests that a general age-related processing decline cannot fully account for the pattern of age effects found. A more useful account is likely to be one which allows for the fractionation of executive processes within working memory.

8.6: Implications for Theoretical Models of Working Memory

The overarching aim of the thesis was to investigate the age-related changes in the slave-system and central executive components of the working memory within the context of the working memory model, originally proposed by Baddeley & Hitch (1974) and later modified by Baddeley (1986, 1996) and Logie (1995). Within this framework, the results from all the studies strongly support the notion that tasks which make extensive demands on some central executive processes decline with age, whereas tasks which mainly require slave system processes show no effects of age. This was evident in study 1, which found that the size JND and trajectory JND tasks (which are presumed to be measures of VSSP functioning) showed no effects of age, whereas the pattern span and sequence span tasks (which were assumed to make demands on central executive processes as well as VSSP processes) did decline with age. Studies 2 – 7 provided further evidence of a decline in tasks that placed greatest

demands on executive processes. This age-related decline in tasks which make demands on executive processes, compared to the age-related equivalence on tasks which do not make demands on executive processes is consistent with the fractionated model of working memory proposed by Baddeley & Hitch (1974), Baddeley (1986, 1996, 2000) and supports previous studies such as that by Libon et al (1994), which suggested that visuospatial tasks which make executive processing demands will decline with age.

Given the differential effect of age on tasks which make demands on VSSP slave system and central executive processes found in study 1, the results are inconsistent with unitary models of working memory such as those proposed by Just & Carpenter (1992) and Engle (1996). More recently Engle et al (1999a; 1999b) had suggested that their concept of a unitary working memory capacity was equivalent to only one component of the the Baddelely & Hitch (1974) working memory model, the central executive. However, the findings from the random generation studies (studies 4 & 5) and the task switching studies (studies 6 & 7) indicate differential effects of age on measures of different executive processing. Measures of randomness presumed to rely on executive processes of monitoring and inhibition showed no effects of age independently of speed of processing, whereas measures relying on executive switching processes did show an effect of age. This is inconsistent with the notion of a unitary central executive and provides support for the concept of a fractionated central executive proposed by Baddeley (1996) and Miyake et al (2000). Section 8.7 will consider the implications of the findings in relation to executive processing in greater detail.

The differential effects of age found in study 1 have so far been considered in terms of support for the Baddeley & Hitch (1974) multicomponent model of working memory, however they can also be explained to some extent by the distributed continuum model proosed by Cornoldi & Vecchi (2000), which suggests that individual differences in working memory are a consequence of either the type of information to be processed, or the amount of active processing required. The age differences evident in study 1 could be a consequence of an impaired ability for active processing in the older adults, as the pattern span and sequence span tasks are likely to place greater demands on active processing than the size JND task. However, it is not clear

why no effects of age would be evident in the trajectory JND task as this task is likely to rely on more active processing. The distributed continnum model can also not account for the differential effects of age found on the different measures of randomness in studies 4 & 5. Random generation is likely to require a high degree of active processing and therefore older adults would be expected to show poorer performance on all measures of randomness according to this model. However, age-related declines in randomness were not evident across all measures, only in the switching measure.

8.7: Executive processing and Cognitive Aging

Chapter 3 discussed a number of previous studies which suggested that tasks which make demands on executive processes will decline with age (Baddeley, 1986; Keys & White, 2000; Van der Linden et al, 1998). However, firm conclusions from this previous research were difficult to reach because of the contradictory nature of the results and difficulties in identifying valid measures of executive processes. Results from studies 2 – 7 add to this debate and suggest that one specific executive process which does show an age-related decline is that of task switching. By using a range of different tasks and measures throughout these studies it is hoped that the problems of the previous research will be overcome. The validity of the tasks and measures used will be discussed in section 8.8.

Findings from the current studies, similarly to the previous research on task switching, show evidence of an age-related decline on performance; however, this is not consistent across all measures of task switching. One potential explanation for the differing effects of age across the different task switching measures is that age differences during task switching may be a consequence of the requirement for an internal, voluntarily controlled switch between tasks and that age differences will not occur if the task switch is externally controlled, as in the cued task switching paradigm. A comparison of the age-related performance on specific switch costs for studies 6 & 7 seem to support this conclusion. Study 6 used a task switching paradigm which required participants to internally monitor when a task switch was required and older adults showed a decline in specific switch costs, whereas in study 7, which utilised an externally cued task switching paradigm, no effects of age were

found. The requirement for voluntary control of actions is one of the key functions of the SAS (Norman & Shallice, 1980) and hence the central executive (Baddeley, 1986). If the requirement for internal, voluntary control is a defining feature of central executive processing then, task switching which is externally controlled by the presence of a cue is not likely to be make demands on executive processes as no internal, voluntary control is required. This suggests that externally cued task switching is therefore not an 'executive' task and that age-related impairment would not be expected. Logan & Bundesen (2003) have also suggested that externally cued task switching is not an executively demanding task and the findings from study 7 provide further support for this conclusion.

The results from study 4 also support the conclusion that age differences in task switching may be a consequence of the requirement for an internal, voluntary controlled switch. Age differences in the switching measure of random generation were found only with a set size of 10 and not with a set size of 5. A set size of 10 would allow greater voluntary control of when to switch between ascending and descending strategies, compared to a set size of 5, where the switch would be more externally constrained. However, no direct comparison was made between set size 5 and set size 10 results, because the different number of responses would affect the baseline measures of randomness (Towse & Neil, 1998), this makes it difficult to draw firm conclusions regarding any explanation of the different patterns of age-related performance across the two set sizes.

Anderson & Craik (2000) have also emphasized the importance of voluntary control as an account of age differences in cognitive tasks. They suggest that tasks which require a greater amount of voluntary control, and which are not externally cued by the environment, will show a greater age-related decrement in performance. Whilst the results from studies 6 & 7 are consistent with this view, they do not provide a direct test of voluntary control as a direct comparison between cued and non cued task switching was not made, and other differences such as increased memory demands could account for the difference in results between the two task switching paradigms. The cued task switching paradigm not only removes the requirement for internal voluntary control of the switch by the provision of the cue, but also removes the requirement for the participant to keep track of when to make the switch, thus also

reducing the memory demands during the task. Any conclusions relating to voluntary control from a direct comparison between the cued and non cued task switching paradigms would therefore be confounded by the difference in memory demands.

Study 7 did attempt to directly manipulate the degree of voluntary control required by varying the potency of the task cue. However, even with a weak potency cue no age differences were evident. These results could be interpreted as either suggesting that: any cue, even a weak potency cue, is sufficient to externally control the task switch and thus remove the demands on executive processing; or that variations in the requirement for voluntary control are not able to account for the patterns of age equivalence and age differences in task switching. However, given that the results from study 4 also support the argument that age differences in switching are likely to be a consequence of the need for an internal, voluntary controlled switch, it seems likely that voluntary control may be a potential explanation for age differences in the specific executive process of task switching and that this is likely to be an important area for future research to explore. Further studies that provide a direct manipulation of voluntary control, whilst controlling for other potential task variations, such as memory demands, may be able to provide a clearer indication of this possible source of age-related impairment.

As well as the requirement for internal voluntary control, age differences in specific switch costs also seem to be a consequence of a decline in some sort of active memory process. Study 6 found that age-related impairment in specific switch costs during non-cued task switching only occurred when participants had to keep track of a longer sequence before switching. The precise nature of this age–related impairment however is difficult to determine: it may be a specific executive process responsible for the retention of sequential information; a specific executive process responsible for updating or keeping track of information in working memory; or a more general executive process that is responsible for the integration or c-oordination of memory and processing components of the tasks.

Age differences have previously been found in a memory updating task (Van der Linden et al 1994) and it could be argued that the task switching paradigm used in study 6 makes demands on similar central executive updating process, in that

participants are required to keep track of the sequence of tasks and initiate a task switch at the appropriate point in the sequence. However, it could also be argued that both the updating task used by Van der Linden et al (1994) and the task switching paradigm used in study 6 also require some sort of integration between memory and processing components of the task and that it is a decline in this integration ability that is responsible for the age differences found. Integration can be defined as the processing of two information sources simultaneously, when the sources of information are related to each other and need to be combined to derive a single answer or solution (Emerson, Miyake & Rettinger, 1999).

Emmerson, Miyake & Rettinger (1999) have investigated individual differences in integration and co-ordination abilities and have suggested that the ability to integrate information is closely linked to the ability to co-ordinate information. Co-ordination is similar to integration in that two sources of information have to be processed simultaneously, but the information is unrelated and needs to be kept separate to complete the two tasks with minimal interference form each other (Emerson et al, 1999). They suggest that there may be a relationship between integration and co-ordination and task switching.

The work by Emmerson et al (1999) suggests that the ability to integrate information and the ability to co-ordinate information are highly related and may reflect a common underlying mechanism. However, the results from study 6 suggest that these two abilities may be separable as different effects of age were found on the specific switch cost measures (which may reflect the ability to integrate information in order to perform the task switch) and the mixing cost measures (which is likely to reflect the ability to co-ordinate the two tasks within working memory). The specific switch cost occurs at the point when an actual switch is made between the two tasks and will require the integration of information regarding the place in the sequence, and information regarding the task set to be switched to, in order to complete the switch. The mixing cost is the increased cost incurred on repeat trials in the mixed block. At this point information relating to keeping tack of the sequence and the task set still have to be processed, but separately, and therefore likely to rely on co-ordination, rather than integration. Whilst age effects were also found on the mixing cost measures, the pattern of these age effects was the opposite to that found on the

specific switch cost measures, with older adults showing greater costs when switching every second trial compared to every fifth trial. This was interpreted as indicating an impairment in the ability to co-ordinate and maintain two task sets within working memory, rather than an impairment of being able to switch tasks, as the measure indicated the difference in performance on repeat trials only, during mixed task blocks in comparison to pure task blocks.

Age-related impairments were also evident on the mixing cost measure in study 7, which utilised a cued task switching paradigm, demonstrating that even when the task switch itself does not rely on the voluntary, internal control function of the central executive, there is still evidence of an age-related impaired executive process of co-ordination which affects performance on cued task switching. This age related decline in co-ordination seems to be a more general processing deficit which is not specific to task switching, but is apparent across tasks that require co-ordination, such as the random generation tasks under load conditions.

Results from the random generation measures under load conditions in study 5 would also be consistent with the notion that the ability to co-ordinate information during a task declines with age and that this age-related decline is common across a range of randomness measures. Results generally showed that when participants had to combine either a memory load or an inhibitory load with the random generation task, age differences were apparent across the monitoring, inhibitory and general measures of randomness, as well as the task switching. Whilst the majority of these age differences in randomness were removed when controlling for speed of processing, age differences in error rates remained after controlling for speed of processing, indicating that older adults were indeed impaired by the load conditions.

These results have a number of implications, both in terms of our understanding of the processes involved in task switching, and in terms of our understanding of executive processing. Firstly, in relation to task switching it seems likely that there are a number of processes responsible for task switching performance, which can account for the pattern of age equivalence and age impairment. Secondly, cued task switching would appear to utilise non-executive, externally activated processes at the specific switch point, to switch from one task to another, and these processes do not seem to

be affected by age. However, central executive processes responsible for the co-ordination of two tasks within working memory are utilised throughout task switching in mixed blocks and these co-ordination processes decline with age. This would lead to age differences being evident in mixing costs and in alternation costs, but not in specific switch costs during cued task switching. For non-cued task switching central executive co-ordination processes are still required during mixed task blocks, but the processes responsible for the specific switch would no longer be externally driven, but would require some degree of internal, voluntary, executive control. The specific switch costs may also make demands on integration processes which will be required to integrate the information required for each task, with the information to determine when a switch is required, in order to switch between tasks effectively. This central executive process does seem to decline with age and hence an age-related decline in all of the three measures of switching would be expected.

This is consistent with the results found in studies 6 and 7 and can explain some of the results found in the previous task switching literature regarding age-related performance, where no effects of age were found for specific switch costs when instructional cues were used (Mayr & Liebscher, 2001; Meiran et al, 2001), whereas age-related declines in both mixing and alternation costs were found (Meiran et al, 2001). For non cued task switching alternation costs have shown consistent effects of age (Kramer et al, 1999, Kray & Lindenberger, 2000), and specific switch costs have shown effects of age when memory and integration or updating demands were high (Cepeda et al, 2001; Kramer et al, 1999).

In terms of our understanding of executive processes the findings from the random generation and task switching studies in particular support a model of specific separable executive processes, not all of which decline with age. Firstly, specific voluntary controlled task switching processes which seem to rely on integration processes, and which decline with age; secondly, inhibitory processes responsible for the inhibition of prepotent responses, which do not decline with age; and thirdly, co-ordination processes which seem to have a more general influence across the different tasks and measures, and which decline with age. The differential effects of age on these three putative executive processes strongly suggests that the processes are separable, rather than rely on a single, underlying common executive resource and as

such support a fractionated model of the central executive, with some common or shared co-ordination resources.

The conclusion that some executive processes are distinct and separable from others is consistent with a number of other studies that have investigated executive processing (Miyake et al, 2000; Verhaeghen & Basak, 2005, Ward, Roberts & Phillips, 2001). In a correlational study, Ward et al (2001) found that the executive processes responsible for task switching and stroop tasks are separate specialised control processes, although there may be some small degree of overlap between the two, which could indicate a common, shared executive resource. The conclusions from the current study are consistent with this view, in that voluntary controlled task switching shows differing effects of age in comparison to the inhibition of prepotent responses, which shows no effect of age. Stroop tasks are thought to rely on the ability to inhibit prepotent responses and based on the findings from the current studies would not be expected to show a high correlation with specific task switching. The convergence of evidence from these two different types of studies strengthens the argument for separable executive processes. Ward et al (2001) also suggest that there may be some common or shared resources responsible for the small correlations between switching and stroop tasks. The findings from the current study would suggest that co-ordination processes may be an executive resource that is common across a range of executively demanding tasks.

To some extent similar findings of separable executive processes which are to some extent related have been demonstrated using confirmatory factor analysis by Miyake et al (2000). They identified three separable executive processes of set shifting, updating and inhibition of prepotent responses. The process termed 'shifting' by Miyake et al (2000) is the process referred to as switching throughout the thesis. As discussed earlier the findings of the current study support the separability of executive switching and inhibition of prepotent responses. However, conclusions from study 6 suggested that the executive process that Miyake et al (2000) term 'updating', may be related to specific task switching in terms of executive processes required to integrate information. However, these results are not completely inconsistent with the conclusions of Miyake et al (2000), as they found a correlation of 0.56 between shifting and updating. The fact that study 6, which provides the main evidence in

support of a relationship between specific switching and updating or integration, utilised a non-cued task switching, in contrast to the Miyake et al (2000) study, which cued the task switching, may account for the differences between the current results and the conclusions of Miyake et al (2000) regarding the separability or unity of the task switching and updating or integration.

The results from studies 5, 6 & 7 suggested that co-ordination processes may be some sort of common or shared executive resource across the different tasks and measures used, but that it is a separable process from switching and integration or updating. This conclusion is consistent with that of Miyake et al (2000) who found that none of the three executive processes of shifting, updating and inhibition were related to dual task performance. The data from studies 6 & 7 would support this view as the age-related effects of co-ordination during task switching were evident on a different component of the task (mixing cost), in comparison to the age-related effects of switching (which were evident only on specific switch costs). Study 7 also demonstrated that age-related co-ordination effects were evident on cued task switching tasks, even though specific executive switching processes are unlikely to be utilised during this task, which demonstrates the separable effects of executive switching and co-ordination processes on age-related task switching performance.

8.8: Issues relating to Central Executive Tasks

One of the main problems associated with investigating central executive processing is finding valid measures of executive processes which take into account the fractionation of executive functions (Burgess, 1997; Phillips, 1997). The tasks used throughout studies 2 – 7 have all been presumed to rely on executive processes; however, the results from the studies suggest that not all of the tasks or measures can be considered valid measures of executive functioning. Studies 2 & 3 utilised four fluency tasks: initial letter fluency, excluded letter fluency, shape fluency and excluded shape fluency. Of these tasks it can be concluded that only excluded fluency appears to reflect some sort of executive processing. Although initial letter fluency has been shown to be related to switching strategies in previous literature (Robert et al, 1998; Troyer et al, 1997) and therefore is likely to reflect executive strategic retrieval processes, findings from study 2 showed no effects of age and word

generation during initial letter fluency seemed to make use of an automatic task consistent strategy, which suggests that the task relies on automatic, non-executive retrieval processes rather than executively demanding, voluntary controlled retrieval processes. This conclusion that initial letter fluency does not make demands on executive processes has also been put forward by Phillips (1997), who found that under dual task conditions initial letter fluency is not disrupted by random generation, an executive demanding secondary task. Although the precise nature of the processes underlying initial letter fluency are not clear, it can be concluded that initial letter fluency should not be considered a valid measure of executive processing, given the findings both from the Phillips (1997) study and the study 2 reported in chapter 5. The shape fluency and excluded shape fluency tasks were designed as non verbal equivalents to initial letter and excluded letter fluency tasks, however results suggested that retrieval during both these tasks utilised an automatic task-consistent strategy and showed no effects of age, suggesting that neither task is executively demanding.

One fluency task that did appear to make demands on executive processes is the excluded letter fluency task. Consistent effects of age were found and age differences in the use of a task-discrepant strategy and executively mediated strategy switching, leading to the conclusion that excluded letter fluency is a valid measure of executive processing. This conclusion is also supported by previous studies (Bryan & Luszcz, 2000; Hughes & Bryan, 2002) who suggest that excluded letter fluency makes high demands on executive processes. Although it is clear that excluded letter fluency does make demands on executive processes, what is not clear is precisely which executive processes underlie excluded letter fluency performance, either age-related declines in inhibitory processing or executive switching processes may be responsible for the age differences in excluded letter fluency found in study 2, however further research is necessary to identify the precise executive processes utilised during the task, in order for excluded letter fluency to be considered a useful tool in the investigation of a fractionated central executive.

Studies 4 & 5 utilised oral and keypress random generation tasks. One of the key debates within the random generation literature is whether oral and keypress random generation utilise the same underlying resources (Baddeley et al, 1998; Towse, 1998).

Results from the current studies suggest that they do rely on the same resources as there were few interactions between modality and other task or age manipulations. However, effects of modality on some measures of randomness suggested that oral random generation places greater demands on central executive resources than keypress random generation.

Random generation is a complex task which relies on a number of different executive and non-executive resources (Baddeley et al, 1998; Towse & Neil, 1998; Towse & Valentine, 1997). Results from the differing measures of randomness and for the two set size conditions in study 4, found differing effects of age and response rate and differing interactions, which supports this conclusion and demonstrates the importance of using a wide range of randomness measures for random generation tasks. This will allow the underlying processes to be investigated separately and provide the opportunity for more valid measures of executive processes to be investigated. Although using differing measures of randomness is useful for separating out some of the processes underlying random generation performance, the precise nature of the processes involved in the task still needs further investigation to fully elucidate the precise nature of the processes utilised during the task. In particular further research is needed to clarify whether random generation relies on the same or different resources for different set sizes.

Study 4 found differing effects of age and response rate for the two set sizes, with effects of age and response rate being consistently greater for set size 10, suggesting that set size 10 random generation utilises executive resources, whereas set size 5 random generation does not. However, as the two set sizes were not directly compared, it is difficult to draw firm conclusions regarding the differences in underlying processes. One possible explanation which supports this conclusion is the argument that executively demanding tasks require the voluntary control of action (Norman & Shallice, 1980). Random generation from small set sizes is likely to have a greater degree of external constraints because of the small set size, which will minimise the degree of voluntary control which can be exerted, thus minimising reliance on executive processes. What is clear from this, is that future research utilising random generation as an executively demanding task needs to take into account the differing randomness measures and the differing set sizes when

interpreting findings in relation to executive processes, and to identify precisely which executive processes are being measured.

The final two studies utilised task switching as a specific measure of the executively mediated switching process. As with random generation, task switching is a complex task which relies on a number of executive and non-executive processes (Meiran et al, 2000; Rogers & Monsell, 1995). However, it has been suggested that by looking at the reaction time for mixed task blocks, in comparison to the reaction time for pure task blocks, it is possible to isolate the time cost associated with switching between the tasks, from the processes responsible for the tasks themselves (Meiran, 1996) and thus obtain a purer measure of executive switching. However, even this switch cost has been shown to rely on a number of executive and non-executive processes (see chapter 7).

Results from studies 6 & 7, which attempted to isolate the executive control process responsible for advance preparation during task switching, suggested that this process only relied on specific executive switching processes when the switch was under voluntary control, as in the non-cued task switching paradigm, not under external control as in the cued task switching paradigm. The interaction between age and memory load also suggested that the executive process underlying specific switch costs may be a consequence of an impaired executive ability to integrate information. The executive resources responsible for co-ordination of two tasks also seemed to be implicated for both switch and non-switch trials (as measured by the mixing cost) for both non-cued and cued task switching. Task switching then does seem to be a promising measure for executive processes and the different measures of specific switch costs and mixing costs will allow for the measurement of the separable executive processes of integration of information during task switching and the coordination of two tasks within working memory.

The conclusions made throughout the thesis regarding the central executive tasks used, add to the debate regarding the validity of central executive tasks and suggest that using a range of measures, which allow the separation out of task processes, may provide a fruitful method for investigating central executive processes.

8.9: Limitations of Methodology

The reliability and validity of the tasks used throughout the current studies is one of the most important features which could limit the findings of the studies. Section 8.8 has considered the validity of the executive measures used throughout the studies and it has been concluded that whilst some of the measures used do appear to make demands on executive processes, it is not always clear what the precise nature of these executive processes are. This limits the conclusions that can be drawn from the studies. There are a number of other tasks and more traditional test batteries such as the CANTAB (Robbins, James, Owen, Sahakian, McInnes & Rabbitt, 1994), which could have been used. However, the majority of the tasks included in test batteries such as these, e.g. the WCST, Tower of London Task, can be criticised for making demands on a number of different executive and non-executive processes (Baddelely et al, 1997) and it is difficult to separate out the underlying processes.

A further limitation of the methods used is that there may have been individual differences between the young and old adult age groups, besides age, which could have accounted for the differences found in the studies. Individual differences in factors such as speed of processing, IQ, educational background, physical health, mental health, medication use, eye sight, hearing, mood, motivation, substance abuse could all potentially influnce performance on the tasks and therefore account for any differences between the groups. An attempt was made to control for some of these factors within the design of the studies. Speed of processing, IQ and dementia were all measured and controlled for statistically to minimise their influence on performance.

Whilst a convenience sampling method was used, an attempt was made to control for other factors such as physical health mental health, medication use, eyesight and hearing, by asking participants to verbally self report on these, and then excluding any participants with problems that could potentially influence performance. However, this method is dependent upon participants providing an accurate account of any potential problems and therefore does not provide a consistent approach to controlling for these potential confounding factors. Future research could take a more consistent

and reliable approach in controlling for these extraneous variables, by perhaps using a written questionnaire to identify any relevant medical problems.

It is also likely, given the sampling method, that the age groups will have differed in terms of their educational background. The majority of participants in the young age groups were obtained from an undergraduate population, whereas the older age group were sampled from the general community. This is likely to lead to differences both in IQ and the number of years spent within education. An attempt was made to reduce these differences by obtaining some of the yong adult participants from other sources besides undergraduate students, such as administration staff and nursing auxillary staff from a local nursing home. Comparisons of the IQ score obtained for the different age groups did suggest that in terms of IQ the age groups were on the whole equivalent and where differences did occur IQ, was higher in the older age group. However, a difference in the number of years spent in education is likely to have occurred between the young and old adults. Even if an undergraduate population were not used, this factor would be particularly difficult to control for, given the changes within the educational system and the standard school leaving age that have occurred over time; young and old participants would need to be specifically matched in terms of the number of years spent in education.

Factors such as mood, and substance abuse were not measured or controlled for at all and as such may limit the findings of the studies. In relation to substance abuse a number of studies have found evidence that ecstasy use (Montgomery, Fisk, Newcombe & Murphy, 2005), cocaine use (Jovanovski, Erb & Zakzanis, 2005) and excessive alcohol use (Heffernan, Ling & Batholemew, 2004) all have an adverse effect on some measures of central executive or working memory processing. Given that substance abuse was not measured in the current studies, it is therefore impossible to rule out this as an explanation of the age differences found. Similarly, negative mood state has also been shown to impair some aspects of working memory and central executive performance (Galbraith, 2004; Vieillard & Bougeant, 2005) and as this was not measured or controlled for, could also account for the age differences found.

A further limitation of the sampling is that of the sample size. For studies 2 – 7 a sample size of 20 particuipants in each age group was used (26 in each age group in study 1). This small sample may limit the generalisability of the findings and is likely to make it more difficult to obtain significant findings, thus increasing the chance of making a type 2 error (Salkind, 2000).

8.10: Future Research

Findings from the current studies have contributed to the understanding of age-related changes in executive processing and to the debate regarding the fractionation and valid measurement of separable executive processes. The main limitation of the findings is in relation to the problems associated with the valid measurement of different executive processes, and the development of reliable and valid measures which allow the measurement of different processes to be separated out, is one of the main challenges for future research. Future research also needs to take into consideration the control of individual differences betweent different age groups and ensure their equivalence, to strengthen the conclusions that can be drawn from studies of age differences.

From an age differences perspective the current studies document some of the age differences evident between young and old adults within central executive processing; however, it would be useful for further research to adopt a lifespan approach and examine whether the age-differences evident in old age are mirrored by age differences between children and young adults. Differential development of executive processes throughout childhood, as well as differential decline with aging, would provide additional support for the fractionation of executive processes.

From a theoretical perspective further research would be useful to investigate voluntary control during executive processing. Results from the current studies were equivocal, as studes 4 and 6 suggested that the requirement for voluntary control may be able to account for age differences, whereas study 7 which attempted to directly manipulate the degree of voluntary control was unable to support this conclusion. If voluntary control is an important factor in determining adult age differences in executively demanding tasks, then this may have implications for future research

examining the use of external cues or support to reduce age differences in executively demanding memory tasks. The current studies have been driven by theoretical concepts of memory and executive processing; however, it would be useful for future research to apply this to more practical everyday situations, by investigating age differences in executively demanding tasks that are a regular part of everyday life and how these age differences can be minimised.

8.11: Conclusion

Overall, a number of conclusions can be drawn from the studies presented within the thesis. Firstly, within the context of a fractionated working memory model it seems clear that tasks which make extensive demands on central executive processes decline with age, whereas those which purely make demands on slave system resources remain relatively age-invariant. Secondly, it is also clear that whilst an age-related decline in speed of processing can account for some of the effects of age, not all of the age-related effects on executively demanding tasks can be explained by a general age-related speed of processing deficit. Thirdly, it can be concluded that the effects of age are not consistent across all executive tasks and measures which suggests that there are a number of separable executive processes, which are differentially affected by age. Findings suggested that age-related declines are evident on executive switching processes when this switching process is under voluntary control, and that these effects of age may also be a consequence of an impaired ability to either update or integrate information during the task. Age-related declines were also found in tasks which made demands on executively controlled co-ordination processes. Inhibitory processes responsible for the inhibition of prepotent responses showed no effects of an age-related impairment. These findings supported a model of a fractionated central executive, with separable executive processes. Finally, it can be concluded that the investigation of executive processing is complex and is hindered by the difficulty in identifying tasks or measures which can separate out the different executive processes. In order to develop a clearer understanding of the nature of executive processing the challenge is to develop valid methods for the investigation of different executive processes.

References

Abwender, D.A., Swan, J.G., Bowerman, J.T. & Connolly, S.W. (2001). Qualitative analysis of verbal fluency output: Review and comparison of several scoring methods. *Assessment*, 8(3), 323-336

Allport, A., Styles, E..A. & Hsieh, S. (1994). Shifting Intentional Set: Exploring the Dynamic Control of Tasks. In C. Umilta & M. Moscovitch (Eds.). *Attention & PerformanceXV: Conscious & Nonconscious Information Processing*, (pp.421-452). Cambridge MA: MIT Press

Allport, A. & Wylie, G. (2000). Task switching, stimulus-response bindings, and negative priming. IN s. Monsell & J. Driver (Eds.). *Attention and Peformance XVIII: Control of Cognitive Processes* (pp.35-70). Cambridge MA: MIT Press

Allport, D.A., Antonis, B. & Reynolds, P. (1972). On the division of attention: A disproof of the single channel hypothesis. *Quarterly Journal of Experimental Psychology*, 24, 225-235

Anderson, J.R., Reder, L.M. & Lebiere, C. (1996). Working memory: Activation limitations on retrieval. *Cognitive Psychology*, 30, 221-256

Anderson, N.D. & Craik, F.I.M. (2000). Memory in the aging brain. In E. Tulving & F.I.M. Craik (Eds.). *The Oxford Handbook of Memory*, pp. 411-422. New York: Oxford University Press

Anderson, N.D., Craik, F.I.M. & Naveh-Benjamin, M. (1998). The attentional demands of encoding and retrieval in younger and older adults: 1. Evidence from divided attention costs. *Psychology and Aging*, 13, 405-423

Andres, P. & Van der Linden, M. (2000). Age-related differences in supervisory attentional system functions. *Journal of Gerontology: Psychological Sciences*, 55B(6), 373-380

Arbuthnott, K. & Frank, J. (2000). Executive Control in Set Switching: Residual Switch Cost and Task-set Inhibition.. *Canadian Journal of Experimental Psychology*, 54(1), 33-41

Atkinson, R.C. & Shiffrin, R.M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence (Ed.). *The psychology of learning and motivation: advances in research and theory Vol. 2*, pp89-195. New York: Academic Press

Azouvi, P., Jokic, C., Van der Linden, M., Marlier, N. & Bussel, B. (1996). Working memory and supervisory control after severe closed-head injury. Astudy of dual task performance and random generation. *Journal of Clinical and Experimental Neuropsychology*, 18(3), 317-337

Babcock, R.L. & Salthouse, T.A. (1990). Effects of increased processing demands on age differences in working memory. *Psychology and Aging*, 5(3), 421-428

Baddeley, A.D. (1966). The capacity for generating information by randomization. *Quarterly Journal of Experimental Psychology*, 18, 119-129

Baddeley, A.D. (1986). *Working Memory*. Oxford: Oxford University Press

Baddeley, A.D. (1992). Working memory. *Science*, 255, 556-559

Baddeley, A.D. (1996). Exploring the central executive. *Quarterly Journal of Experimental Psychology*, 49a, 5-28

Baddeley, A.D. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Science*, 4(11), 417-423

Baddeley, A.D. (2002). Is working memory still working? *European Psychologist*, 7(2), 85-97

Baddeley, A.D., Bressi, S., Della Sala, S., Logie, R. & Spinnler, H. (1991). The decline of working memory in Alzheimer's Disease: A longitudinal study. *Brain*, 114, 2521-2542

Baddeley, A.D. & Della Sala, S. (1996). Working memory and executive control. *Philosophical Transactions of the Royal Society of London: Series B*, 351, 1397-1404

Baddeley, A.D., Della Sala, S., Gray, C., Papagno, C. & Spinnler, H. (1997). Testing central executive functioning with a pencil-and-paper test. In P. Rabbitt (Ed.). *Methodology of Frontal and Executive Function*, pp61-80. Hove: Psychology Press

Baddeley, A.D., Emslie, H., Kolodny, J. & Duncan, J. (1998). Random generation and the executive control of working memory. *The Quarterly Journal of Experimental Psychology*, 51A(4), 819-852

Baddeley, A.D., Grant, W., Wight, E. & Thomson, N. (1975). Imagery and visual working memory. In P.M.A. Rabbitt & S. Dornic (Eds.). *Attention and Performance V*, pp205-217. London: Academic Press

Baddeley, A.D. & Hitch, G.J. (1974). Working Memory. In G. Bower (Ed.), *The psychology of learning and motivation, Vol. VIII*, pp.47-90. New York: Academic Press

Baddeley, A.D. & Lewis, V.J. (1981). Inner active processes in reading: The inner voice, the inner ear and the inner eye. In A.M. Lesgold & C.A. Perfetti (Eds.). *Interactive processes in reading*, pp107-129. Hillsdale, NJ: Lawrence Erlbaum Associates

Baddeley, A.D. & Liebermann, K. (1980). Spatial working memory. In R.S. Nickerson 9Ed.). *Attention and Performance VIII*, pp. 521-539. Hillsdale, NJ: Lawrence Erlbaum Associates

Baddeley, A.D. & Logie, R.H. (1999). Working memory: The multi-component model. In A. Miyake & P. Shah (Eds.). *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control*, pp. 28-61. Cambridge: Cambridge University Press

Baddeley, A.D., Logie, R.H., Bressi, S., Della Sala, S. & Spinnler, H. (1986). Senile dementia and working memory. *Quarterly Journal of Experimental Psychology*, 38A, 603-618

Baddeley, A.D., Logie, R., Nimmo-Smith, I. & Brereton, N. (1985). Components of fluent reading. *Journal of Memory and Language*, 24, 119-131

Baddeley, A.D. & Wilson, B. (1988). Frontal amnesia and the dysexecutive syndrome. *Brain and Cognition*, 7, 212-230

Baldo, J.V. & Shimamura, A.P. (1998). Letter and category fluency in patients with frontal lobe lesions. *Neuropsychology*, 12(2), 259-267

Balota, D.A., Dolan, P.O. & Duchek, J.M. (2000). Memory changes in healthy older adults. In E. Tulving & F.I.M. Craik (Eds.). *The Oxford Handbook of Memory*, pp. 395-409. New York: Oxford University Press

Bayles, K.A., Trosset, M.W., Tomoeda, C.K., Montgomery, E.B. & Wilson, J. (1993). Generative naming in Parkinson's disease patients. *Journal of Clinical and Experimental Neuropsychology*, 15, 547-562

Belleville, S., Peretz, I. & Malenfant, D. (1996). Examination of the working memory components in normal aging and in dementia of the Alzheimer type. *Neuropsychologia*, 34, 195-207

Belleville, S., Rouleau, N. & Caza, N. (1998). Effect of normal aging on the manipulation of information in working memory. *Memory and Cognition*, 26(3), 572-583

Benton, A.L. (1968). Differential behavioural effects in frontal lobe disease. *Neuropsychologia*, 6, 53-60

Birch, D.B., Krikorian, R. & Huha, E.M. (1998). The Corsi block-tapping task: Methodological and theoretical considerations. *Brain and Cognition*, 38, 317-338

Bolla, K.I., Gray, S., Resnick, S.M., Galante, R. & Kawas, C. (1998). Category and letter fluency in highly educated older adults. *The Clinical Neuropsychologist*, 12(3), 330-338

Bolla, K.I., Lindgren, K.N., Bonaccorsy, C. & Bleeker, M.L. (1990). Predictors of verbal fluency (FAS) in the healthy elderly. *Journal of Clinical Psychology*, 46, 623-628

Bolter, J.F., Long, C.J. & Wagner, M. (1983). The utility of the Thurstone Word Fluency Test in identifying cortical damage. *International Journal of Clinical Neuropsychology*, 5(2), 77-82

Botwinick, J. (1977). Intellectual abilities. In J.E. Birren & K.W. Schaie (Eds.). *Handbook of the Psychology of Aging*, pp. 580-605. New York: Van Nostrand Reinhold

Botwinick, J., Brinley, J.F. & Robbin, J.S. (1958). Task alternationtime in relation to problem difficulty and age. *Journal of Gerontology*, 13, 414-417

Brayne, C. & Beardsall, L. (1990). Estimation of verbal intelligence in an elderly community: An epidemiological study using NART. *British Journal of Clinical Psychology*, 29, 217-223

Brebion, G., Smith, M.J. & Ehrlich, M-F. (1997). Working memory and aging: Deficit or strategy differences? *Aging, Neuropsychology and Cognition*, 4(1), 58-73

Brinley, J.F. (1965). Cognitive sets, speed and accuracy of performance in the elderly. In A.T. Welford & J.E. Birren (Eds.). *Behaviour, Aging and and the Nervous System*, pp. 114-149. Springfield, IL: Charles C Thomas

Brooks, L.R. (1967). The suppression of visualisation by reading. *The Quarterly Journal of Experimental Psychology*, 19, 289-299

Brooks, L.R. (1968). Spatial and verbal components in the act of recall. *Canadian Journal of Psychology*, 22, 349-368

Brugger, P. (1997). Variables that influence the generation of random sequences: An update. *Perceptual and Motor Skills*, 84, 627-661

Brugger, P., Monsch, A.U., Salmon, D.P. & Butters, N. (1996). Random number generation in dementia of the Alzheimer type: A test of frontal executive functions. *Neuropsychologia*, 34(2), 97-103

Bruyer, R. & Scailquin, J.C. (1998). The visuospatial sketchpad for mental images: Testing the multicomponent model of working memory. *Acta Psychologica*, 98, 17-36

Bryan, J. & Luszcz, M.A. (1996). Speed of information processing as a mediator between age and free recall performance. *Psychology and Aging*, 11, 3-9

Bryan, J. & Luszcz, M.A. (2000). Measurement of executive function: Considerations for detecting adult age differences. *Journal of Clinical and Experimental Neuropsychology*, 22(1), 40-55

Bryan, J., Luszcz, M.A. & Crawford, J.R. (1997). Verbal knowledge and speed of information processing as mediators of age differences in verbal fluency performance among older adults. *Psychology and Aging*, 12(3), 473-478

Burgess, P.W. (1997). Theory and methodology in executive function research. In P. Rabbitt (Ed.). *Methodology of Frontal and Executive Function*, pp. 81-116 Hove: Psychology Press

Burgess, P.W. & Shallice, T. (1996). Response suppression, initiation and strategy use following frontal lobe lesions. *Neuropsychologia*, 34(4), 263-273

Carlson, M., Hasher, L., Zacks, R.T. & Connelly, S.L. (1995). Aging, distraction, and the benefits of predictable location. *Psychology and Aging*, 10, 427-436

Case, R.D., Kurland, D.M. & Goldberg, J. (1982). Operational efficiency and the growth of short-term memory span. *Journal of Experimental Child Psychology*, 33, 386-404

Cepeda, N.J., Kramer, A.F. & Gonzalez de Sather, J.C.M. (2001). Changes in executive control across the life span: Examination of task-switching performance. *Developmental Psychology*, 37(5), 715-730

Cerella, J. (1985). Information processing rates in the elderly. *Psychological Bulletin*, 98, 67-83

Cerella, J. (1990). Aging and information-processing rate. In J.E. Birren & K.W. Schaie (Eds.). *Handbook of the Psychology of Aging*, pp. 201-221. San Diego: Academic Press

Chen, J-Y. (2000). The effects of dual-task performance: A meta-analysis of studies between 1981 and 1997. *Brain and Cognition*, 44(1), 94-97

Cherry, K.E. & Park, D.C. (1993). Individual differences and contextual variables influence spatial memory in younger and older and older adults. *Psychology & Aging*, 8, 517-526

Christ, S.E., White, D.A., Mandernach, T. & Keys, B.A. (2001). Inhibitory control across the lifespan. *Developmental Neuropsychology*, 20(3). 653-669

Chuah, Y.M.L. & Maybery, M.T. (1999). Verbal and spatial short-term memory: Common sources of developmental change. *Journal of Experimental Child Psychology*, 73, 7-44

Chuah, Y.M.L. & Maybery, M.T. (2000). Verbal and spatial short-term memory: Two sources of developmental evidence consistent with common underlying processes. *International Journal of Psychology*, 35(5/6), 374-377

Coates, R., Hamilton, C. & Heffernan, T. (1997). Development of visuo-spatial working memory: The effects of interference tasks on passive and active visuo-spatial working memory components. *Spatial Cognition*, 113, 14-15

Cocchini, G., Logie, R.H., Della Sala, S., MacPherson, S.E. & Baddeley, A.D. (2002). Concurrent performance of two memory tasks: Evidence for domain-specific working memory systems. *Memory & Cognition*, 30(7), 1086-1095

Collette, F., Van der Linden, M. & Salmon, E. (1999). Executive dysfunction in Alzheimer's Disease. *Cortex*, 35, 57-72

Colom, R., Flores-Mendoza, C. & Rebollo, I. (2003). Working memory and intelligence. *Personality & Individual Differences*, 34(1), 33-39

Comalli, P.E., Wapner, S. & Werner, H. (1962). Interference effects of Stroop colour-word test in childhood, adulthood and aging. *Journal of the Genetic Psychology*, 15, 881-8795

Connelly, S.L. & Hasher, L. (1993). Aging and the inhibition of spatial location. *Journal of Experimental Psychology: Human Perception and Performance*, 19(6), 1238-1250

Connelly, S.L., Hasher, L. & Zacks, R.T. (1991). Age and reading: The impact of distraction. *Psychology and Aging*, 6, 533-541

Conway, A.R.A. & Engle, R.W. (1994). Working memory and retrieval: A resource-dependent inhibition model. *Journal of Experimental Psychology: General*, 123(4), 354-373

Cornoldi, C. & Vecchi, T. (2000). Mental imagery in blind people: The role of passive and active visuo-spatial processes. In M. Heller (Ed.). *Touch, Representation and Blindness*, pp143-181. Oxford: Oxford University Press

Corsi, P.M. (1972). Human memory and the medial temporal region of the brain. *Dissertation Abstracts International*, 34(2), 891B(University Microfilms N. AAI05-77717)

Cowan, N. (1988). Evolving conceptions of memory storage, selective attention and their mutual constraints within the human information-processing system. *Psychological Review*, 163-191

Craik, F.I.M. (2000). Age-related changes in human memory. In D, Park & N Schwarz (Eds.). *Cognitive Aging: A Primer*, pp. 75-92. Philadelphia, PA: Psychology Press

Craik, F.I.M. (1983). On the transfer of information from primary to secondary memory. *Philosophical Transactions of the Royal Society of London*, B302, 341-359

Craik, F.I.M. (1986). A functional account of age differences in memory. In F. Klix & H. Hagendorf (Eds.). *Human Memory and Cognitive Capabilities, Mechanisms and Performances*, pp. 409-422. North Holland: Elsevier

Craik, F.I.M. & Byrd, M. (1982). Aging and cognitive deficits: The role of attentional resources. In F.I.M. Craik & S.Trehub (Eds.). *Aging and Cognitive Processes*, pp. 191-211. New York: Plenum

Craik, F.I.M. & Jennings, J.M. (1992). Human Memory. In F.I.M. Craik & T.A. Salthouse (Eds.). *The Handbook of Aging and Cognition*, pp. 51-110. Hillsdale, NJ: Earlbaum

Craik, F.I.M. & McDowd, J.M. (1987). Age differences in recall and recognition. *Journal of Experimental Psychology; Learning, Memory and Cognition*, 13, 474-479

Craik, F.I.M., Morris, R.G. & Gick, M.L. (1990). Adult age differences in working memory. In G. Vallar & T. Shallice (Eds.). *Neuropsychological Impairments in Short–term Memory*, pp. 247-267. New York: Cambridge University Press

Craik, F.I.M. & Rabinowitz, J.C. (1985). The effects of presentation rate and encoding task on age-related memory deficits. *Journal of Gerontology*, 40, 309-315

Craik, F.I.M. & Watkins, M.J. (1973). The role of rehearsal in short-term memory. *Journal of Verbal Learning and Verbal Behavior*, 12, 599-607

Crawford, J.R., Parker, D.M., Stewart, L.E., Besson, J.A.O. & De Lacey, G. (1989). Prediction of WAIS IQ with the National Adult Reading Test: cross validation and extension. *British Journal of Clinical Psychology*, 28, 267-273

Daigneault, S., Braun, C.M.J. & Whitaker, H.A. (1992). Early effects of normal aging on perseverative and non-perseverative prefrontal measures. *Developmental Neuropsychology*, 8(1), 99-114

Daneman, M. & Carpenter, P.A. (1980). Individual differences in working memory and reading. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 9, 561-583

Della Sala, S., Baddeley, A.D., Papagno, C. & Spinnler, H. (1995). Dual task paradigm: A means to examine the central executive. In J Grafman, K.J. Holyoak & F. Boller (Eds.). *Structure and functions of the human prefrontal cortex: Special issue of Annals of the New York Academy of Sciences*, 769, 161-172

Della Sala, S., Gray, C., Baddeley, A.D., Allamano, N. & Wilson, L. (1999). Pattern span: a tool for unwelding visuo-spatial memory. *Neuropsychologia*, 37, 1189-1199

Della Sala, S., Gray, C., Spinnler, H. & Trivelli, C. (1998). Frontal lobe functioning in man: The riddle revisited. *Archives of Clinical Neuropsychology*, 13(8), 663-682

Demakis, G.J. & Harrison, D.W. (1997). Relationships between verbal and nonverbal fluency measures: Implications for assessment of executive functioning. *Psychological Reports*, 81, 443-448

Dempster, F.N. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental Review*, 12, 45-75

Denckla, M. (1994). Measurement of executive function. In G. Reid Lyon (Ed.). *Frames of Reference for the Assessment of Learning Disabilities. New Views on Measurement Issues*, pp. 117-142. Baltimore, MD: Paul H. Brookes

Dobbs, A.R. & Rule, B.G. (1989). Adult age differences in working memory. *Psychology and Aging*, 4, 500-503

Dolman, R., Roy, E.A., Dimeck, P.T. & Hall, C.R. (2000). Age, gesture span and dissociations among component subsystems of working memory. *Brain and Cognition*, 43(1-3), 164-168

Duff, S.C. & Logie, R.H. (1999). Storage and processing in visuo-spatial working memory. *Scandinavian Journal of Psychology*, 40, 251-259

Duff, S.C. & Logie, R.H. (2001). Processing and storage in working memory. *The Quarterly Journal of Experimental Psychology*, 54A(1), 31-48

Duncan, J. (1986). Disorganisation of Behaviour after frontal lobe damage. *Cognitive Neuropsychology*, 3, 271-290

Duncan, J. (1995). Attention, intelligence and the frontal lobes. In M.S. Gazzaniga (Ed.). *The Cognitive Neurosciences*, pp. 721-731. Cambridge, MA: MIT Press

Duncan, J., Johnson, R., Swales, M. & Freer, C. (1997). Frontal lobe deficits after head injury: Unity and diversity of function. *Cognitive Neuropsychology*, 14(5), 713-741

Earles, J.L., Connor, L.T., Frieske, D., Park, D.C., Smith, A.D. & Zwahr, M. (1997). Age differences in inhibition: Possible causes and consequences. *Aging, Neuropsychology, and Cognition*, 4, 45-57

Emerson, M.J., Miyake, A. & Rettinger, D.A. (1999). Individual differences in integrating and coordinating multiple sources of information. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 25(5), 1300-1321

Engle, R.W. (1996). Working memory and retrieval: An inhibition-resource approach. In In J.T.E. Richardson, R.W. Engle, L.Hasher, R.H. Logie, E.R. Stoltzfus, R.T. Zacks (Eds.). *Working Memory and Human Cognition*, pp. 89-119. New York: Oxford University Press

Engle, R.W., Cantor, J. & Carullo, J.J. (1992). Individual differences in working memory and comprehension: A test of four hypotheses. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 18, 972-992

Engle, R.W., Kane, M.J. & Tuholski, S.W. (1999a). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence and functions of the prefrontal cortex. In A. Miyake & P. Shah (Eds.). *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control*, pp. 102-134. Cambridge: Cambridge University Press

Engle, R.W., Tuholski, S.W., Laughlin, J.E. & Conway, A.R.A. (1999b). Working memory, short-term memory and general fluid intelligence: A latent variable approach. *Journal of Experimental Psychology: General*, 128(3), 309-331

Evans, F.J. (1978). Monitoring attention deployment by random number generation: an index to measure subjective randomness. *Bulletin of the Psychonomic Society*, 12, 35-38

Farah, M.J., Hammond, K.M., Levine, D.N. & Calvanio, R. (1988). Visual and spatial mental imagery: Dissociable systems of representation. *Cognitive Psychology*, 20, 439-462

Farmer, E.W., Berman, J.V.F. & Fletcher, Y.L. (1986). Evidence for a visuo-spatial scratch-pad in working memory. *Quarterly Journal of Experimental Psychology*, 38A, 675-688

Farrand, P. & Jones, D. (1996). Direction of report in spatial and verbal serial short-term memory. *Quarterly Journal of Experimental Psychology A*, 49A(1), 140-158

Finkel, D. & Pederson, N.L. (2000). Contribution of age, genes, and environment to the relationship between perceptual speed and cognitive ability. *Psychology and Aging*, 15(1), 56-64

Fisk, J.E. & Warr, P. (1996). Age and working memory: the role of perceptual speed, the central executive, and the phonological loop. *Psychology and Aging*, 11, 316-323

Folstein, M.F., Folstein, S.E., McHugh, P.R. (1975). Mini mental state: A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, 12, 189-198

Foos, P.W. (1989). Adult age differences in working memory. *Psychology and Aging*, 4, 269-275

Foos, P.W. (1995). Working memory resource allocation by young, middle-aged, and old adults. *Experimental Aging Research*, 21, 239-250

Foos, P.W. & Wright, L. (1992). Adult age differences in the storage of information in working memory. *Experimental Aging Research*, 18, 51-57

Foster, J.K., Black, S.E., Buck, B.H. & Bronskill, M.J. (1997). Ageing and executive functions: A neuroimaging perspective. In P.M.A. Rabbitt. *Methodology of frontal and executive function*, pp. 117-134. Hove: Psychology Press

Galbraith, K.M. (2004). Memory and executive functioning in young women reporting mood symptoms. *Dissertation Abstract International: Section B: The Sciences amd Engineering*, 65(1-B), 435

Gick, M.L., Craik, F.I.M. & Morris, R.G. (1988). Task complexity and age differences in working memory. *Memory and Cognition*, 16(4), 353-361

Ginsburg, N. & Karpiuk, P. (1994). Random generation: Analysis of the Responses. *Perceptual and Motor Skills*, 79, 1059-1067

Gladsjo, J.A., Schuman, C.C., Evans, J.D., Peavy, G.M., Miller, S.W. & Heaton, R.K. (1999). Norms for letter and category fluency: Demographic corrections for age, education and ethnicity. *Assessment*, 6(2), 147-178

Glanzer, M. & Cunitz, A.R. (1966). Two storage mechanisms in free recall. *Journal of Verbal Learning and Verbal Behavior*, 5, 351-360

Goldman-Rakic, P.S. & Brown, R.M. (1981). Regional changes of monoamines in cerebral cortex and subcortical structures of aging rhesus monkeys. *Neuroscience*, 6, 177-187

Grant, J.D. & Dagenbach, D. (2000). Further considerations regarding inhibitory processes, working memory, and cognitive aging. *American Journal of Psychology*, 113(1), 66-94

Greene, J.D.W., Hodges, J.R. & Baddeley, A.D. (1995). Autobiographical memory and executive function in early dementia of Alzheimer type. *Neuropsychologia*,33, 1647-1670

Greenwood, P.M. (2000). The frontal aging hypothesis evaluated. *Journal of the International Neuropsychological Society*, 6, 705-726

Grossi, D., Becker, J.T., Smith, C. & Trojano, L. (1993). Memory for visuospatial patterns in Alzheimer's disease. *Psychological Medicine*, 23, 65-70

Guttentag, R.E. (1989). Age differences in dual-task performance: Procedure, Assumptions and Results. *Developmental Review*, 9, 146-170

Guttmann, G. (1967). Die empirische erprobung von methoden zur überprüfung der ergodizität von ereignisfolgen. Cited in Brugger, P., Monsch, A.U., Salmon, D.P. & Butters, N. (1996). Random number generation in dementia of the Alzheimer type: A test of frontal executive functions. *Neuropsychologia*, 34(2), 97-103

Hamilton, C.J., Coates, R.O. & Heffernan, T. (2003). What develops in visuo-spatial working memory development? *European Journal of Cognitive Psychology*, 15(1), 43-69

Hamm, V.P. & Hasher, L. (1992). Age and the availability of inferences. *Psychology and Aging*, 7(1), 56-64

Hanley, J.R., Pearson, N.A. & Young, A.W. (1990). Impaired memory for new visual forms. *Brain*, 113, 1131-1148

Hartley, A.A., Kieley, J.M. & Slabach, E.H. (1990). Age differences and similarities in the effects of cues and prompts. *Journal of Experimental Psychology: Human Perception and Performance*, 16, 523-538

Hartman, M. & Hasher, L. (1991). Aging and suppression: Memory for previously relevant information. *Psychology and Aging*, 6, 587-594

Hasher, L., Quig, M.B. & May, C.P. (1997). Inhibitory control over no-longer-relevant information: Adult age differences. *Memory & Cognition*, 25(3), 286-295

Hasher, L., Stoltzfus, E.R., Zacks, R.T. & Rypma, B. (1991). Age and inhibition. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 17(1), 163-169

Hasher, L., Tonev, S.T., Lustig, C. & Zacks, R.T. (2001). Inhibitory control, environmental support, and self-initiated processing in aging. In M. Naveh-Benjamin, M. Moscovitch & H.L. Roediger (Eds.). *Perspectives on Human Memory and Cognitive Aging: Essays in honour of Fergus Craik*, pp.286-297. New York: Psychology Press

Hasher, L. & Zacks, R.T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation, Vol. 22*, pp.193-225. San Diego, CA: Academic Press

Hasher, L., Zacks, R.T. & May, C.P. (1999). Inhibitory control, circadian arousal and age. In D.Gopher & A Koriat (Eds.). *Attention and Performance XVII: Cognitive regulation of performance: Interaction of theory and application*, pp. 653-675. Cambridge, MA: MIT Press

Haug, H. & Eggers, R. (1991). Morphometry of the human cortex cerebri and corpus striatum during aging. *Neurobiology of Aging*, 12, 336-338

Hecker, R. & Mapperson, B. (1997). Dissociation of visual and spatial processing in working memory. *Neuropsychologia*, 35(5), 599-603

Heffernan, T., Ling, J. & Bartholomew, J. (2004). Self-rated prospective memory and central executive deficits in excessive alcohol users. *Irish Journal of Psychological Medicine*, 21(4), 122-124

Hertzog, C. (1989). The influence of cognitive slowing on age differences in intelligence. *Developmental Psychology, 25, 636-651*

Hess, T.M. & Blanchard-Fields, F. (1996). Introduction to the study of cognitive change in adulthood. In F. Blanchard-Fields & T.M. Hess (Eds.). Perspectives *on Cognitive Change in Adulthood and Aging*, pp. 3-24

Horn, J.L. (1982). The theory of fluid and crystallized intelligence in relation to concepts of cognitive psychology and aging in adulthood. In F.I.M. Craik & S. Trehub (Eds.). *Aging and Cognitive Processes*, pp. 237-278. New York: Plenum

Houx, P.J., Jolles, J. & Vreeling, F.W. (1993). Stroop interference: Aging effects assessed with the Stroop color-word test. *Experimental Aging Research*, 19, 209-224

Hughes, D.L. & Bryan, J. (2002). Adult age differences in strategy use during verbal fluency performance. *Journal of Clinical and Experimental Neuropsychology*, 24(5), 642-654

Humphrey, D.G. & Kramer, A. (1999). Age-related differences in perceptual organization and selective attention: Implications for display segmentation and recall performance. *Experimental Aging Research*, 25, 1-26

Jersild, A. (1927). Mental Sret and Shift. Cited in Rubinstein, J.S., Meyer, D.E. & Evans, J.E. (2001). Executive Control of Cognitive Processes in Task Switching. *Journal of Experimental Psychology: Human Perception and Performance*, 27(4), 763-797

Jones, D.M. (1994). Objects, streams and threads of auditory attention. In A.D. Baddeley & L. Weiskrantz (Eds.). *Attention, Selection, Awareness and Control*, pp87-104. Oxford: Clarendon Press

Jones, D., Farrand, P., Stuart, G. & Morris, N. (1995). Functional equivalence of verbal and spatial information in serial short-term memory. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 21(4), 1008-1018

Jones-Gotman, M. & Milner, B. (1977). Design fluency: The invention of nonsense drawings after focal cortical lesions. *Neuropsychologia*, 15, 653-674

Jovanovski, D., Erb, S. & Zakzanis, K.K. (2005). Neurocognitive deficits in cocaine users: A quantitative review of the evidence. *Journal of Clinical and Experimental Neuropsychology*, 27(2), 189-204

Just, M.A. & Carpenter, P.A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review*, 99, 122-149

Kane, M.J., Hasher, L., Stoltzfus, E.R., Zacks, R.T. & Connelly, S.L. (1994). Inhibitory attentional mechanisms and aging. *Psychology and Aging*, 9, 103-112

Kane, M.J., May, C.P., Hasher, L., Rahhal, T. & Stoltzfus, E.R. (1997). Dual mechanisms of negative priming. *Journal of Experimental Psychology: Human Perception and Performance*, 23, 632-650

Kausler, D.H. (1994). *Learning and Memory in Normal Aging.* New York: Academic Press

Kendal, M.G. (1976). *Time-Series*. (2nd ed.). London: Griffin

Kensinger, E.A., Shearer, D.K., Locascio, J.J., Growden, J.H. & Corkin, S. (2003). Working memory in mild Alzheimer's disease and early Parkinson's disease. *Neuropsychology*, 17(2), 230-239

Keys, B.A. & White, D.A. (2000). Exploring the relationship between age, executive abilities and psychomotor speed. *Journal of the International Neuropsychological Society*, 6, 76-82

Klauer, K.C. & Stegmeier, R. (1997). Interference in immediate spatial memory: shifts of spatial attention or central-executive involvement? *Quarterly Journal of Experimental Psychology*, 50A(1), 79-99

Klauer, K.C. & Zhao, Z. (2004). Double dissociations in visual and spatial short-term memory. *Journal of Experimental Psychology: General*, 133(3), 355-381

Kozora, E. & Cullum, C.M. (1995). Generative naming in normal aging: Total output and qualitative changes using phonemic and semantic constraints. *The Clinical Neuropsychologist*, 9, 313-325

Kramer, A.F., Hahn, S. & Gopher, D. (1999). Task coordination and aging: Explorations of executive control processes in the task switching paradigm. *Acta Psychologica*, 101, 339-378

Kramer, A.F., Humphrey, D.G., Larish, J.F., Logan, G.D. & Stayer, D.L. (1994). Aging and inhibition: Beyond a unitary view of inhibitory processing in attention. *Psychology and Aging*, 9(4), 491-512

Kray, J. & Lindenberger, U. (2000). Adult age differences in task switching. *Psychology and aging*, 15(1), 126-147

Kyllonen, P.C. (1996). Is working memory capacity Spearman's g? In I. Dennis 7 P. Tapsfield (Eds.). *Human Abilities: Their Nature and Measurement*, pp. 49-75. xv,189pp

Kyllonen, P.C. & Christal, R.C. (1990). Reasoning ability is (little more than) working memory capacity? *Intelligence*, 14, 389-433

Kynette, D., Kemper, S., Norman, S. & Cheung, H. (1990). Adults word recall and word repetition. *Experimental Aging Research*, 16, 117-121

Lehto, J. (1996). Are Executive function tests dependent on working memory capacity? *The Quarterly Journal of Experimental Psychology*, 49A(1), 29-50

Lezak, M. D. (1995). *Neuropsychological Assessment*. (3rd edition). New York: Oxford University Press

Libon, D.J., Glosser, G., Malamut, B.L., Kaplan, E., Goldberg, E., Swenson, R. & Sands, L.P. (1994). Age, executive functions and visuospatial functioning in healthy older adults. *Neuropsychology*, 8(1), 38-43

Light, L. L. & Anderson, P. A. (1985). Working-memory capacity, age, and memory for discourse. *Journal of Gerontology*, 40(6), 737-747.

Light, L.L. & Zelinski, E.M. (1983). Memory for spatial information in young and old adults. *Developmental Psychology*, 19, 901-906

Lindenberger, U., Mayr, U. & Kliegl, R. (1993). Speed and intelligence in old age. *Psychology and Aging*, 8, 207-220

Lipman, P.D. & Caplan, L.J. (1992). Adult age differences in memory for routes: Effects of instruction and spatial diagram. *Psychology and Aging*, 7(3), 435-442

Logan, G.D. & Bundesen, C. (2003). Clever homunculus: Is there an endogenous act of control in the explicit task-cuing procedure? *Journal of Experimental Psychology: Human Perception and Performance*, 29(3), 575-599

Logie, R.H. (1986). Visuo-spatial processing in working memory. *Quarterly Journal of Experimental Psychology*, 38A, 229-247

Logie, R.H. (1989). Characteristics of visual short-term memory. *European Journal of Cognitive Psychology*, 1, 275-284

Logie, R.H. (1995). *Visuo-spatial working memory.* Hove: Lawrence Erlbaum Associates Ltd

Logie, R.H. & Marchetti, C. (1991). Visuo-spatial working memory: Visual, spatial or central executive? In R.H. Logie & M. Denis, (Eds.). *Mental Images in Human Cognition*, pp. 105-115. Amsterdam: North Holland Press

Logie, R.H. & Pearson, D.G. (1997). The inner eye and the inner scribe of visuo-spatial working memory: evidence from developmental fractionation. *European Journal of Cognitive Psychology*, 9(3), 241-257

Logie, R.H. & Salway, A.F.S. (1990). Working memory and modes of thinking: A secondary task approach. In K.J. Gilhooly, M.T.G. Keane, R.H. Logie & G. Erdos. *Lines of Thinking: Reflections on the Psychology of Thought (volume 2).* Chichester: Wiley & Sons

Logie, R.H., Zucco, G.M. & Baddeley, A.D. (1990). Interference with visual short-term memory. *Acta Psychologica*, 75, 55-74

Lowe, C. & Rabbitt, P. (1997). Cognitive models of ageing and frontal lobe deficits. In P.M.A. Rabbitt. *Methodology of frontal and executive function*, pp. 39-60. Hove: Psychology Press

Luria, A.R. (1969). Frontal lobe syndromes. Cited in Baddeley, A.D. (1986). *Working Memory.* Oxford: Oxford University Press

Luria, A.R. (1980). *Higher Cortical Functions in Man.* New York: Basic Books

Lustig, C., Hasher, L. & May, C.P. (2001). Working memory span and the role of proactive interference. *Journal of Experimental Psychology: General*, 130, 149-207

Madden, D.J. (1984). Data-driven and memory-driven selective attention in visual search. *Journal of Gerontology*, 39, 72-78

Madden, D.J. (1989). Visual word identification and age-related slowing. *Cognitive Development*, 4, 1-29

Martin, A., Wiggs, C.L., Lalonde, F. & Mack, C. (1994). Word retrieval to letter and semantic cues: A double dissociation in normal subjects using interference tasks. *Neuropsychologia*, 32(12), 1487-1494

May, C.P., Hasher, L. & Kane, M.J. (1999). The role of interference in memory span. *Memory and Cognition*, 27, 759-767

Maylor, E.A. & Wing, A.M. (1996). Age differences in postural stability are increased by additional cognitive demands. *Journal of Gerontology: Psychological Sciences*, 51B(3), 143-154

Mayr, U. (2001). Age differences in the selection of mental sets: The role of inhibition, stimulus ambiguity and response-set overlap. *Psychology and Aging*, 16(1), 96-109

Mayr, U. & Keele, S.W. (2000). Changing Internal Constraints on Action: The Role of Backward Inhibition. *Journal of Experimental Psychology: General*, 129(1), 4-26

Mayr, U. & Kliegl, R. (2000). Task-set switching and long-term memory retrieval. *Journal of Experimental Psychology: General*, 26(5), 1124-1140

Mayr, U. & Liebscher, T. (2001). Is there an age deficit in the selection of mental sets? *European Journal of Cognitive Psychology*, 13(1/2), 47-69

McConnell, J. & Quinn, J.G. (1996). Interference at the encoding and maintenance of visual information. *Psychologische Beiträge*, 38, 343-354

McCrae, R.R., Arenberg, D. & Costa, P.T. (1987). Declines in divergent thinking with age: Cross-sectional, longitudinal and cross-sequential analyses. *Psychology and Aging*, 2, 130-137

McDowd, J.M. (2001). Levels of processing in selective attention and inhibition: Age differences and similarities. In M. Naveh-Benjamin, M. Moscovitch & H.L. Roediger (Eds.). *Perspectives on Human Memory and Cognitive Aging: Essays in honour of Fergus Craik*, pp.135-147. New York: Psychology Press

McDowd, J.M. & Craik, F.I.M. (1988). Effects of aging and task difficulty on divided attention performance. *Journal of Experimental Psychology: Human Perception and Performance*, 14, 267-280

McDowd, J.M. & Filion, D.L. (1995). Aging and negative priming in a location suppression task: The long and short of it. *Psychology and Aging*, 10, 34-47

McDowd, J.M. & Oseas-Kreger, D.M. (1991). Aging, inhibitory processes, and negative priming. *Journal of Gerontology: Psychological Sciences*, 46, 340-345

McDowd, J.M. & Shaw, R.J. (2000). Attention and aging: A functional perspective. In F.I.M. Craik & T.A. Salthouse (Eds.). *Handbook of Aging and Cognition*, pp. 221-292. Mahwah, NJ: Lawrence Earlbaum Associates

Meiran, N. (1996). Reconfiguration of processing mode prior to task performance. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 22(6), 1423-1442

Meiran, N. (2000). Modeling cognitive control in task-switching. *Psychological Research*, 63, 234-249

Meiran, N., Chorev, Z. & Sapir, A. (2000). Component processes in task switching. *Cognitive Psychology*, 41, 211-253

Meiran, N., Gotler, A. & Perlman, A. (2001). Old age is associated with a pattern of relatively intact and relatively impaired task-set switching abilities. *Journal f Gerontology: Psychological Sciences*, 56B(2), 88-102

Mittenberg, W., Seidenberg, M., O'Leary, D.S. & DiGiulio, D.V. (1989). Changes in cerebral functioning associated with normal aging. *Journal of Clinical and Experimental Neuropsychology*, 11, 918-932

Miyake, A., Friedman, N.P., Emerson, M.J., Witzki, A.H., Howerter, A. & Wager, T.D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, 41, 49-100

Miyake, A. & Shah, P. (1999). Toward Unified Theories of Working Memory. In A. Miyake & P. Shah (Eds.). *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control*, pp. 442-481. Cambridge: Cambridge University Press

Monsch, A.U., Bondi, M.W., Butters, N., Paulsen, J.S., Salmon, D.P., Brugger, P. & Swenson, M.R. (1994). A comparison of category and letter fluency inAlzheimer's disease and Huntington's disease. *Neuropsychology*, 8(1), 25-30

Montgomery, C., Fisk, J.E., Newcombe, R. & Murphy, P.N. (2005). The differential effects of ecstasy/polydrug use on executive components: Shifting, inhibition, updating and acess to semantic memory. *Psychopharmacology*, 182(2), 262-276

Morris, N. (1987). Exploring the visuo-spatial scratch pad. *Quarterly Journal of Experimental Psychology*, 39A, 409-430

Morris, N. & Jones, D.M. (1990). Memory updating in working memory: the role of the central executive. *British Journal of Psychology*, 81, 111-121

Morris, R.G. (1986). Short-term forgetting in senile dementia of the Alzheimer's type. *Cognitive Neuropsychology*, 3, 77-97

Morris, R.G., Gick, M.L. & Craik, F.I.M. (1988). Processing resources and age differences in working memory. *Memory and Cognition*, 16(4), 362-366

Moscovitch, M. (1995). Models of consciousness and memory. In M.S. Gazzaniga (Ed.). *The Cognitive Neurosciences*, pp. 1341-1356. Cambridge, MA: MIT Press

Neill, W.T. & Valdes, L.A. (1992). The persistence of negative priming: Steady state or decay. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 18, 565-576

Neill, W.T. & Valdes, L.A. (1996). Facilitatory and inhibitory aspects of attention. In A.F. Kramer, M.G.H. Coles 7 G.D. Logan (Eds.). *Converging Operations in the Study of Selective Attention*, pp. 77-106. Washington, DC: American Psychological Association

Nelson, H.E. & Willison, J. (1991). *National Adult Reading Test (NART) 2ND edition Test Manual: includes new data supplement.* Windsor: NFER-NELSON

Norman , D.A. & Shallice, T. (1980). Attention to action. Willed and automatic control of behaviour. Cited in Baddeley, A. (1986). *Working Memory.* Oxford: Clarendon Press

Oberauer, K. & Kliegl, R. (2001). Beyond resources: Formal models of complexity effects and age differences in working memory. In U. Mayr, D.H. Spieler, R. Kliegl (Eds.). *A Special Issue of the European Journal of Cognitive Psychology: Ageing and executive control*, pp187-215. Hove: Psychology Press

O'Connor, D.W., Pollitt, P.A., Hyde, J.B., Fellows, J.L., Miller, N.D., Brook, C.P. & Reiss, B.B. (1989). The reliability and validity of the Mini-Mental State in a British community survey. *Journal of Psychiatric Research*, 23(1), 87-96

Okura, M. & Ikuta, T. (1987). Optimal tempo for the random number generation test. Cited in Brugger, P. (1997). Variables that influence the generation of random sequences: An update. *Perceptual and Motor Skills*, 84, 627-661

Park, D.C. & Heddon, T. (2001). Working memory and Aging. In M. Naveh-Benjamin, M. Moscovitch & H.L. Roediger, III (Eds.), *Perspectives on Human Memory and Cognitive Aging: Essays in honour of Fergus Craik.* pp. 148-167. New York: Psychology Press

Park, D.C., Puglisi, J.T. & Lutz, R. (1982). Spatial memory in older adults: Effects ofr intentionality. *Journal of Gerontology*, 37(3), 330-335

Park, D.C., Puglisi, J.T. & Smith, A.D. (1986). Memory for pictures: Does an age-related decline exist? *Psychology and Aging*, 1, 11-17

Park, D.C., Smith, A.D., Lautenschlager, G., Earles, J., Frieske, D., Zwahr, M. & Gaines, C. (1996). Mediators of long-term memory performance across the lifespan. *Psychology and Aging*, 11, 621-637

Parkin, A.J. & Walter, B.M. (1992). Recollective experience, normal aging and frontal dysfunction. *Psychology and Aging*, 7, 290-298

Parkin, A.J., Walter, B.M. & Hunkin, N.M. (1995). Relationships between normal aging, frontal lobe function, and memory for temporal and spatial information. *Neuropsychology*, 9(3), 304-312

Pearson, D.G., Logie, R.H. & Gilhooly, K. (1999). Verbal representations and spatial manipulation during mental synthesis. *European Journal of Cognitive Psychology*, 11(3), 295-314

Pearson, D.G., Logie, R.H. & Green, C. (1996). Mental manipulation, visual working memory and executive processes. *Psychologische Beiträge*, 38, 324-342

Phillips, L.H. (1997). Do "frontal" tests measure executive function?: Issues of assessment and evidence from fluency tests. In P.M.A. Rabbitt. *Methodology of frontal and executive function*, pp191-214. Hove: Psychology Press

Phillips, L.H. (1999). Age and individual differences in letter fluency. *Developmental Neuopsychology*, 15(2), 249-267

Phillips, L.H. & Della Sala, S. (1998). Aging, intelligence, amd anatomical segregation in the frontal lobes. *Learning and Individual Differences*, 10(3), 217-243

Phillips, L.H., Gilhooly, K.J., Logie, R.H., Della Sala, S. & Wynn, V.E. (2003). Age, working memory, and the Tower of London task. *European Journal of Cognitive Psychology*, 15(2), 291-312

Phillips, L.H. & Hamilton, C. (2001). The working memory model in adult aging research. In J. Andrade, (Ed.). *Working Memory in Perspective*, pp101-125. Hove: Psychology Press

Phillips, W.A. & Christie, D.F.M. (1977a). Components of visual memory. *The Quarterly Journal of Experimental Psychology*, 29, 117-133

Phillips, W.A. & Christie, D.F.M. (1977b). Interference with visualisation. *The Quarterly Journal of Experimental Psychology*, 29, 637-650

Pickering, S.J., Gathercole, S.E., Hall, M. & Lloyd, S.A. (2001). Development of memory for pattern and path: Further evidence for the fractionation of visuo-spatial memory. *The Quarterly Journal of Experimental Psychology*, 54A(2), 397-420

Pickering, S.J., Gathercole, S.E. & Peaker, S.M. (1998). Verbal and visuospatial short-term memory in children: Evidence for common and distinct mechanisms. *Memory and Cognition*, 1117-1130

Pollux, P.M., Wester, A. & De Haan, E.H. (1995). Random generation deficit in alcoholic Korsakoff patients. *Neuropsychologia*, 33, 125-129

Quinn, J.G. & McConnell, J. (1996a). Irrelevant pictures in visual working memory. *The Quarterly Journal of Experimental Psychology*, 49A (1), 200-215

Quinn, J.G. & McConnell, J. (1996b). Indications of the functional distinction between the components of visual working memory. *Psychologische Beiträge*, 38, 355-367

Quinn, J.G. & Ralston, G.E. (1986). Movement and attention in visual working memory. *The Quarterly Journal of Experimental Psychology*, 38A, 689-703

Rabbitt, P.M.A. (1997). *Methodology of frontal and executive function.* Hove: Psychology Press

Rabbitt, P., Lowe, C. & Shilling, V. (2001). Frontal tests and models of cognitive ageing. *European Journal of Cognitive Psychology*, 13(1/2), 5-28

Raz, N. (2000). Aging of the brain and its impact on cognitive performance: Integration of structural and functional findings. In F.I.M. Craik & T.A. Salthouse (Eds.). *The Handbook of Aging and Cognition*, 2nd edition, pp. 1-90. Mahwah, NJ: Erlbaum

Reason, J.T. (1979). Actions not as planned: The price of automatisation. Cited in Baddeley, A.D. (1986). *Working Memory.* Oxford: Oxford University Press

Reitan, R.M. & Wolfson, D. (1994). A selective and critical review of neuropsychological deficits and the frontal lobes. *Neuropsychology Review*, 4, 161-198

Rende, B., Ramsberger, G. & Miyake, A. (2002). Commonalities and differences in the working memory components underlying letter and category fluency tasks: A dual-task investigation. *Neuropsychology*, 16(3), 309-321

Richardson, J.T.E. (1996). In J.T.E. Richardson, R.W. Engle, L.Hasher, R.H. Logie, E.R. Stoltzfus, R.T. Zacks (Eds.). *Working Memory and Human Cognition*, pp. 3-30. New York: Oxford University Press

Riedell-Heller, S.G., Busse, A., Aurich, C, Matschinger, H. & Angermyer, M.C. (2001). Prevalence of dementia according to DSM-III-R and ICD-10: Results of the Leipzig Longitudinal Study of the Aged (LEILA 75+) Part 1. *British Journal Of Psychiatry*, 179(3), 250-254

Robert, P.H., Lafont, V., Medecin, I., Berthet, L., Thauby, S., Baudu, C. & Darcourt, G. (1998). Clustering and switching strategies in verbal fluency tasks: Comparison between schizophrenics and healthy adults. *Journal of the International Neuropsychological Society*

Robertson, C., Hazelwood, R. & Rawson, M.D. (1996). The effects of Parkinson's disease on the capacity to generate information randomly. *Neuropsychologia*, 34(11), 1069-1078

Robbins, T.W., James, M., Owen, A.M., Sahakian, B.J., McInnes, L. & Rabbitt, P.M. (1994). Cambridge Neuropsychological Test Automated Battery (CANTAB): a factor analytic study of a large sample of normal elderly volunteers. *Dementia*, 5, 266-281

Robbins, T.W., James, M., Owen, A.M., Sahakian, B.J., McInnes, L. & Rabbitt, P. (1997). In P.M.A. Rabbitt. *Methodology of frontal and executive function*, pp. 215-238. Hove: Psychology Press

Robbins, T.W., James, M., Owen, A.M., Sahakian, B.J., Lawrence, A.D., McInnes, L. & Rabbitt, P. (1998). A study of performance on tests from the CANTAB battery sensitive to frontal lobe dysfunction in a large sample of normal volunteers: implications for theories of executive functioning and cognitive aging. *Journal of the International Neuropsychological Society*, 4, 474-490

Rogers, R.D. & Monsell, S. (1995). Cost of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General*, 124(2), 207-231

Rosen, W.G. (1980). Verbal fluency in aging and dementia. *Journal of Clinical Neuropychology*, 2, 135-146

Rouleau, N. & Belleville, S. (1996). Irrelevant speech effect in aging: An assessment of inhibitory processes in working memory. *Journal of Gerontology: Psychological Sciences*, 51B(6), 356-363

Rubinstein, J.S., Meyer, D.E. & Evans, J.E. (2001). Executive Control of Cognitive Processes in Task Switching. *Journal of Experimental Psychology: Human Perception and Performance*, 27(4), 763-797

Ruff, R.M., Light, R.H. & Evans, R. (1987). The Ruff Figural Fluency Test: A normative study with adults. *Developmental Neuropsychology*, 3, 37-51

Salkind. N.J. (2000). *Statistics for people who (think they) hate statistics.* California: Sage

Salthouse, T.A. (1982). *Adult Cognition: An experimental psychology of Human Aging*. New York: Springer-Verlag

Salthouse, T.A. (1985). *A Theory of Cognitive Aging*. Amsterdam: North-Holland

Salthouse, T.A. (1988). The role of processing resources in cognitive aging. In M.L. Howe & C.J. Brainerd (Eds.). *Cognitive Development in Adulthood.* Pp. 185-239. New York: Springer-Verlag

Salthouse, T.A. (1990). Working memory as a processing resource in cognitive aging. *Developmental Review*, 10, 101-124

Salthouse, T.A. (1991a). Mediation of adult age differences in cognition by reductions in working memory and speed of processing. *Psychological Science*, 2, 179-183

Salthouse, T.A. (1991b). *Theoretical Perspectives on Cognitive Aging*. Hillsdale, NJ: Lawrence Earlbaum Associates

Salthouse, T.A. (1992a). Working memory mediation of adult age differences in integrative reasoning. *Memory & Cognition*, 20, 413-423

Salthouse, T.A. (1992b). Influence of processing speed on adult age differences in working memory. *Acta Psychologica*, 79, 155-170

Salthouse, T.A. (1993). Speed and knowledge as determinants of adults age differences in verbal tasks. *Journal of Gerontology: Psychological Sciences*, 48, 29-36

Salthouse, T.A. (1994). The aging of working memory. *Neuropsychology*, 8(4), 535-543

Salthouse, T.A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review*, 103, 403-428

Salthouse, T.A. & Babcock, R.L. (1991). Decomposing adult age differences in working memory. *Developmental Psychology*, 27, 763-776

Salthouse, T.A., Babcock, R.L. & Shaw, R.J. (1991). Effects of adult age on structural and operational capacities in working memory. *Psychology and Aging*, 6(1), 118-127

Salthouse, T.A. & Ferrer-Caja, E. (2003). What needs to be explained to account for age-related effects on multiple cognitive abilities. *Psychology and Aging*, 18,(1), 91-110

Salthouse, T.A., Fristoe, N., McGuthry, K.E. & Hambrick, D.Z. (1998). Relation of task switching to speed, age, and fluid intelligence. *Psychology and Aging*, 13(3), 445-461

Salthouse, T.A., Fristoe, N. & Rhee, S.H. (1996). How localised are age-related effects on neuropsychological measures. *Neuropsychology*, 10, 272-285

Salthouse, T.A., Kausler, D.H. & Saults, J.S. (1988). Investigation of student status, background variables and the feasibility of standard tasks in cognitive aging research. *Psychology and Aging*, 3, 29-37

Salthouse, T.A. & Meinz, E.J. (1995). Aging, inhibition, working memory and speed. *Journal of Gerontology: Psychological Sciences*, 50B(6). 297-306

Salthouse, T.A. & Mitchell, D.R.D. (1990). Effects of age and naturally occurring experience on spatial visualization performance. *Developmental Psychology*, 26(5), 845-854

Salthouse, T.A., Mitchell, D.R.D., Skovronek, E. & Babcock, R.L. (1989). Effects of adult age and working memory on reasoning and spatial abilities. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 15(3), 507-516

Salthouse, T.A., Rogan, J.D. & Prill, K.A. (1984). Division of attention; Age differences on a visually presented memory task. *Memory & Cognition*, 12, 613-620

Salway, A.F.S. & Logie, R.H. (1995). Visuospatial working memory, movement control and executive demands. *British Journal of Psychology*, 86, 253-269

Schaie, K.W. (1989). Perceptual speed in adulthood: Cross-sectional and longitudinal studies. *Psychology and Aging*, 4, 443-453

Schooler, C., Neumann, E., Caplin, L.J. & Roberts, B.R. (1997). Continued inhibitory capacity throughout adulthood: Conceptual negative priming in younger and older adults. *Psychology and Aging*, 12, 667-674

Schretlan, D., Pearlson, G.D., Anthony, J.C., Aylward, E.H., Augustine, A.M., Davis, A. & Barta, P. (2000). Elucidating the contributions of processing speed, executive ability, and frontal lobe volume to normal age-related differences in fluid intelligence. *Journal of the International Neuropsychological Society*, 6(1), 56-61

Shah, P. & Miyake, A. (1996). Models of working memory: An introduction. In A. Miyake & P. S hah (Eds.). *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control*, pp1-27. Cambridge: Cambridge University Press

Shah, P. & Miyake, A. (1999). Models of Working Memory: An introduction. In A. Miyake & P. Shah (Eds.). *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control*, pp. 1-27. Cambridge: Camridge University Press

Shallice, T. (1982). Specific impairments of planning. *Philosophical Transaction of the Royal Society London, B*, 298, 199-209

Shallice, T. (1988). *From Neuropsychology to Mental Structure*. Cambridge: Cambridge University Press

Shallice, T. & Warrington, E.K. (1970). Independent functioning of verbal memory stores: A neuropsychological study. *Quarterly Journal of Experimental Psychology*, 22, 261-273

Sherman, A.M. & Massman, P.J. (1999). Prevalence and correlates of category versus letter fluency discrepancies in Alzheimer's disease. *Archives of Clinical Neuropsychology*, 14(5), 411-418

Shilling, V.M., Chetwynd, A. & Rabbitt, P.M.A. (2002). Individual inconsistency across measures of inhibition: An investigation of the construct validity of inhibition in older adults. *Neuropsychologia*, 40, 605-619

Shimamura, A.P. & Jurica, P.J. (1994). Memory interference effects and aging: Findings from a test of frontal lobe function. *Neuropsychology*, 8, 408-412

Skinner, B.F. (1942). The processes involved in the repeated guessing of alternatives. *Journal of Experimental Psychology*, 30, 495-503

Smyth, M.M. (1996). Interference with rehearsal in spatial working memory in the absence of eye movements. *Quarterly Journal of Experimental Psychology A*, 49A(4), 940-949

Smyth, M.M. & Pelky, P.L. (1992). Short-term retention of spatial information. *British Journal of Psychology*, 83, 359-374

Smyth, M.M. & Scholey, K.A. (1994). Interference in immediate spatial memory. *Memory & Cognition*, 22(1), 1-13

Smyth, M.M. & Scholey, K. (1996). Serial order in spatial immediate memory. *Quarterly Journal of Experimental Psychology*, 49A, 159-177

Spatt, J. & Goldenberg, G. (1993). Components of random generation by normal subjects and patients with dysexecutive syndrome. *Brain and Cognition*, 23, 231-242

Spector, A. & Biederman, I. (1976). Mental set and mental shift revisited. *American Journal of Psychology*, 89, 669-679

Spreen, O. & Benton, A.L. (1969). *Neurosensory Centre Comprehensive Examination for Aphasia*. Victoria, Canada: Neuropsychology Laboratory, University of Victoria

Stankov, L. (1999). Capacity versus speed in intelligence and aging. *Australian Psychologist*, 34(2), 138-143

Stine, E. & Wingfield, A. (1990). How much do working memory deficits contribute to age differences in discourse memory? *European Journal of Cognitive Psychology*, 2, 289-304

Stoltzfus, E.R., Hasher, L. & Zacks, R.T. (1996). Working memory and aging: Current status of the inhibitory view. In J.T.E. Richardson, R.W. Engle, L.Hasher, R.H. Logie, E.R. Stoltzfus, R.T. Zacks (Eds.). *Working Memory and Human Cognition*, pp. 66-88. New York: Oxford University Press

Stuss, D.T. & Benson, D.F. (1986). *The Frontal Lobes*. New York: Raven Press

Thompson, J.M., Hamilton, C.J., Gray, J.M., Quinn, J.G., Mackin, P., Ferrier, I.N. & Young, A.H. (in press). Executive and visuospatial sketchpad resources in euthymic bipoloar disorder: Implications for visuospatial working memory architecture. *Memory*.

Tipper, S.P. (1991). Less attentional selectivity as a result of declining inhibition in older adults. *Bulletin of the Psychonomic Society*, 29, 45-47

Tombaugh, T.N., Kozak, J. & Rees, L. (1999). Normative data stratified by age and education for two measures of verbal fluency: FAS and animal naming. *Archives of Clinical Neuropsychology* , 14(2), 167-177

Tomer, R. & Levin, B.E. (1993). Differential effects of aging on two verbal fluency tasks. *Perceptual and motor skills*, 76, 465-466

Towse, J.N. (1998). On random generation and the central executive of working memory. *British Journal of Psychology*, 89, 77-101

Towse, J.N. & Hitch, G.J. (1995). Is there a relationship between task demand and storage space in tests of working memory capacity. *The Quarterly Journal of Experimental Psychology*, 48A(1), 108-124

Towse, J.N., Hitch, G.J. & Hutton, U. (1998). A re-evaluation of working memory capacity in children. *Journal of Memory and Language*, 39, 195-217

Towse, J.N. & Neil, D. (1998). Analyzing human random generation behavior: A review of methods used and a computer program for describing performance. *Behavior Research Methods, Instruments & Computers*, 30(4), 583-591

Towse, J.N. & Valentine, J.D. (1997). Random generation of numbers: A search for underlying processes. *European Journal of Cognitive Psychology*, 9(4), 381-400

Tranel, D., Anderson, S.W. & Benton, A. (1994). Development of the concept of 'executive function' and its relationship to the frontal lobes. In F. Boller & J Graffman (eds.). *Handbook of Neuropsychology, Vol. 9.* Amsterdam: Elsevier Science

Troyer, A.K. (2000). Normative data for clustering and switching on verbal fluency tasks. *Journal of Clinical and Experimental Neuropsychology*, 22, 370-378

Troyer, A.K., Moscovitch, M. & Winocur, G. (1997). Clustering and switching as two components of verbal fluency: Evidence from younger and older healthy adults. *Neuropsychology*, 11(1), 138-146

Tune, G.S. (1964). A brief survey of variables that influence random generation. *Perceptual and Motor Skills*, 18, 705-710

Van der Linden, M., Beerton, A. & Pesenti, (1998). Age related differences in random generation. *Brain and Cognition*, 38, 1-16

Van der Linden, M., Bredart, S. & Beerten, A. (1994). Age-related differences in updating working memory. *British Journal of Psychology*, 85, 145-152

Vecchi, T., Monticelli, M.L. & Cornoldi, C. (1995). Visuo-spatial working memory: Structures and variables affecting a capacity measure. *Neuropsychologia*, 33, 1549-1564

Vecchi, T., Phillips, L.H. & Cornoldi, C. (2001). Individual differences in visuo-spatial working memory. In M. Denis, R.H. Logie, C. Cornoldi, M De Vega & J. Englekamp (Eds.). *Imagery, Language and Visuo-spatial Thinking*, pp. 29-58. Hove: Psychology Press

Verhaeghen, P. & Basak, C. (2005). Ageing and switching of the focus of attention in working memory: Results from a modified N-Back task. *The Quarterly Journal of Experimental Psychology,* 58A(1), 134-154

Verhaeghen, P., Steitz, D.W., Sliwinski, M.J. & Cerella, J. (2003). Aging and dual-task performance: A meta-analysis. *Psychology and Aging*, 18(3), 443-460

Vieillard, S. & Bougeant, J. (2005). Effect of an induced negative emotion on working memory task performance: The moderating effect of emotional state on storage and executive processes. *L'annee Psychologique*, 105(1), 63-104.

Wagenaar, W.A. (1972). Generation of random sequences by human subjects: A critical survey of the literature. *Psychological Bulletin*, 77, 65-72

Wahlin, T-B.R., Bäckman, L., Wahlin, A. & Winblad, B. (1993). Visuospatial functioning and spatial orientation in a community-based sample of healthy very old persons. *Archives of Gerontology and Geriatrics*, 17, 165-177

Ward, G., Roberts, M.J. & Phillips, L.H. (2001). Task-switching costs, Stroop-costs and executive control: A correlational study. *The Quarterly Journal of Experimental Psychology*, 54A(2), 491-511

Warren, P.A. & Morin, R.W. (1965). Random generation: number of symbols to be randomised and time per response. *Psychonomic Science*, 3, 557-558

Waters, G.S. & Caplan, D. (1996). The measurement of verbal working memory capacity and its relation to reading comprehension. *The Quarterly Journal of Experimental Psychology*, 49A(1), 51-79

West, R.L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin*, 120(2), 272-292

Whelihan, W.M. & Lesher, E.L. (1985). Neuropsychological changes in frontal functions with aging. *Developmental Neuropsychology*, 1, 371-380

Wiegersma, S. (1982). Can repetition avoidance in randomisation be explained by randomness concepts? *Psychological Research*, 44, 189-198

Wiegersma, S. (1984). High speed sequential vocal response production. *Perceptual and Motor Skills*, 59, 43-50

Wiegersma, S. & Meertse, K. (1990). Subjective ordering, working memory and aging. *Experimental Aging Research*, 16(2), 73-77

Wilson, J.L., Scott, J.H. & Power, K.G. (1987). Developmental differences in the span of visual memory for pattern. *British Journal of Developmental Psychology*, 5(3), 249-255

Wingfield, A., Stine, E.A.L., Lahar, C.J. & Aberdeen, J.S. (1988). Does the capacity of working memory change with age? *Experimental Aging Research*, 14, 103-107

Zimprich, D. & Martin, M. (2002). Can longitudinal changes in processing speed explain longitudinal age changes in fluid intelligence? *Psychology and Aging*, 17(4), 690-695

Appendix 1
Mini Mental State Exam Questions

Mini Mental State Examination Questions presented verbally to participant

What is the:
Year?.....Season?.....Date?.....Day?.....Month?.....

Where are we:
Country?.....County?.....Town?.....Place?.....Street?.....

Try to remember these three objects (repeat up to 6 times until learned):
Apple.....Penny.....Table.....

Spell world backwards:
d.....l.....r.....o.....w.....

Can you tell me the names of the three objects I asked you to remember?
Apple.....Penny.....Table.....

Name the items I point to:
Pen.....Watch.....

Repeat this saying after me "No ifs, and, or buts" (1 trial).....

I am going to ask you to carry out three commands. When I have told you all three I want you to carry them out.
"Take this paper in your right hand.....Fold the paper in half.....Put the paper on the floor....."

Read and obey the following statement.....

Write a sentence of your own choice.....

Copy the following design.....

Total.....

Appendix 2
NART Words

NART Words presented in large print booklet, one word per page

Cord
Ache
Depot
Aisle
Bouquet
Psalm
Capon
Deny
Nausea
Debt
Courteous
Rarefy
Equivocal
Naïve
Catacomb
Gaoled
Thyme
Heir
Radix
Assignate
Hiatus
Subtle
Procreate
Gist
Gouge
Superfluous
Simile
Banal
Quadruped
Cellist
Façade
Zealot
Drachm
Aeon
Placebo
Abstemious
Détente
Idyll
Puerperal
Aver
Gauche
Topiary
Leviathan
Beatify
Prelate
Sidereal
Demense
Syncope
Labile
Campanile

Total

Appendix 3
Definitions and calculation of strategy measures used in studies 2 and 3

Definitions of types of Strategy Measured

Semantic strategy: the production of word sequences which are semantically related

Phonemic strategy: the production of word sequences which either sound similar or which have the same second letter (initial letter fluency task) or same initial letter (excluded letter, shape and excluded shape fluency tasks)

Alphabetic strategy: the production of word sequences which are ordered alphabetically by their second letter (initial letter fluency task) or by their first letter (excluded letter, shape and excluded shape fluency tasks)

Total strategy use: the production of word sequences using any type of strategy

Percentage Strategy Use Calculation

Percentage strategy use was calculated using the following formula:

$$\frac{\textit{Total number of words within a strategy}}{\textit{Total number of words produced}} \times 100$$

Clustering Measurement and Calculation

Cluster size: total number of words produced within a strategy cluster, counted beginning with the second word within the cluster.

Mean cluster size is calculated in the following way:

$$\frac{\textit{Sum of cluster sizes}}{\textit{Number of clusters}}$$

Switching Measurement and Calculation

Switches: calculated as the total number of transitions between clusters, including groups of non-clustered words between clusters

Hard switches: calculated as the total number of transitions between a cluster and non-clustered words and between two non-clustered words

Cluster switches: calculated as the total number of transitions between adjacent or overlapping clusters, where clusters comprise at least two words

Appendix 4
Studies 2 & 3 Additional ANCOVA analyses

A4.1) Verbal Fluency ANCOVA Results for Total Number of Words Generated

ANCOVA controlling for Speed of Processing only
No significant main effect of age was found ($F(1,36) = 0.178$, $p = 0.675$), however a significant main effect of task type ($F(1,36) = 8.789$, $p = 0.005$) and a significant interaction between age and task type ($F(1,36) = 12.693$, $p = 0.001$) were found. Post hoc analysis of the interaction indicated no significant simple effects at the 0.0125 level.

ANCOVA controlling for IQ only
No significant main effect of task type was found ($F(1,36) = 2.495$, $p = 0.125$), however a significant main effect of age ($F(1,36) = 6.736$, $p = 0.014$) and a significant interaction between age and task type ($F(1,36) = 16.634$, $p = 0.0001$). Post hoc analysis found a significant simple effect of age in the excluded letter fluency task ($F(1,36) = 13.301$, $p = 0.001$), but no other significant simple effects at the $p \leq 0.0125$ level.

A4.2) Verbal Fluency ANCOVA Results for Strategy Use

A4.2.1) Total Strategy Use

ANCOVA controlling for speed of processing only
A significant main effect of task type ($F(1,36) = 90197$, $p = 0.004$) and age ($F(1,36) = 4.691$, $p = 0.037$) however no interaction effect was found ($F(1,36) = 0.469$, $p = 0.498$).

ANCOVA controlling for IQ only
No significant main effects of age ($F(1,36) = 0.119$, $p = 0.732$), task type ($F(1,36) = 0.176$, $p = 0.677$) or interaction between age and task type ($F(1,36) = 2.577$, $p = 0.177$) were found.

A4.2.2) Phonemic Strategy Use

ANCOVA controlling for speed of processing
A significant main effect of age was evident ($F(1,36) = 11.607$, $p = 0.0023$), but no main effect of task type ($F(1,36) = 1.460$, $p = 0.235$) or interaction between age and task type ($F(1,36) = 1.084$, $p = 0.305$).

ANCOVA controlling for IQ only
No significant main effect of task type was found ($F(1,36) = 2.626$, $p = 0.144$) or interaction between age and task type ($F(1,36) = 0.019$, $p = 0.892$), but the main effect of age was approaching significance ($F(1,36) = 4.082$, $p = 0.051$).

A4.2.3) Semantic Strategy Use

ANCOVA controlling for speed of processing only
A significant main effect of age was evident ($F(1,36) = 4.211$, $p = 0.047$), but no main effect of task type ($F(1,36) = 3.524$, $p = 0.069$) or interaction between age and task type ($F(1,36) = 3.255$, $p = 0.080$).

ANCOVA controlling for IQ only
A significant main effect of age was found ($F(1,36) = 4.694$, $p = 0.037$), but no main effect of task type ($F(1,36) = 1.912$, $p = 0.175$) or interaction between age and task type ($F(1,36) = 3.306$, $p = 0.077$).

A4.3) Verbal Fluency ANCOVA results for Clustering and Switching

A4.3.1) Cluster Size

ANCOVA controlling for speed of processing only
A significant main effect of task type ($F(1,36) = 4.286$, $p = 0.046$) and a significant main effect of age ($F(1,36) = 10.858$, $p = 0.002$) were found, however no significant interaction was apparent ($F(1,36) = 0.027$, $p = 0.870$).

ANCOVA controlling for IQ only
No significant effect of task type ($F(1,36) = 0.001$, $p = 0.978$) , age ($F(1,36) = 1.327$, $p = 0.257$) or interaction ($F(1,36) = 0.576$, $p = 0.453$) were evident.

A4.3.2) Number of Switches

ANCOVA controlling for speed of processing only
No significant main effects of task type ($F(1,36) = 1.227$, $p = 0.275$) or age ($F(1,36) = 3.059$, $p = 0.089$) were found, however the interaction between age and task type was significant ($F(1,36) = 7.669$, $p = 0.009$). Post hoc analysis of the interaction found a significant difference between the age groups in the excluded letter fluency task ($F(1,36) = 9.369$, $p = 0.004$), however no significant effect of age in the letter fluency or significant effect of task type in either young or old adults was found ($p \geq 0.0125$).

ANCOVA controlling for IQ only
No significant effect of task was evident ($F(1,36) = 0.980$, $p = 0.329$), however the effect of age was significant ($F(1,36) = 14.871$, $p = 0.0001$) and a significant interaction between age and task type ($F(1,36) = 7.590$, $p = 0.009$) was evident. Post hoc analysis indicated a significant difference between the age groups in the excluded letter fluency task ($F(1,36) = 19.892$, $p = 0.0001$) but not in the letter fluency task ($p \geq 0.0125$). No significant simple effects of task type in either young or adults were evident ($p \geq 0.0125$).

A4.3.3) Number of Hard Switches

ANCOVA controlling for speed of processing only
No significant effects of task type ($F(1,36) = 1.703$, $p = 0.200$), age ($F(1,36) = 2.082$, p 0.158) or interaction between them ($F(1,36) = 2.138$, $p = 0.152$) were evident.

ANCOVA controlling for IQ only
No significant effect of task type (F1,36) = 0.679, p = 0.415) or interaction between age and task type (F(1,36) = 0.707, p = 0.406) were evident. However there was a significant main effect of age (F(1,36) = 7.644, p = 0.009).

A4.3.4) Number of Cluster Switches

ANCOVA controlling for speed of processing only
No significant main effects of task type (F(1,36) = 2.831, p = 0.101, age (F(1,36) = 0.128, p = 0.722) or interaction between them (F(1,36) = 1.743,. p = 0.195) were found.

ANCOVA controlling for IQ only
No significant main effects of task type (F(1,36) = 1.343, p = 0.254), age (F(1,36) = 3.486, p = 0.070), or interaction (F(1,36) = 2.242, p = 0.143) were found.

A4.4) Shape Fluency ANCOVA Results for Number of Words Produced

ANCOVA controlling for speed of processing only
No significant main effects of task (F(1,36) = 3.834, p = 0.058), age (F(1,36) = 0.001, p = 0.981) or interaction between age and task type (F(1,36) = 0.275, p = 0.603) were evident, although the main effect of task type was approaching significance.

ANCOVA controlling for IQ only
No significant main effects of task (F(1,36) = 0.054, p = 0.818), age (F(1,36) = 2.791, p = 0.103) or interaction between task type and age (F(1,36) = 0.064), p = 0.802) were found.

A4.5) Shape Fluency ANCOVA results for Strategy Use

A4.5.1) Total Strategy

ANCOVA controlling for speed of processing only
No significant main effects of task type (F(1,36) = 1.364, p = 0.250), or age (F(1,36) = 0.017, p = 0.895) were evident, however a significant interaction between age and task type was found (F(1,36) = 5.526, p = 0.024). Post hoc analysis showed no significant simple effects for any of the comparisons (p ≥0.0125).

ANCOVA controlling for IQ only
No significant main effects of task type (F(1,36) = 1.134, p = 0.294), age (F(1,36) =0.023, p = 0.881) or interaction between age and task type (F(1,36) = 2.653, p = 0.112) were found.

A4.5.2) Phonemic Strategy Use

ANCOVA controlling for speed of processing only
No significant main effects of task type ($F(1,36) = 0.562$, $p = 0.458$), age ($F(1,36) = 0.034$, $p = 0.855$) or interaction between age and task type ($F(1,36) = 0.233$, $p = 0.632$) were evident.

ANCOVA controlling for IQ only
No significant main effects of task type ($F(1,36) = 1.076$, $p = 0.307$), age ($F(1,36) = 0.017$, $p = 0.897$) or interaction between age and task type ($F(1,36) = 0.233$, $p = 0.632$) were found.

A4.5.3) Semantic / Visualisation Strategy Use

ANCOVA controlling for speed of processing only
No significant main effects of task type ($F(1,36) = 1.114$, $p = 0.298$) or age ($F(1,36) = 0.000$, $p = 0.995$) were evident, however the interaction between age and task type was significant ($F(1,36) = 5.830$, $p = 0.021$). Post hoc analysis showed no significant simple effects for any of the comparisons ($p \geq 0.0125$).

ANCOVA controlling for IQ only
No significant main effects of task type ($F(1,36) = 0.950$, $p = 0.336$), age ($F(1,36) = 0.062$, $p = 0.805$) or interaction between age and task type ($F(1,36) = 3.127$, $p = 0.085$) were found.

A4.6 Shape Fluency ANCOVA results for Clustering and Switching Measures

A4.6.1) Cluster Size

ANCOVA controlling for speed of processing only
No significant main effects of task type ($F(1,36) = 1.197$, $p = 0.281$), age ($F(1,36) = 0.112$, $p = 0.739$) were found. The interaction between age and task type was approaching significance ($F(1,36) = 3.985$, $p = 0.054$).

ANCOVA controlling for IQ only
No significant main effects of task type ($F(1,36) = 0.000$, $p = 0.998$), age ($F(1,36) = 0.404$, $p = 0.529$) or interaction between age and task type ($F(1,36) = 1.934$, $p = 0.173$) were evident.

A4.6.2) Number of Switches

ANCOVA controlling for speed of processing only
No significant main effects of task type ($F(1,36) = 3.610$, $p = 0.065$), age ($F(1,36) = 0.015$, $p = 0.904$) or interaction between age and task type ($F(1,36) = 0.088$, $p = 0.769$) were found.

ANCOVA controlling for IQ only
No significant main effects of task type ($F(1,36) = 0.220$, $p = 0.642$), age ($F(1,36) = 1.813$, $p = 0.187$) or interaction between age and task type ($F(1,36) = 0.570$, $p = 0.455$) were found.

A4.6.3) Number of Hard Switches

ANCOVA controlling for speed of processing only
No significant main effects if task type ($F(1,36) = 3.684$, $p = 0.063$), age ($F(1,36) = 1.588$, $p = 0.216$) or interaction between age and task type ($F(1,36) = 2.109$, $p = 0.155$) were evident.

ANCOVA controlling for IQ only
No significant main effect of task type ($F(1,36) = 0.932$, $p = 0.341$) or interaction between age and task type ($F(1,36) = 0.010$, $p = 0.920$) were found, however a main effect of age was evident ($F(1,36) = 4.858$, $p = 0.034$).

A4.6.4) Number of Cluster Switches

ANCOVA controlling for speed of processing only
No significant main effect of age ($F(1,36) = 0.019$, $p = 0.890$) or interaction between age and task type ($F(1,36) = 0.114$, $p = 0.738$) was found, however the main effect of task type ($F(1,36) = 6.004$, $p = 0.019$) was significant.

ANCOVA controlling for IQ only
No significant main effects of task type ($F(1,36) = 0.364$, $p = 0.550$), age ($F(1,36) = 1.664$, $p = 0.205$) or interaction between age and task type ($F(1,36) = 1.122$, $p = 0.297$) were found.

Appendix 5
Binomial Probability Calculation for Scoring Method in Study 1

Formula:

$$P(k \text{ out of } n) = \frac{n!}{k!(n-k)!}(pk)(qn-k)$$

Where:
n is the number of occasions
k is the number of times a binomial outcome is observed or stipulated to occur
p is the probability that the outcome will occur on any particular occasion
q is the complementary probability (1-p) that the outcome will not occur on any particular occasion

Appendix 6
Randomness Measures used in Studies 4 & 5

The following measures of randomness used in studies 4 & 5 were calculated using Towse & Neil's (1998) RGCalc program. A brief explanation of each measure is given below. See Towse & Neil (1998) for full explanation and formulae for calculation.

General Measures of Randomness

Random Number Generation (RNG Index)
The RNG index is a measure of sequential response bias identified by Evans (1978) which examines the distribution of response pairs or digrams. It looks at how often one response follows any other response. Scores can range from 0 to 1 where 0 indicates a perfectly equal distribution and 1 indicates complete predictability of pair sequences.

Null Score Quotient (NSQ)
Guttman's (1967) NSQ measure indicates the number of digram possibilities that the participant does not use. NSQ scores are given as a percentage of the maximum number of digram possibilities not used, with 100% indicating the use of 1 digram repeatedly and 0% all possible digrams used.

Randomness Measures relying on Monitoring and Updating Processes

Redundancy (R)
The redundancy measure examines the frequency of response alternatives generated and compares that to the selection of responses with equal frequency. R scores are given as a percentage where 0% indicates equality of response alternatives (no redundancy) and 100% indicates the same response used repeatedly (complete redundancy).

Coupon
Coupon is a measure developed by Ginsburg & Karpiuk (1994) which measures the mean number of responses produced before all the response alternatives are given. It looks at the specific strategy of cycling (working through the set of all possible responses). Sequences where a strategy of cycling is used will produce a low coupon score.

Randomness Measures relying on the Ability to Inhibit Stereotypical Responses

Adjacency (A)
Adjacency measures a specific type of stereotyped score, i.e. the proportion of adjacent items from an ordinal sequence, rather than all possible response pairings as in the RNG index. It is calculated as a combined score for both ascending and descending adjacent pairs and is expressed as a percentage, with scores of 0%

indicating no adjacent pairs and 100% indicating a response which is entirely made up of adjacent pairs.

Runs

Identified by Ginsburg & Karpiuk (1994) the runs measure describes the variability in interval length between 2 turning points. It is measured as the variance of ascending sequence lengths. A high runs score indicates greater variation in the length of ascending sequences.

Randomness Measure relying on the Ability to Switch Between Different Strategies

Turning Point Index (TPI)

The TPI is a measure reported by Kendall (1976) which looks at the number of turning points made (changes from ascending to descending sequences, compared to a theoretically determined ideal number of turning points). TPI scores are given as a percentage, with scores of 100% indicating the expected number of turning points, those greater than 100% indicating too many turning points and less than 100% too few turning points.

Appendix 7
Study 4: Additional ANCOVA Analysis

A7.1.1 RNG Index Set Size 5 Results

ANCOVA controlling for speed of processing only
No significant main effects of modality, rate or age and no significant interactions were found ($p>0.05$).

ANCOVA controlling for IQ only
A significant main effect of age was evident ($F(1,36) = 6.03$, $p = 0.019$) with older adults showing higher RNG scores than young adults, suggesting that older adults are less random. No significant main effects of modality or rate ($p>0.05$) and no significant interactions apparent ($p>0.05$).

A7.1.2 RNG Index Set Size 10 Results

ANCOVA controlling for speed of processing only
No significant main effects and no significant interactions were found ($p>0.05$).

ANCOVA controlling for IQ only
A significant main effect of age ($F(1,36) = 6.187$, $p = 0.018$) was found with older adults showing higher RNG scores than young adults, suggesting that they are less random. No significant main effects of modality or rate and no significant interactions were evident ($p>0.05$).

A7.2.1 NSQ Set Size 5 Results

ANCOVA controlling for speed of processing only
A significant main effect of age was found ($F(1,36) = 4.68$, $p = 0.037$) with older adults showing higher NSQ scores than young adults, suggesting that they are less random. No significant main effects of modality or rate and no significant interactions were found (p.0.05).

ANCOVA controlling for IQ only
A significant main effect of age was evident ($F(1,36) = 6.63$, $p = 0.014$) with older adults having higher NSQ scores than young adults indicating that they are less random. No significant main effects of modality or rate and no significant interactions were found ($p>0.05$).

A7.2.2 NSQ Set Size 10 Results

ANCOVA controlling for speed of processing only
No significant main effects and no significant interactions were evident ($p>0.05$).

ANCOVA controlling for IQ only
A significant main effect of age was evident ($F(1,36) = 5.655$, $p = 0.023$) with older adults showing higher NSQ scores than young adults suggesting that they are less random. No significant main effects of modality or response rate and no significant interactions were evident.

7.3.1 Redundancy Set Size 5 Results

ANCOVA controlling for speed of processing only
No significant main effects of modality, rate or age and no significant 2-way interactions were present ($p>0.05$), however the 3-way interaction between modality, rate and age was significant ($F(1,36) = 4.45$, $p = 0.042$). Post hoc analysis, however found no significant simple effects for any comparisons at the Bonferroni corrected p value of $p = 0.004$ apart from a significant simple effect of modality for young adults at the fast response rate, with redundancy being higher in the keypress condition than the oral condition.

ANCOVA controlling for IQ only
No significant main effects or significant 2-way interactions were evident, however the 3-way interaction between modality, rate and age was significant ($F(1,36) = 4.64$, $p = 0.038$). Post hoc analysis however found no significant simple effects using the Bonferroni corrected p value ($p>0.004$).

7.3.2 Redundancy Set Size 10 Results

ANCOVA controlling for speed of processing only
No significant main effects or interactions were evident ($p>0.05$).

ANCOVA controlling for IQ only
No significant main effects or interactions were found ($p>0.05$)

7.4.1 Coupon Set Size 5 Results

ANCOVA controlling for speed of processing only
A significant main effect of modality was found ($F(1,36) = 7.89$, $p = 0.008$) with higher coupon scores in the oral condition compared to the keypress condition, suggesting that there is less reliance on a strategy of cycling in the oral conditions than in the keypress conditions. No significant main effect of response rate or age and no significant interactions found.

ANCOVA controlling for IQ only
No significant main effects and no significant interactions evident ($p>0.05$).

7.4.2 Coupon Set Size 10 Results

ANCOVA controlling for speed of processing only
No significant main effects and no significant interactions present ($p>0.05$).

ANCOVA controlling for IQ only
No significant main effects and no significant interactions evident ($p>0.05$).

7.5.1 Adjacency Set Size 5 Results

ANCOVA controlling for speed of processing only
A significant main effect of response rate was evident ($F(1,36) = 8.39$, $p = 0.006$) with higher adjacency scores in the fast conditions compared to the slow conditions indicating that randomness is poorer at faster generation rates. No significant main effects of age or modality were evident ($p>0.05$). No significant 2-way or 3-way interactions were found ($p>0.05$).

ANCOVA controlling for IQ only
No significant main effects of modality, rate or age were found ($p>0.05$). The 2-way interaction between rate and age was significant however ($F(1,36) = 4.31$, $p = 0.045$) and the 3-way interaction between modality, rate and age was also significant ($F(1,36) = 5.85$, $p = 0.021$). Post hoc analysis of the 3-way interaction showed no significant simple effects at the Bonferroni adjusted p value ($p>0.004$), although there was a non-significant trend for young adults to have higher adjacency scores in the oral modality under fast generation rates.

7.5.2. Adjacency Set Size 10 Results

ANCOVA controlling for speed of processing only
No significant main effects of modality, rate or age were found ($p>0.05$). A significant 2-way interaction between modality and response rate was evident ($F(1,36) = 9.006$, $p = 0.005$). Post hoc analysis found a simple effect of response rate in the oral modality which was approaching significance ($F(1,37) = 6.566$, $p = 0.015$) with higher adjacency scores at the faster response rate indicating less inhibition of stereotypical respones. No other simple effects were significant at the Bonferroni corrected p value ($p>0.0125$).

ANCOVA controlling for IQ only
No significant main effects of modality, response rate or age and no significant 2-way or 3-way interactions were evident ($p>0.05$).

7.6.1 Runs Set Size 5 Results

ANCOVA controlling for speed of processing only
ANCOVA analysis found a significant main effect of modality ($F(1,36) = 11.67$, $p = 0.002$) with a higher runs score in the oral modality compared to the keypress modality, indicating greater variability in sequence lengths in the oral modality. No significant main effects of response rate or age, and no significant 2 or 3-way interactions were found ($p>0.05$).

ANCOVA controlling for IQ only
No significant main effects of modality, response rate or age were found ($p>0.05$). Significant 2-way interactions were found between modality and response rate ($F(1,36) = 7.78$, $p = 0.008$) and between modality and age ($F(1,36) = 5.88$, $p = 0.02$) and a significant 2-way interaction between modality, response rate and age was also evident ($F(1,36) = 6.62$, $p = 0.014$). Post hoc analysis of the 3-way interaction showed no significant simple effects at the Bonferroni corrected p value ($p>0.004$), however non-significant trends suggested that older adults showed higher runs scores at the slow response rate compared to the fast response rate for the oral modality and that older adults also showed higher runs scores in the keypress compared to the oral modality at the fast generation rate. At fast generation rates older adults showed higher runs scores than young adults in the keypress modality but lower runs scores than young adults in the oral modality.

7.6.2 Runs Set Size 10 Results

ANCOVA controlling for speed of processing only
No significant main effects of modality, response rate or age and no significant 2-way or 3-way interactions were found ($p>0.05$).

ANCOVA controlling for IQ only
No significant main effects of modality, response rate or age and no significant 2-way or 3-way interactions were evident ($p>0.05$).

7.7.1 Turning Point Index Set Size 5 Results

ANCOVA controlling for speed of processing only
No significant main effects of modality, response rate or age were found ($p>0.05$), however a significant interaction between modality and response rate was evident ($F(1,36) = 5.16$, $p = 0.029$). Post hoc analysis indicated a significant simple effect of response rate in the oral modality ($F(1,37) = 7.956$, $p = 0.008$) with the TPI score being below the average 100 at both rates, but lowest at the fast rate, indicating that in oral generation participants switch between ascending and descending sequences less frequently at the faster response rate. A significant simple effect of modality was evident at the fast response rate ($F(1,37) = 14.33$, $p = 0.001$), with a higher TPI score in the keypress modality compared to the oral modality, indicating that participants switched between ascending and decending sequences less frequently in the oral modality. No other simple effects were found at the Bonferroni corrected p value ($p>0.0125$). No other 2-way or 3-way interactions were significant ($p>0.05$).

ANCOVA controlling for IQ only
No significant main effects of modality, response rate or age and no significant 2-way interactions were present ($p>0.05$). The 3-way interaction between modality, response rate and age was significant ($F(1,36) = 5.07$, $p = 0.031$) however post hoc analysis showed no significant simple effects using the Bonferroni corrected p value ($p>0.004$). A non-significant trend suggested that in the keypress modality older adults had a lower TPI score than young adults at fast response rates, indicating that they switched between ascending and descending strategies less frequently.

7.7.2 Turning Point Index Set Size 10 Results

ANCOVA controlling for speed of processing only

No significant main effects of modality, response rate or age and no significant 2-way interactions were found. The 3-way interaction between modality, response rate and age was significant however ($F(1,36) = 4.439$, $p = 0.042$). Using the Bonferroni corrected post hoc analysis found no significant simple effects ($p>0.004$). Non-significant trends suggested that older adults had a lower TPI score than young adults at the fast response rate in the oral generation task and at the slower response rate in the keypress task.

ANCOVA controlling for IQ only

No significant main effects of modality or age were found, however the main effect of age was significant ($F(1,36) = 11.009$, $p = 0.002$) with older adults having a lower TPI score than the young adults, indicating that they switch between ascending and descending strategies less frequently. No significant 2-way or 3-way interactions were found ($p>0.05$).

Appendix 8
Study 5: Additional ANCOVA Analysis

8.1 RNG Results

ANCOVA controlling for speed of processing
No significant main effects of modality, load or age and no significant 2 or 3-way interactions were evident ($p>0.05$).

ANCOVA controlling for IQ
No significant main effects of modality, load or age and no 2-way or 3-way interactions were evident ($p>0.05$).

8.2 NSQ Results

ANCOVA controlling for speed of processing
No significant main effects of modality or load and no significant 2or 3-way interactions ($p>0.05$). A significant main effect of age was found ($F(1,36) = 4.557$, $p = 0.040$) with older adults showing higher NSQ scores than young adults.

ANCOVA controlling for IQ
A significant main effect of age was evident ($F(1,36) = 11.738$, $p = 0.002$) with older adults having higher NSQ scores than young adults. A significant 2-way interaction between load and age was also evident ($F(2,72) = 3.875$, $p = 0.026$), with post hoc analysis showing a significant simple effect of age in the inhibitory load condition ($F1,36) = 17.491$, $p = 0.0001$), with older adults showing higher NSQ scores than young adults. No other simple effects were significant at the Bonferroni adjusted p value of 0.005. No main effects of modality or load were significant and no other significant interactions were evident ($p>0.05$).

8.3 Redundancy Results

ANCOVA controlling for speed of processing
A significant main effect of load was found ($F(2,72) = 5.254$, $p = 0.007$) and post hoc analysis revealed a significant difference between the memory and inhibitory load condition ($F(1,37) = 8.438$, $p = 0.006$) with higher redundancy scores in the memory load condition compared to the inhibitory load condition. No other significant differences between the load conditions were found with the Bonferroni corrected p value ($p>0.017$). ANCOVA analysis showed no significant main effects of modality or age and no significant 2-way or 3-way interactions ($p>0.05$).

ANCOVA controlling for IQ
ANCOVA analysis showed a significant main effect of load ($F(2,72) = 6.646$, $p = 0.002$) and a significant 3-way interaction between modality, load and age ($F(2,72) = 3.388$, $p = 0.025$). Post hoc analysis found that no simple effects were significant using the Bonferroni corrected p value ($p>0.002$). No other significant main effects or interactions were found in the ANCOVA analysis ($p>0.05$).

8.4 Coupon Results

ANCOVA controlling for speed of processing
No significant main effects of modality, load or age were found ($p>0.05$). The 2-way interaction between modality and age was significant ($F(1,36) = 5.082$, $p = 0.030$). Post hoc analysis showed no significant simple effects at the Bonferroni adjusted p value ($p>0.0125$). No other 2-way or 3-way interactions were significant ($p>0.05$).

ANCOVA controlling for IQ
No significant main effects of age or modality were found, however the main effect of load was significant ($F(2,72) = 3.173$, $p = 0.048$). Post hoc analysis showed no significant simple effects of load using the Bonferroni adjusted p value ($p>0.0125$). No 2-way or 3-way interactions were significant ($p>0.05$).

8.5 Adjacency Results

ANCOVA controlling for speed of processing
No significant main effects of age, modality or load were evident ($p>0.05$). The 2-way interaction between modality and age was significant ($F(1,36) = 5.168$, $p = 0.029$), however post hoc analysis showed no significant simple effects at the Bonferroni adjusted p value ($p>0.0125$). The 2-way interaction between load and age was also significant ($F(2,72) = 3.872$, $p = 0.025$), however post hoc analysis showed no significant simple effects using the Bonferroni adjusted p value ($p>0.005$). No other 2-way or 3-way interactions were significant ($p>0.05$).

ANCOVA controlling for IQ
A significant main effect of age was evident ($F(1,36)5.525$, $p = 0.024$) and a significant 2-way interaction between age and load ($F(2,72) = 4.815$, $p = 0.011$), however post hoc analysis showed no significant simple effects using the Bonferroni adjusted p value ($p>0.005$). No other main effects or interactions were significant ($p>0.05$).

8.6 Runs Results

ANCOVA controlling for speed of processing
No significant main effects of age, load or modality were evident ($p>0.05$). The 2-way interaction between age and load was significant ($F(2,72) = 4.695$, $p = 0.012$), however no simple effects were significant using the Bonferroni adjusted p value ($p>0.005$). No other 2-way or 3-way interactions were significant.

ANCOVA controlling for IQ
A significant main effect of age was found ($F(1,36) = 6.629$, $p = 0.014$) and a significant interaction between load and age ($F(2,72) = 4.523$, $p = 0.014$), however post hoc analysis showed no significant simple effects at the Bonferroni adjusted p value ($p>0.005$). No other main effects or interactions were evident ($p>0.05$).

8.7 TPI Results

ANCOVA controlling for speed of processing
A significant main effect of age was found ($F(1,36) = 5.409$, $p = 0.026$) with older adults showing a lower TPI score than young adults. No other main effects or interactions were significant ($p>0.05$).

ANCOVA controlling for IQ
A significant main effect of age was found ($F(1,36) = 14.885$, $p = 0.0001$) with older adults showing a lower TPI score than young adults. No other main effects or interactions were significant ($p>0.05$).

8.8. Study 5 Error Analysis

Table A8.1) Mean (standard deviation) error scores for Memory and Inhibitory Load Tasks

	Oral Generation Memory Load	Oral Generation Inhibitory Load	Keypress Generation Memory Load	Keypress Generation Inhibitory Load
Young adults	0.650 (0.998)	1.400 (1.536)	0.000 (0.000)	0.150 (0.489)
Older adults	1.650 (1.663)	2.450 (1.820)	0.300 (0.571)	0.450 (0.605)

ANOVA results indicated: a significant main effect of modality ($F(1,38) = 52.804$, $p = 0.0001$) with higher error scores evident during oral random generation compared to keypress random generation (see table A8.1); a significant main effect of load ($F(1,38) = 7.358$, $p = 0.010$) with higher error scores evident in the inhibitory load conditions compared to the memory load conditions; and a significant main effect of age ($F(1,38) = 12.144$, $p = 0.001$) with older adults showing higher error scores than young adults. No significant 2-way or 3-way interactions between modality, load and age were evident ($p>0.05$).

ANCOVA analysis controlling for speed of processing and IQ found a significant main effect of age ($F(1,35) = 16.725$, $p = 0.0001$), a significant main effect of modality ($F(1,35) = 6.096$, $p = 0.019$) and a significant interaction between modality and age ($F91,35) = 5.642$, $p = 0.023$). No other 2-way or 3-way interactions were significant ($p>0.05$).

Appendix 9
Formulae for Calculating Task Switching Measures

Absolute Alternation Cost = RT for switch trials in mixed trial block – RT for repeat trials in pure single trial block

Absolute Mixing Cost = RT for repeat trials in mixed trial block – RT for repeat trials in pure single trial block

Absolute Specific Switching Cost = RT for switch trials in mixed trial block – RT for repeat trials in mixed trial block

Appendix 10
Study 6 Additional ANCOVA Analysis

10.1 Absolute Alternation Cost Results

ANCOVA controlling for speed of processing
A significant main effect of memory load ($F(1,34) = 9.230$, $p = 0.005$) and a significant main effect of age ($F(1,34) = 12.625$, $p = 0.001$) were found. The interaction between memory load and age ($F(1,34) = 6.164$, $p = 0.018$) and the interaction between memory load and task type ($F(1,34) = 6.614$, $p = 0.015$) were also significant. No other significant main effects or interactions were evident ($p>0.05$).

ANCOVA controlling for IQ
The main effect of age was significant ($F(1,35) = 10.204$, $p = 0.003$), however no other main effects and no 2-way or 3-way interactions were significant ($p>0.05$).

10.2 Absolute Mixing Cost

ANCOVA controlling for speed of processing
A significant main effect of task type ($F(1,34) = 4.585$, $p = 0.040$) and age ($F(1,34) = 4.773$, $p = 0.036$) were apparent and the 2-way interaction between memory load and age was also so significant ($F(1,34) = 19.035$, $p = 0.0001$). No other main effects or interactions were significant ($p>0.05$).

ANCOVA controlling for IQ
Both the main effects of task type ($F(1,35) = 4.155$, $p = 0.049$) and age ($F(1,35) = 6.277$, $p = 0.017$) were significant. The interaction between memory load and age was also significant ($F(1,35) = 20.624$, $p = 0.0001$). No other main effects or interactions were found to be significant ($p>0.05$).

10.3 Absolute Switching Cost

ANCOVA controlling for speed of processing
A significant main effect of memory load ($F(1,34) = 9.737$, $p = 0.004$) and a significant main effect of age ($F(1,340 = 14.551$, $p = 0.001$) were found. The interaction between memory load and age was also significant ($F(1,34) = 12.815$, $p = 0.001$). No other main effects or interactions were significant ($p>0.05$).

ANCOVA controlling for IQ
The main effect of age ($F(1,35) = 8.317$, $p = 0.007$) and the interaction between memory load and age ($F(1,35) = 8.035$, $p = 0.008$) were significant, however no other main effects or interactions were found to be significant ($p>0.05$).

Appendix 11
Study 6 Error Analysis and Practice Effects

11.1 Study 6: Error Analysis ANOVA Results

ANOVA analysis of error scores showed a significant main effect of age ($F(1,36) = 4.950$, $p = 0.032$) with older adults showing a higher proportion of error than young adults (see table A11.1). A significant main effect of trial type ($F(1,36) = 11.484$, $p = 0.002$) was also evident with switch trials showing a greater proportion of errors compared to repeat trials (see table A11.1). Main effects of task modality and memory load were not significant ($p>0.05$) and no significant interactions were evident ($p>0.05$).

Table A11.1 Mean (standard deviation) Error Proportions for Young and Old Adults

	DE 2nd repeat	DE 2nd switch	DE 5th repeat	DE 5th switch	SC 2nd repeat	SC 2nd switch	SC 5th repeat	SC 5th switch
Young adults	0.0031 (0.0028)	0.0043 (0.0035)	0.0026 (0.0016)	0.0050 (0.0048)	0.0036 (0.0047)	0.0060 (0.0068)	0.0029 (0.0023)	0.0063 (0.0066)
Old adults	0.0098 (0.0097)	0.1057 (0.1027)	0.0078 (0.1287)	0.0079 (0.0085)	0.1279 (0.1749)	0.1365 (0.1813)	0.1010 (0.1504)	0.1227 (0.1931)

11.2 Study 6: Practice Effects

ANOVA analyses were conducted separately for each pure task and for mixed blocks with different switch frequencies. Main effects of age under different task conditions are not of interest in relation to practice effects, therefore only main effects of order and interactions between order and age will be reported here.

11.2.1 Pure Block Practice Effects

No significant main effects of order occurred for either the digit task or the element task during pure task blocks ($p>0.05$), however both the shape task ($F(1,34) = 5.316$, $p = 0.027$) and the colour task ($F(1,35) = 15.212$, $p = 0.0001$) showed order effects with RT in both tasks being slower in trials 3 and 4, compared to trials 1 and 2 (see table A11.2), suggesting that participants showed effects of fatigue rather than practice.

Table A11.2) Mean (standard deviation) RT for Pure Tasks Blocks

		Trials 1 & 2 RT	Trials 3 & 4 RT
Digit Task	Young adults	412.91 (47.96)	445.62 (92.14)
	Old adults	639.88 (107.90)	653.29 (116.61)
Element Task	Young adults	455.35 (93.54)	455.92 (87.05)
	Old adults	652.10 (133.07)	675.97 (144.86)
Shape Task	Young adults	412.64 (60.66)	438.37 (129.29)
	Old adults	572.71 (109.09)	615.18 (140.39)
Colour Task	Young adults	419.47 (66.10)	433.73 (80.28)
	Old adults	546.92 (131.50)	655.68 (144.12)

A significant interaction between order and age was also evident for the colour task ($F(1,35) = 8.976$, $p = 0.005$), with older adults showing a greater effect of fatigue than young adults (see table A11.2). The interaction between order and age was not significant for any other pure task blocks ($p>0.05$).

11.2.2 Mixed Block Practice Effects

No significant main effects of order or interactions with order in the digit element switching every 2nd trial, the digit element switching every 5th trial or the shape colour switching every 5th trial mixed blocks ($p>0.05$). A significant interaction between order and age ($F(1,37) = 9.311$, $p = 0.004$) was evident in the shape colour switching every 2nd trial blocks, with younger adults showing slower RTs in later trials compared to earlier trials and older adults showing quicker RTs in the later trials compared to the earlier trials (see table A11.3). This suggests that whilst young adults show a fatigue effect, older adults show a practice effect.

Table A11.3) Mean (standard deviation) RT for Mixed Task Blocks

		Repeat trials 1 - 4	Repeat trials 5 - 8	Switch trials 1 - 4	Switch trials 5 - 8
Digit Element Switch 2nd trial	Young	773.72 (296.56)	742.75 (309.08)	1078.87 (353.76)	1078.21 (325.51)
	Old	1359.69 (723.32)	1277.95 (450.65)	1896.02 (945.13)	1774.75 (595.20)
Digit Element Switch 5th Trial	Young	793.73 (325.74)	699.06 (248.13)	1467.07 (975.07)	1293.80 (664.75)
	Old	1199.74 (507.21)	996.72 (273.49)	2551.08 (1159.14)	2420.98 (1291.64)
Shape Colour Switch 2nd Trial	Young	686.94 (238.75)	735.29 (280.94)	1163.80 (352.57)	1253.02 (465.90)
	Old	1399.34 (609.83)	1286.07 (358.39)	2079.89 (655.70)	1724.81 (642.50)
Shape Colour Switch 5th Trial	Young	784.96 (320.81)	738318 (271.97)	1531.39 (710.61)	1398.83 (462.59)
	Old	1129.05 (481.33)	999.89 (370.75)	2748.97 (1895.15)	2303.69 (739.97)

Appendix 12
Study 7 Additional ANCOVA Analysis

12.1) Absolute Alternation Costs

ANCOVA results controlling for speed of processing
ANCOVA results showed a significant main effect of age ($F(1,35) = 8.733$, $p = 0.006$). The main effects of task type and cue potency were not significant and no 2-way or 3-way interactions were found ($p>0.05$).

ANCOVA results controlling for IQ
A significant main effect of age was found ($F(1,36) = 13.429$, $p = 0.001$). No other main effects or interactions were significant ($p>0.05$).

12.2) Absolute Mixing Costs

ANCOVA results controlling for speed of processing
The main effect of age was significant ($F(1,35) = 9.319$, $p = 0.004$), however no other main effects or interactions were significant ($p>0.05$).

ANCOVA results controlling for IQ
A significant main effect of age was found ($F(1,36) = 13.245$, $p = 0.001$). No other significant main effects or interactions were evident ($p>0.05$).

12.3) Absolute Switching Costs

ANCOVA results controlling for speed of processing
No significant main effects of age, task type or cue potency were found ($p>0.05$). The interaction between age and task type was significant however ($F(1,35) = 4.517$, $p = 0.041$). No other 2-way or 3-way interactions were significant.

ANCOVA results controlling for IQ
The main effect of age was significant ($F(1,36) = 4.789$, $p = 0.035$). Main effects of task type and cue potency and all 2-way and 3-way interactions were not significant ($p>0.05$).

Appendix 13
Study 7 Error Analysis and Practice Effects

13.1 Study 7: Error Analysis ANOVA Results

ANOVA analysis of the error proportions showed a significant main effect of age ($F(1,37) = 4.322$, $p = 0.045$) with older adults showing higher error rates than young adults (see table A13.1). A significant main effect of trial type was also evident ($F(1,370 = 7.625$, $p = 0.009$) with a higher proportion of errors during switch trials compared to repeat trials (see table A13,1). No other main effects or interactions were evident ($p>0.05$).

Table A13.1) Mean (standard deviation) Error Proportions for Young and Old Adults

	DE strong potency switch	DE strong potency repeat	DE weak potency switch	DE weak potency repeat	SC strong potency switch	SC strong potency repeat	SC weak potency switch	SC weak potency repeat
Young adults	0.0051 (0.0030)	0.0045 (0.0031)	0.0056 (0.0070)	0.0058 (0.0079)	0.0062 (0.0092)	0.0042 (0.0045)	0.0094 (0.1121)	0.0064 (0.1016)
Old adults	0.1390 (0.1429)	0.1219 (0.1220)	0.0090 (0.1160)	0.0081 (0.0091)	0.1236 (0.1517)	0.1017 (0.1371)	0.1272 (0.1476)	0.1207 (0.1482)

13.2 Study 7: Practice Effects

ANOVA analyses were conducted separately for each pure task and for mixed blocks with different cue potencies. Main effects of age under different task conditions are not of interest in relation to practice effects, therefore only main effects of order and interactions between order and age will be reported here.

13.2.1 Pure Block Practice Effects

Table A13.2) Mean (standard deviation) RT for Pure Task Blocks

		Trials 1 & 2 RT	Trials 3 & 4 RT
Digit Task	Young adults	412.91 (47.96)	441.17 (104.17)
	Old adults	431.80 (253.87)	731.06 (250.27)
Element Task	Young adults	444.39 (99.77)	456.18 (83.68)
	Old adults	719.44 (207.77)	695.70 (253.25)
Shape Task	Young adults	412.65 (60.67)	427.88 (121.58)
	Old adults	610.19 (212.27)	643.50 (184.46)
Colour Task	Young adults	418.18 (66.89)	433.73 (80.28)
	Old adults	635.33 (207.09)	731.16 (284.21)

No main effects of order or interactions between order and age were apparent for the pure block digit task, element task or shape task ($p>0.05$). The colour task however showed a significant main effect of order ($F(1,37)= 6.882$, $p = 0.013$), with slower RTs in trials 3 and 4 compared to trials 1 & 2 (see table A13.2). This suggests that

rather than RTs getting quicker with practice over the trials, RT s slow down indicating an effect of fatigue rather than practice.

13.2.2 Mixed Block Practice Effects

No significant main effect of order and no significant interactions with order were found for either the digit element weak potency blocks or the shape colour strong potency blocks ($p>0.05$). A significant main effect of order ($F(1,38) = 8.881$, $p = 0.005$) was evident for the digit element strong potency blocks, along with a significant 2-way interaction between order and age ($F(1,38) = 9.001$, $p = 0.005$) and a significant 3-way interaction between trial type, order and age ($F(1,38) = 5.745$, $p = 0.022$). The 3-way interaction indicates that young and old adults show a differential effect of order, young adults show little effect of order for either repeat or switch trials, whereas older adults show slightly quicker RT s among later trials compared to earlier trials, particularly for switch trials (see table A13.3). A significant main effect of order was also evident for the shape colour weak potency blocks ($F(1,38) = 22.412$, $p = 0.0001$) and the interaction between trial type and order was also significant ($F(1,38) = 32.353$, $p = 0.0001$). The trial type by order interaction shows that whilst repeat trials are not affected by order, switch trials show quicker RTs for later trials compared to earlier trials suggesting that switch trial performance improves with practice.

Table A13.3) Mean (standard deviation) RT for Mixed Task Blocks

		Repeat trials 1 - 4	Repeat trials 5 - 8	Switch trials 1 - 4	Repeat trials 5 - 8
Digit Element Weak Potency	Young	660.80 (218.92)	668.46 (249.46)	828.04 (407.34)	683.96 (239.80)
	Old	1428.17 (685.27)	1327.99 (736.24)	1674.44 (992.92)	1501.71 (609.59)
Digit Element Strong Potency	Young	683.96 (239.80)	659.49 (218.48)	847.78 (474.94)	873.92 (703.29)
	Old	1428.80 (717.24)	1284.97 (635.57)	1793.22 (1037.57)	1443.12 (763.12)
Shape Colour Weak Potency	Young	706.71 (245.93)	683.37 (213.94)	972.10 (356.80)	715.06 (265.79)
	Old	1497.58 (891.97)	1404.21 (818.40)	1682.08 (1033.73)	1249.78 (794.23)
Shape Colour Strong Potency	Young	657.97 (195.34)	639.80 (212.74)	844.00 (549.99)	856.85 (520.57)
	Old	1270.87 (720.87)	1208.69 (954.39)	1543.69 (928.75)	1402.92 (1011.19)

Appendix 14
Additional Shape Colour Task Analysis

14.1 Study 7: Absolute Alternation Cost Results

ANOVA with no controls
Significant main effects of cue potency ($F(1,38) = 29.232$, $p = 0.0001$) and age ($F(1,38) = 6.460$, $p = 0.015$) were found. The interaction between cue potency and age was not significant ($p>0.05$).

ANCOVA controlling for both speed of processing and IQ
A significant main effect of age was found ($F(1,35) = 4.992$, $p = 0.032$). No significant effect of cue potency and no significant interaction between cue potency and age were evident ($p>0.05$).

ANCOVA controlling for IQ only
Results showed a significant effect of age ($F(1,37) = 7.285$, $p = 0.010$). The effect of cue potency and the interaction between age and cue potency were not significant ($p>0.05$).

ANCOVA controlling for speed of processing only
A significant effect of age was evident ($F(1,36) = 4.223$, $p = 0.047$). No significant effect of age and no significant interaction between cue potency and age were found ($p>0.05$).

14.2 Absolute Mixing Cost Results

ANOVA with no controls
Significant effects of age ($F(1,38) = 7.826$, $p = 0.008$) and cue potency ($F(1,38) = 8.823$, $p = 0.005$) were found. The interaction between cue potency and age was not significant ($p>0.05$).

ANCOVA controlling for speed of processing and IQ
A significant effect of age was evident ($F(1,38) = 6.616$, $p = 0.015$). No significant effect of cue potency and no significant interaction between cue potency and age were found ($p>0.05$).

ANCOVA controlling for IQ only
The effect of age was significant ($F(1,37) = 8.515$, $p = 0.06$), however the effects of cue potency and the interaction between cue potency and age were not significant ($p>0.05$).

ANCOVA controlling for speed of processing alone
A significant effect of age was evident ($F(1,36) = 5.759$, $p = 0.022$). No significant effect of cue potency and no significant interaction between age and cue potency were found ($p>0.05$).

14.3 Absolute Switching Cost

ANOVA with no controls
A significant effect of cue potency was evident ($F(1,38) = 5.866$, $p = 0.020$). The effect of age and the interaction between age and cue potency were not significant ($p>0.05$).

ANCOVA controlling for speed of processing and IQ
No significant effects of cue potency or age and no significant interaction was found ($p>0.05$).

ANCOVA controlling for IQ alone
No significant effects of cue potency or age and no significant interaction was found ($p>0.05$).

ANCOVA controlling for speed of processing only
No significant effects of cue potency or age and no significant interaction was found ($p>0.05$).

Appendix 15
Standardised Instructions for Study 4 Tasks

Size JND Task Instructions

Your task is to look at a square on the screen and to remember its size.

The square will disappear and after a few seconds will re-appear. Then please decide on whether the square has changed size.

Either press the 'F1' key to indicate the square has changed size or press the 'F10' key to indicate the square size has remained the same.

Press the 'F1' key or the 'F10' key to begin the procedure.

Pattern Span Task Instructions

Your task is to look at the green spots on the screen and remember their location.

Please wait until the spots re-appear and then press the 'F1' key to indicate different locations or press the 'F10' key to indicate the same locations for the spots.

Please wait until the spots re-appear before making your decision.

The PC will make a sound when the number of spots increases.

Press the space bar to begin the procedure.

Trajectory JND Task Instructions

Your task is to look at the moving spot on the screen and to remember its trajectory (direction across space). The spot will disappear and after a few seconds will re-appear.

Please wait until the spot stops and then either press the 'F1' key to indicate the spot changed trajectory or press the 'F10' key to indicate the spot trajectory remained the same.

Press the 'F1' key or 'F10' key to begin the procedure.

Sequence Span Task Instructions

Your task is to look at the green spots as they appear on the screen and remember their sequence order.

Please wait until the spot sequence re-appears and when the spots stop flashing then either press the 'F1' key to indicate a different sequence, or press the 'F10' key to indicate the same sequence order.

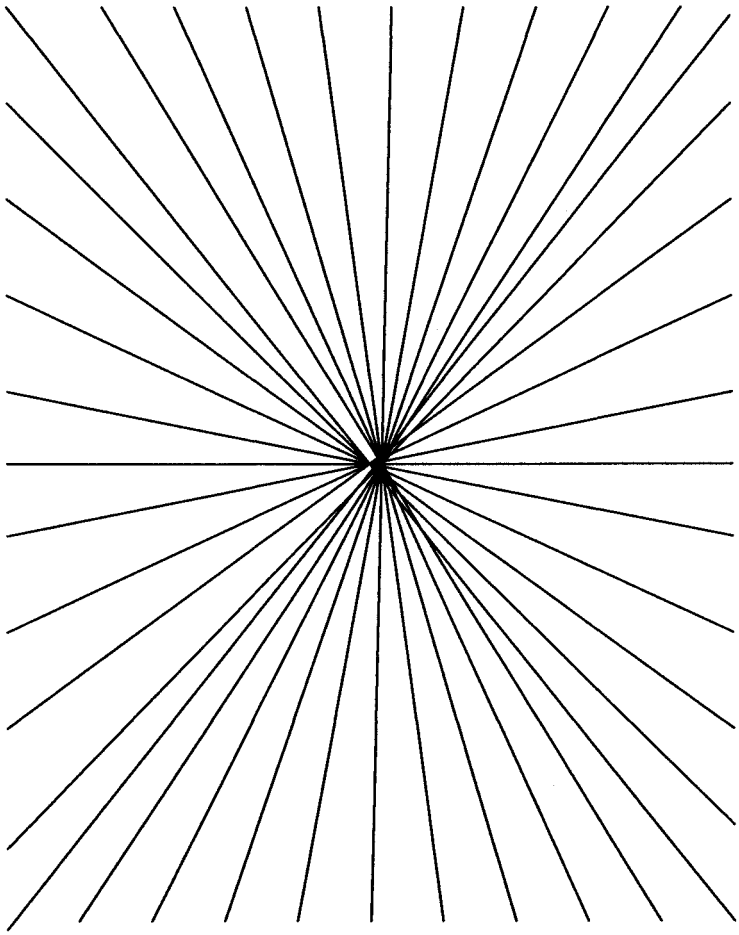
Please do not make your decision until requested.

The PC will make a sound when the number of spots increases.

Press the space bar to begin the procedure.

Appendix 16

Masking Pattern used in Study 4 Tasks



Appendix 17
Standardised Instructions for Studies 6 & 7

A17.1: Study 6 Standardised Instructions

Mixed Block Digit and Element Tasks Switching every 2nd Trial

In this task you will be presented with a set of numbers on the screen.

You have to switch between the digit and element number tasks.
Start with the digit task then switch to the element number task after 2 trials.
Continue throughout the block switching every 2 trials.

You will have to remember when to switch between the tasks.

If you are responding to "digit" press the left key if 3 and the right key if 5.
If you are responding to "elements" press the left key if 3 and the right key if 5.

Try to respond as quickly as you can to each number
but still try to be as accurate as possible.

WHEN YOU ARE READY PRESS ANY KEY TO BEGIN

Mixed Block Digit and Element Tasks Switching every 5th Trial

As above but instructed to switch after 5 trials.

Mixed Block Shape and Colour Tasks Switching every 2nd trial

In this task you will be presented with a series of coloured shapes on the screen.
You have to switch between the colour and shape tasks.
Start with the colour task then switch to the shape task after 2 trials.
Continue throughout the block switching tasks after every 2 trials.
You will have to remember when to switch between the tasks.

If you are responding to the colour press the left key if blue and the right key if red.
If youa re responding to shape press the left key if square and the right key if triangle.
Try to respond as qiuickly as you can toeach colour or shape
But still try to be as accurate as possible.

WHEN YOU ARE READY PRESS ANY KEY TO BEGIN

Mixed Block Shape and Colour Tasks Switching every 5th trial

As above but instructed to switch after 5 trials.

A17.2: Study 7 Standardised Instructions

Mixed Block Digit and Element Number Tasks Strong Potency Cue

In this task you will be presented with a set of number on the screen.
You have to switch between the digit and element number tasks.
Before the number set is presented you will be given a cue.
The cue will tell you which task to do.
The cue will tell you either to respond to the number of digits or the number of elements in the number set.

If you are responding to "digits" press the left key if 3 and the right key if 5.
If you are responding to "elements" press the left key if 3 and the right key if 5.

Try to respond as quickly as you can to each number
But still try to be as accurate as possible.

WHEN YOU ARE READY PRESS ANY KEY TO BEGIN

Mixed Block Digit and Element Number Tasks Weak Potency Cue

In this task you will be presented with a set of numbers on the screen.
You have to switch between the digit and element number tasks.
Before the number set is presented you will be given a cue.
The cue will tell you which task to do.
If the cue appears in the top half of the screen respond to the digit number.
If the cue appears in the bottom half of the screen respond to the number of elements.

If you are responding to "digits" press the left key if 3 and the right key if 5.
If you are responding to "elements" press the left key if 3 and the right key if 5.

Try to respond as quickly as you can to each number
But still try to be as accurate as possible.

WHEN YOU ARE READY PRESS ANY KEY TO BEGIN

Mixed Block Shape and Colour Tasks Strong Potency Cue

In this task you will be presented with a series of coloured shapes on the screen.
You have to switch between the colour and shape tasks.
Before the shape is presented you will be given a cue.
The cue will tell you which task to do.
The cue will tell you either to respond to the colour or the shape.

If you are responding to the colour press the left key if blue and the right key if red.

If you are responding to the shape press the left key if square and the right key if triangle.
Try to respond as quickly as you can to each colour or shape
But still be as accurate as possible.

WHEN YOU ARE READY PRESS ANY KEY TO BEGIN

Mixed Block Shape and Colour Tasks Weak Potency Cue

In this task you will be presented with a series of coloured shapes on the screen.
You have to switch between the colour and shape tasks.
Before the shape is presented you will be given a cue.
The cue will tell you which task to do.
If the cue appears in the top half of the screen respond to the colour.
If the cue appears in the bottom half of the screen respond to the shape.

If youa re responding to the colour press the left key if blue and the right key if red.
If you are responding to the shape press the left key if square and the right key if triangle.
Try to respond as quickly as you can to each colour or shape
But still be as accurate as possible.

WHEN YOU ARE READY PRESS ANY KEY TO BEGIN